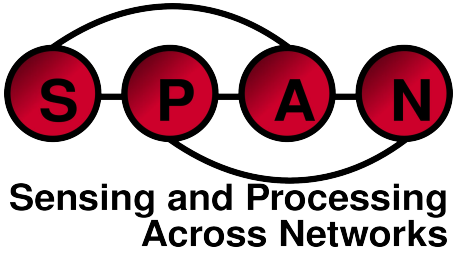


Device-Free Decade: the Past and Future of RF Sensing Systems

(at least 16 minutes worth)

Neal Patwari

HotWireless 2017

16 October 2017

Talk Outline

- The Past
- The Future
- Today

Talk Outline

- The Past
- The Future
- Today

“RF” Sensor Network

> *The radio itself, provided that it can measure the strength of the incoming signal, is the only sensor we use; with this sensorless sensing approach, any wireless network becomes a sensor network.*

— From Kristen Woyach, Daniele Puccinelli, Martin Haenggi, “Sensorless sensing in wireless networks: implementation and measurements”, *IEEE WiOpt 2006*

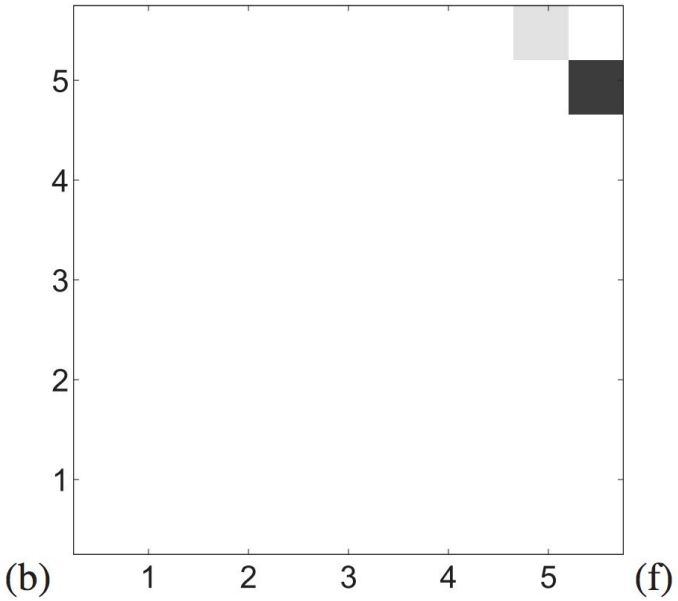
“RF” Sensor Network Advantages

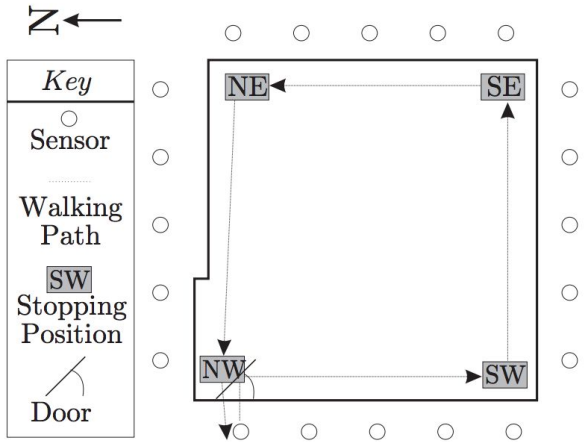
- Inexpensive RFICs
- Small, low transmit power
- Can be hidden
- Sensors can be “in” outlets, light switches, bulbs
- Not video or audio surveillance

Radio Tomographic Imaging

- Developing correlated link shadowing stat. models
- Needed a semester UG student project in Spring 2007

Radio tomographic image for person standing in SE corner of room.

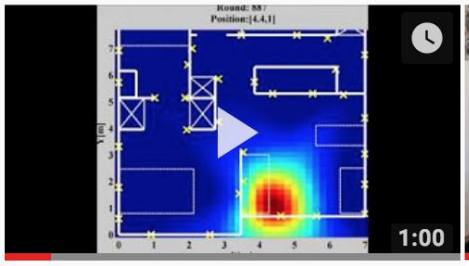


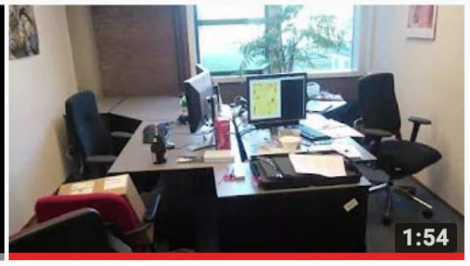


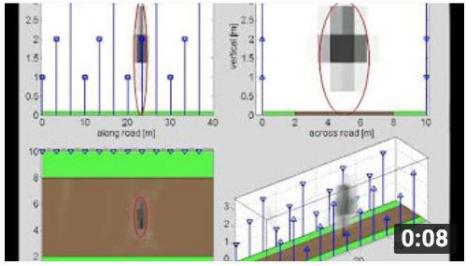
Experimental setup: 20 sensors outside of room walls, person walks in square path, pausing in each corner.

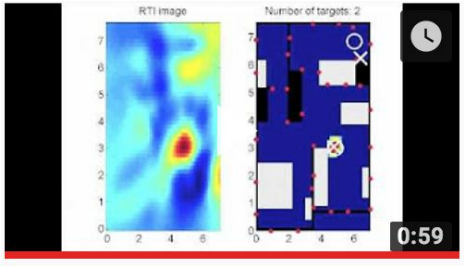
N. Patwari and P. Agrawal, Effects of Correlated Shadowing: Connectivity, Localization, and RF Tomography, IEEE/ACM IPSN 2008.

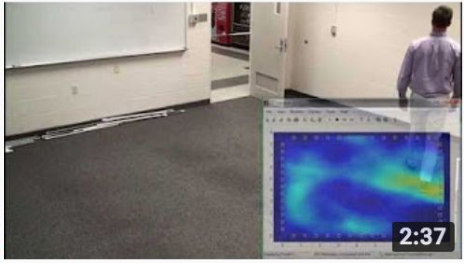
Research Developments via RTI Videos

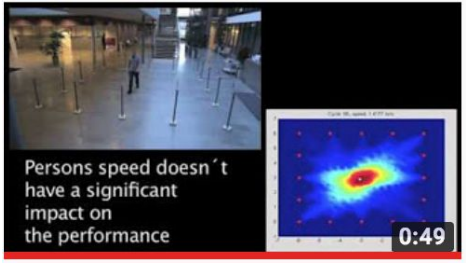


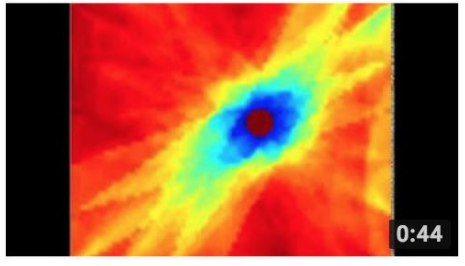


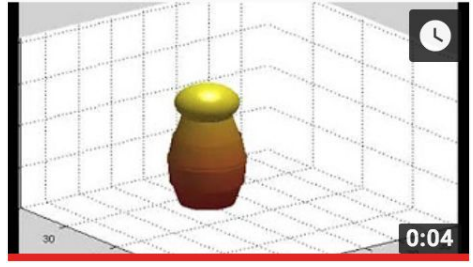






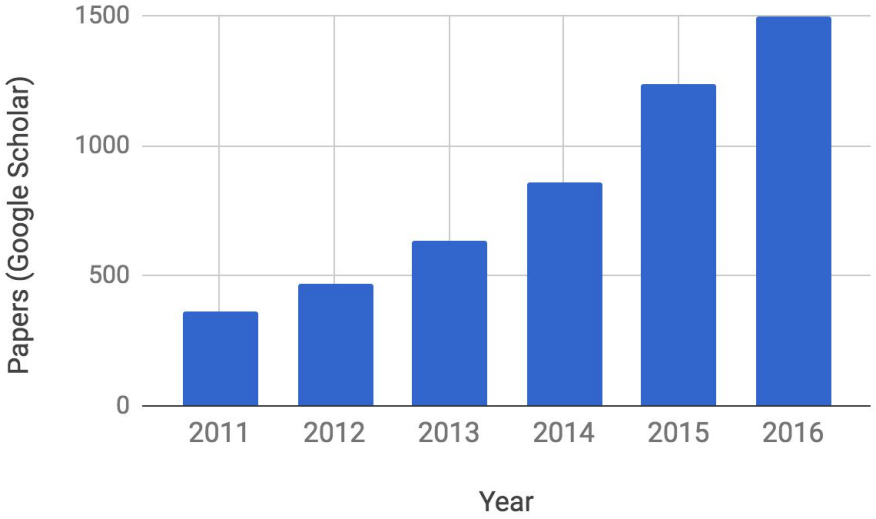






Selection of videos from https://www.youtube.com/results?search_query=radio+tomographic+imaging

New RF Sensing Adding Up

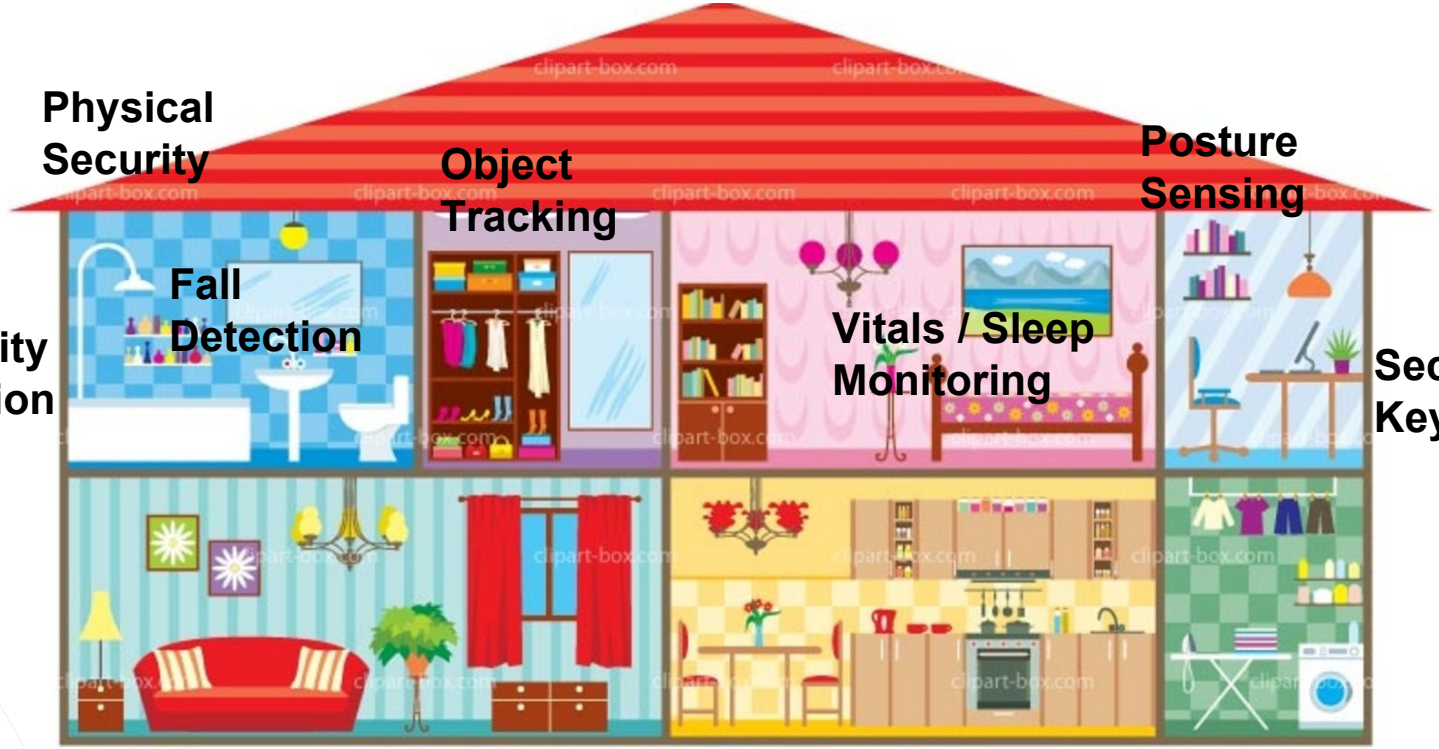


2011 CSITool:

- CSI meas’ts on COTS WiFi
- Led to 1000s of publications
- Mostly on RF sensing

Daniel Halperin, Wenjun Hu, Anmol Sheth, and David Wetherall (2011). Tool release: Gathering 802.11n traces with channel state information. ACM SIGCOMM Computer Communication Review, 41(1), 53-53.

RF Sensing Everywhere...



RF Sensing Everywhere is Not a Theory

XANDEM HOME

ResMed

aura

XETHRU
BY NOVELDA

Origin Wireless

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Limits on RF Sensing

Three physical barriers:

1. **Multipath**: Enabling + limiting. Need for diversity
2. **Bandwidth**: RF sensors will interfere with each other & wireless comms for spectrum
3. Space: Sensing may need to be limited to an area

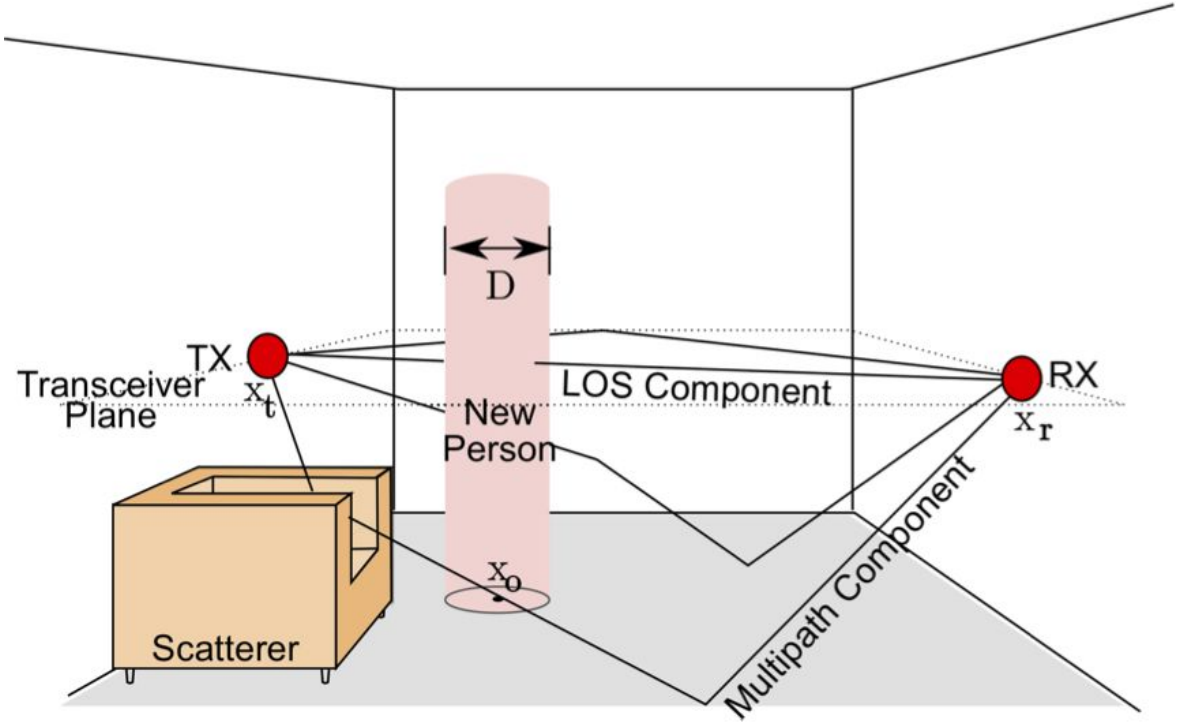
Don’t forget:

1. **Cost**: Large-scale RFICs are not designed for RF sensing, provide quantized & limited channel info

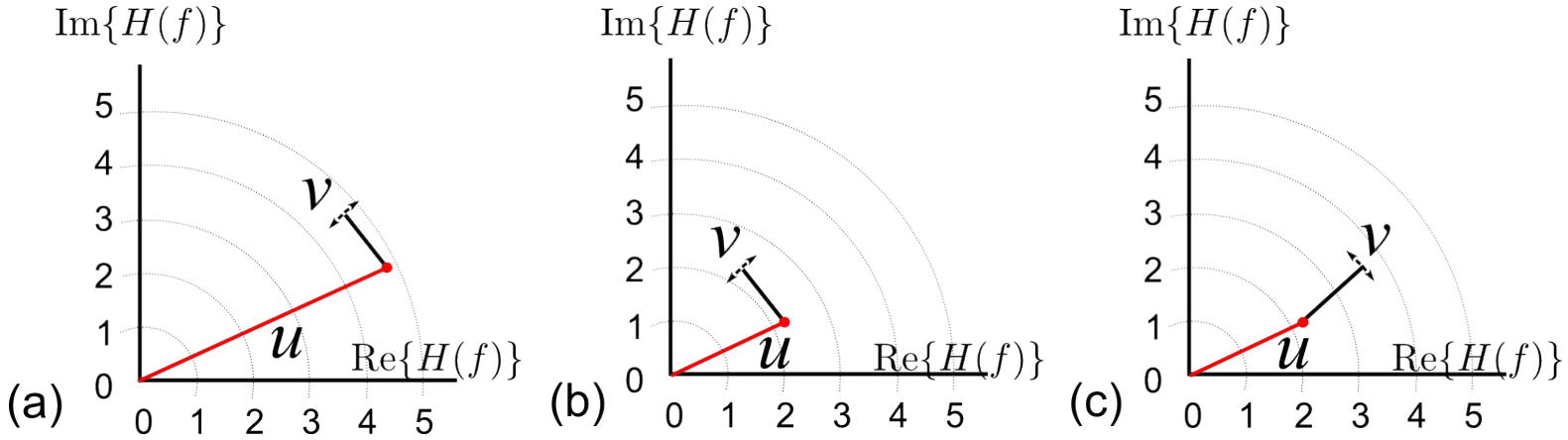
Physical Barrier: Multipath Fading

Types of multipath waves:

- Interact with a person (call the sum u)
- Don't interact with the person (call the sum v)



Physical Barrier: Multipath Fading

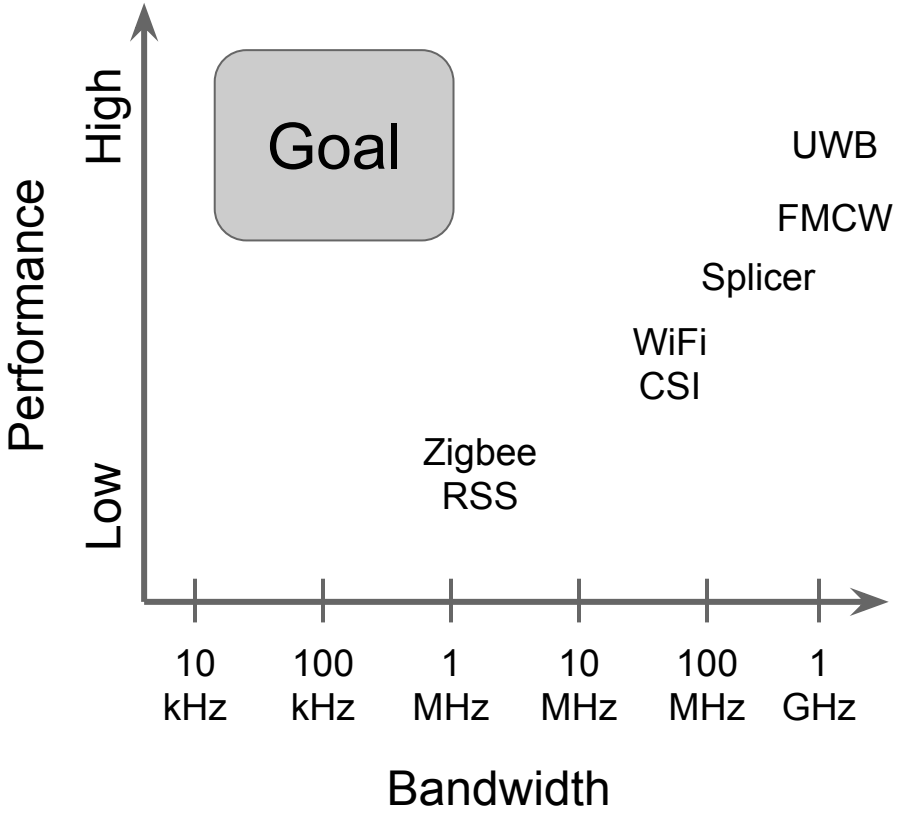


Type 1: Changing phase of v changes the RSS (magn. of sum). In (b) the lower amplitude of u makes the dB change larger for the same phase change in v.

Type 2: The phase of v (since it is □ to u) has no effect on the RSS

Frequency Diversity: Phases of multipath components have low correlation if frequencies are sufficiently far apart

Physical Barrier: RF Sensing Bandwidth



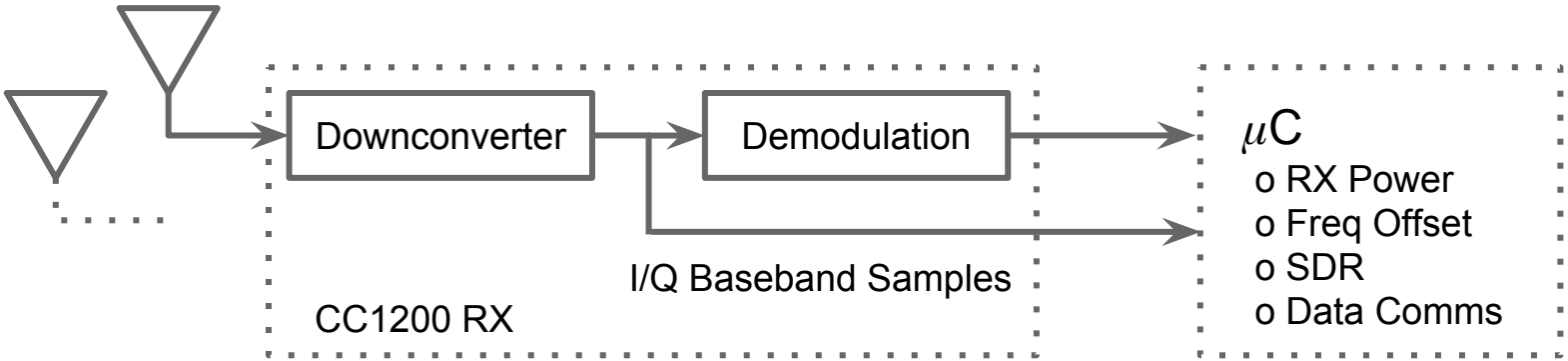
- Many propose 1000s of packets/sec -- i.e., occupy one channel continuously
- Zigbee RSS problem is quantization, not single-channel
- WiFi CSI, Zigbee compete in busiest comms bands

Practical Barrier: Specialized H/w is Costly

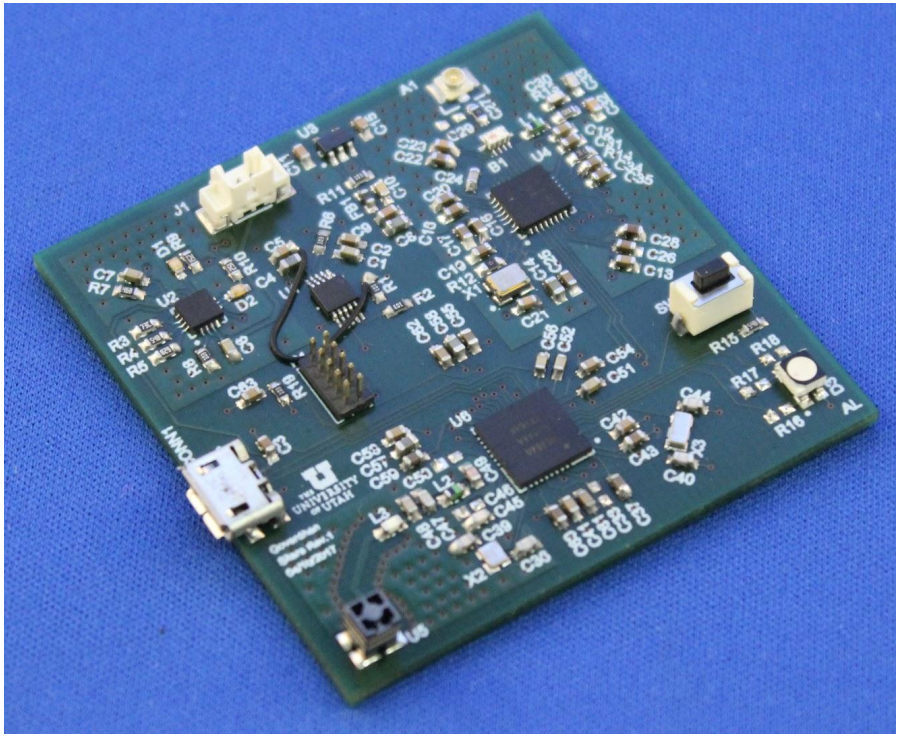
- Limited by cost to large scale comms RFICs
- Rare to have full access to channel sensing data
  - One channel estimate per packet (typically only RSS)
  - Zigbee RFICs still have 1.0 dB RSS step size
- CSITool, Decawave are thus two breakthroughs
- Prediction: CC1200 is similarly desirable

The TI CC1200 is a Low Cost SDR TX/RX

- FSK transceiver at frequencies below 1 GHz
- $4 RFIC
- FSK / MSK transmitter
- RX able to export complex baseband samples to SPI bus (at 45 kHz)



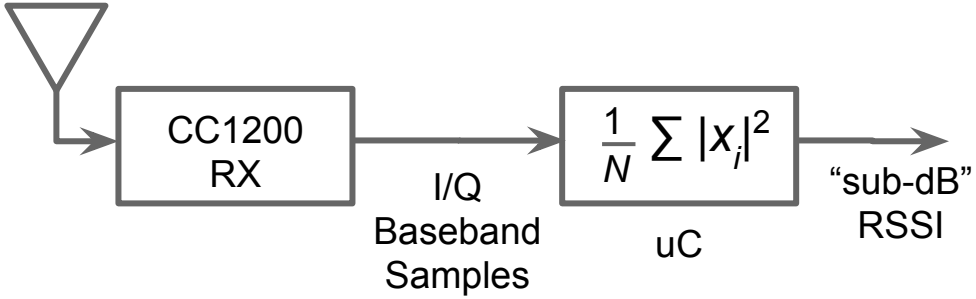
Sitara: TI CC1200 Prototype Platform

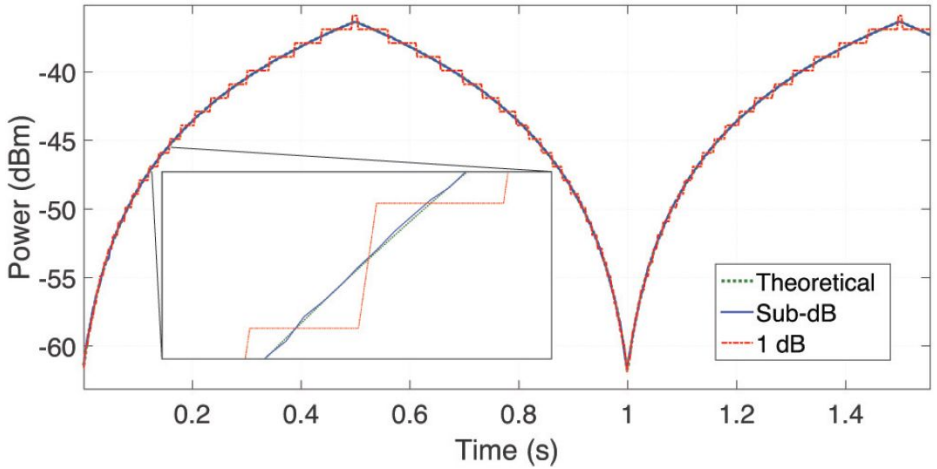


Credit: Anh Luong, Goverdhan Pandla

- TI CC1200: sub-GHz SDR
- NRF52840:
  - 32 bit Cordic M4
  - BLE 5.0
  - 802.15.4
- < $20 small (5 x 5 cm) SDR that will pair with your cell phone

Obtaining accurate RX power via CC1200





- Before: RX provide RSSI with 1 dB quantization: 0.25 dB median error
- CC1200: Compute the sample average power in uC: Median error of 0.013 dB

Anh Luong, Alemayehu Solomon Abrar, Thomas Schmid, Neal Patwari, "RSSI step size: 1 dB is not enough!", HotWireless 2016.

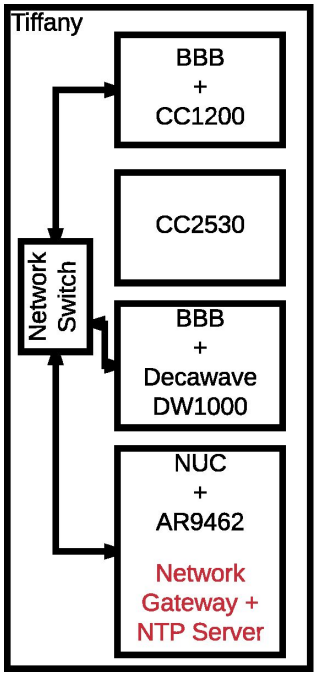
What to do with sub-dB?

Same as what is done with CSI, UWB:

- Breathing monitoring
- Pulse monitoring
- Gesture recognition
- Localization

But bandwidth utilization is 10^3 to 10^5 times lower

Current work: Multi-tech comparison



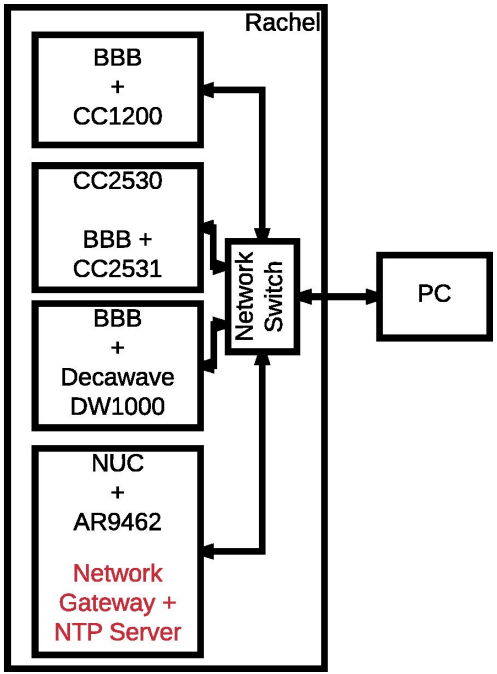
Sleep-Wake Center at the University of Utah

20 Sleep study patients

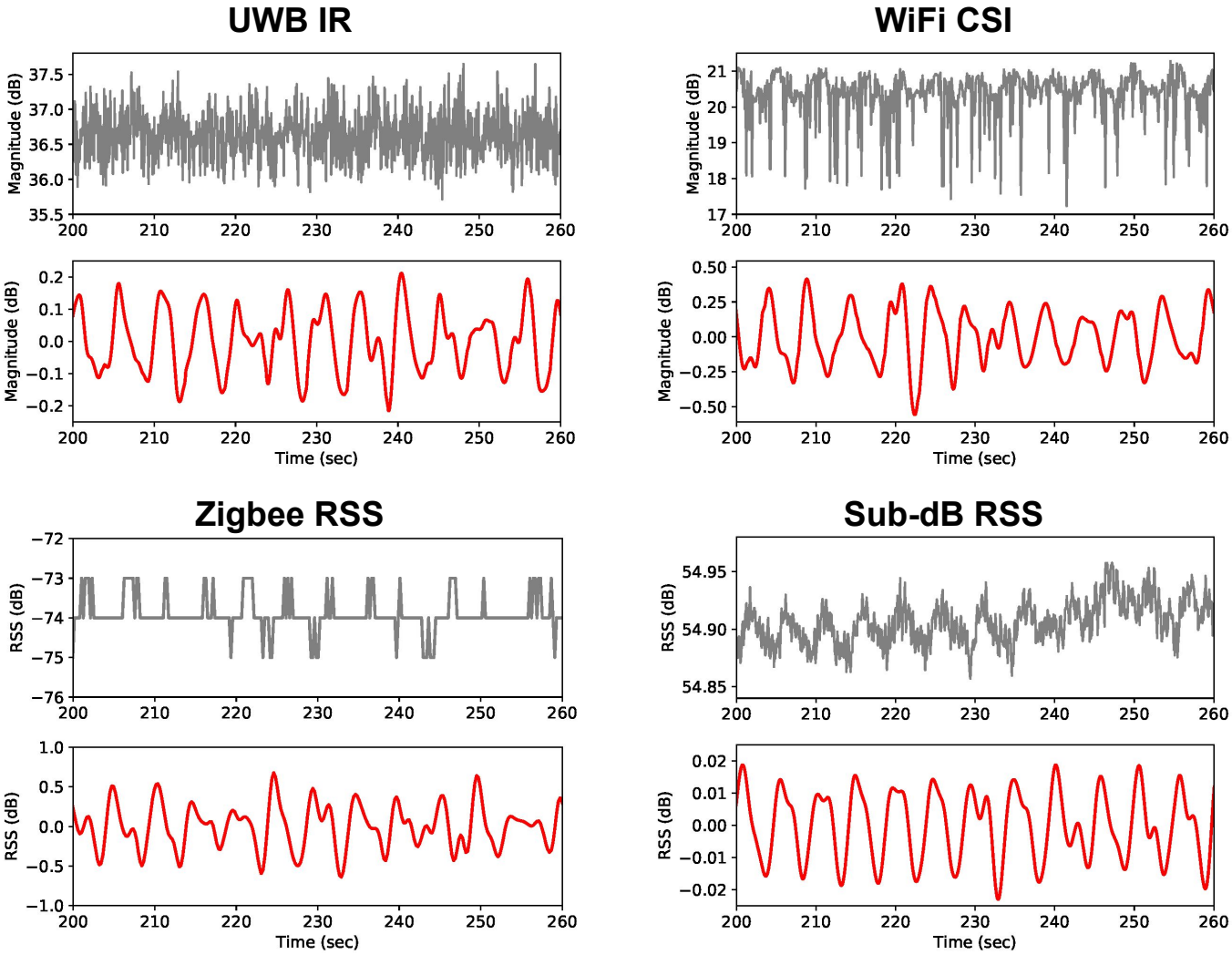
Four RF technologies, deployed bedside for each patient

- UWB-IR - 500 MHz @ 4 GHz
- WiFi CSI - 40 MHz @ 5 GHz
- Zigbee RSS - 2 MHz @ 2.4 GHz
- Sub-dB RSS 10 kHz @ 900 MHz

Goal: Compare results side-by-side for breathing estimation, apnea detection



Credit: Peter Hillyard, Anh Luong



Some Results:

Raw

Filtered

Truth: 12 breaths / min

Credit: Peter Hillyard

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What Should We Do Today

- We need to be clear about what the range of needs are for RF sensing, and argue for bandwidth that we need
- For now: Hack RFICs to get more, better channel info so that we can conduct quality research and testing

Problems: 1 dB quantization, single channel, killing WiFi

No Problem: Magnitude, narrowband (w/ channel hopping)