



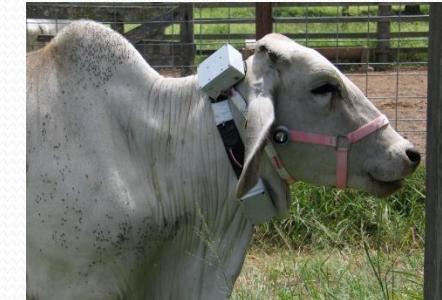
Sensor-less Sensing: The Future of Ubiquitous Context-Awareness

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Traditional Sensor Networks

- Active field of research for many years
- Many applications



- Require special hardware
- Attach a sensor to the subject



Wireless Communication Networks

- Ubiquitous
 - WiFi, Bluetooth, Cellular, FM, etc
- Gaining momentum everyday

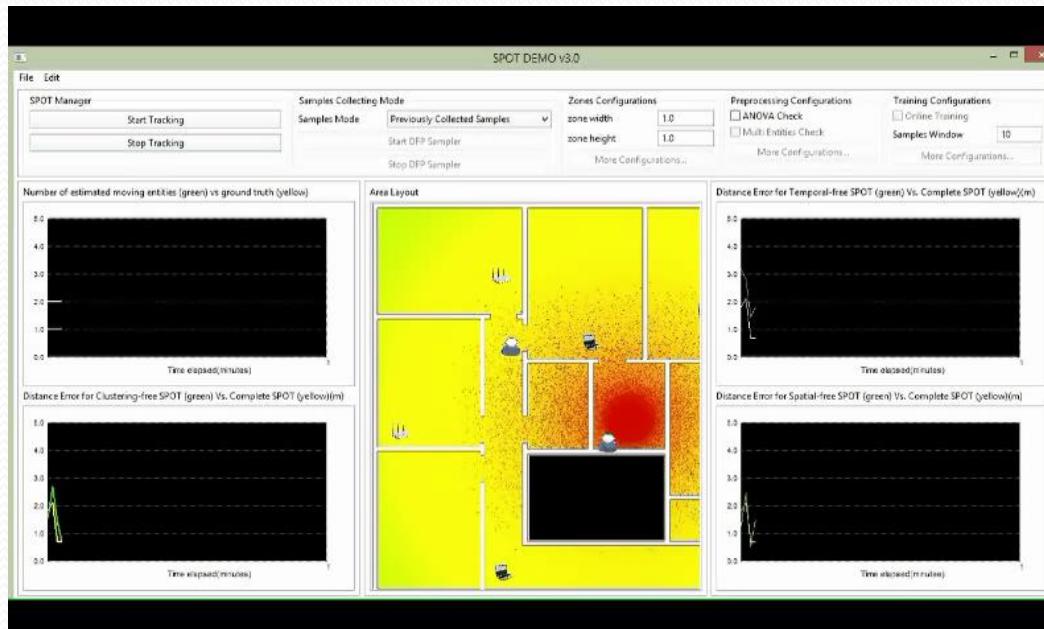


Can we leverage them for ubiquitous sensor-less sensing?

Device-free Sensor-less Sensing

Device-free Sensor-less Sensing

- Changes in the RF signal are the base of detecting changes in the environment
 - No special infrastructure/sensors
 - User does not need to carry a device



Goals/Functions

- **Detection:** identifying whether there are changes in an area of interest or not
 - May include detection of the number of entities
- **Tracking:** tracking the position of entities inside the area of interest
 - Can be for a single entity or multiple entities
- **Identification:** detecting the identity entities that caused the changes
 - Detecting the type of entity
 - Its identity
 - Its size, mass, shape, and/or composition

Applications

- Intrusion detection
- Border protection
- Smarthomes
- Gesture recognition
- Traffic estimation
- M-health
- Smoke detection
- Material identification
- Many more

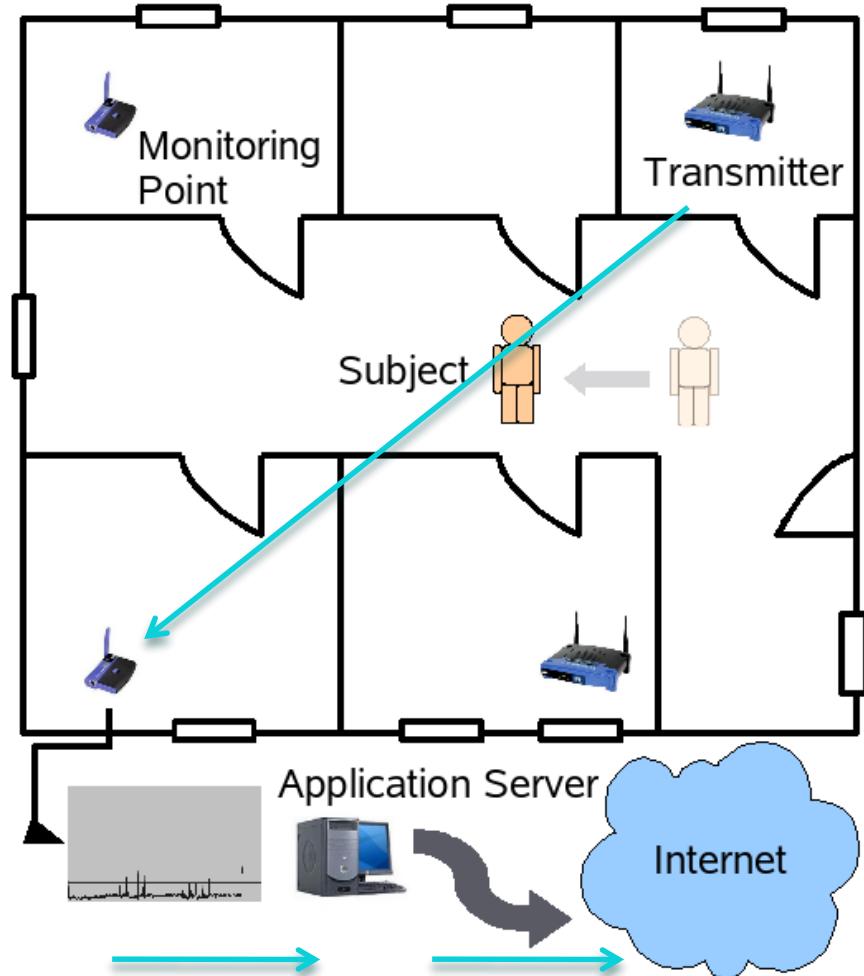
Agenda

- Introduction
- Basic Concept
 - Detection
 - Tracking
- Identification
- Current Trends

Device-free Localization

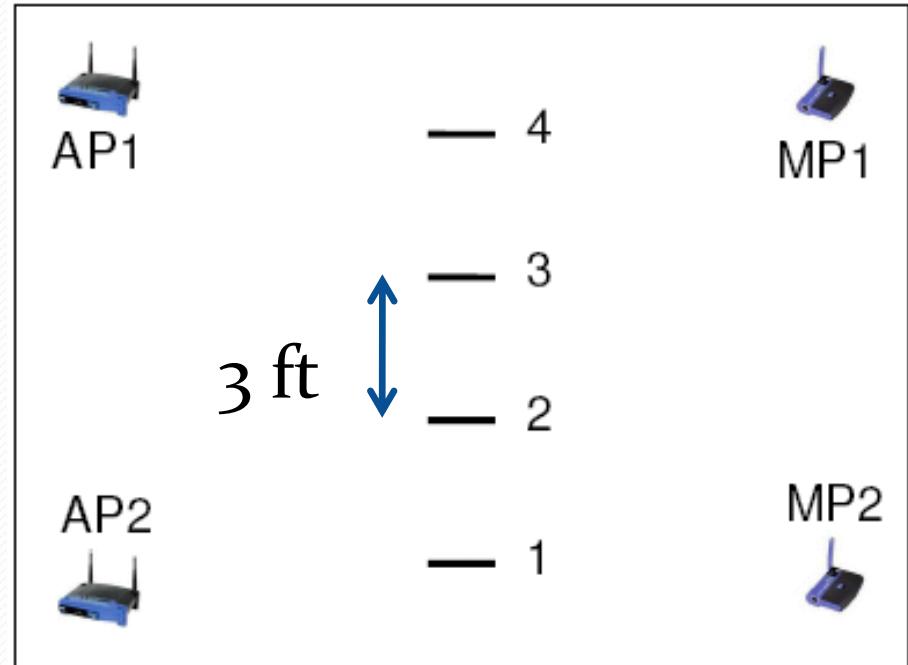
Architecture

- Signal transmitters
 - E.g., Access Points
- Monitoring Points
 - Sniffers
 - Standard laptops/phones
 - Other APs
- Processing server
 - Detection, tracking, identification, others



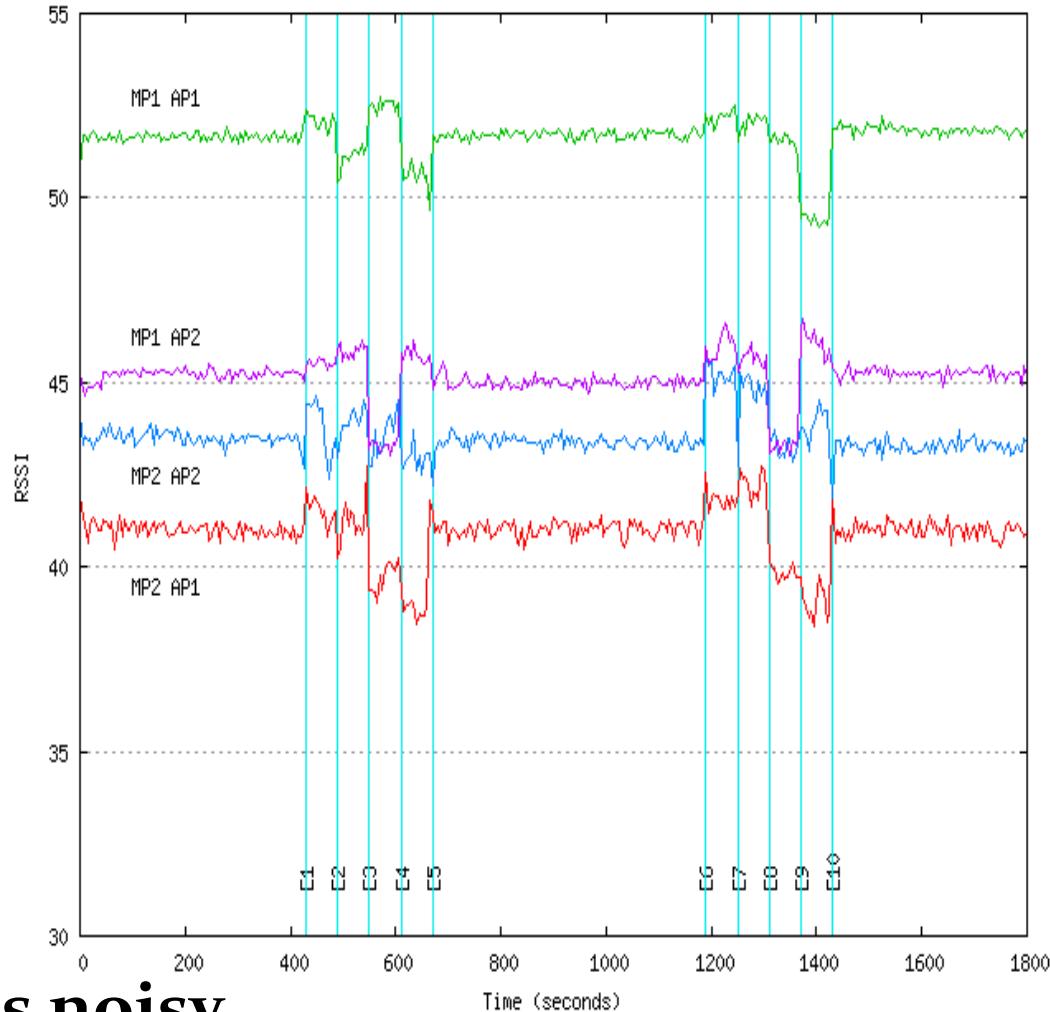
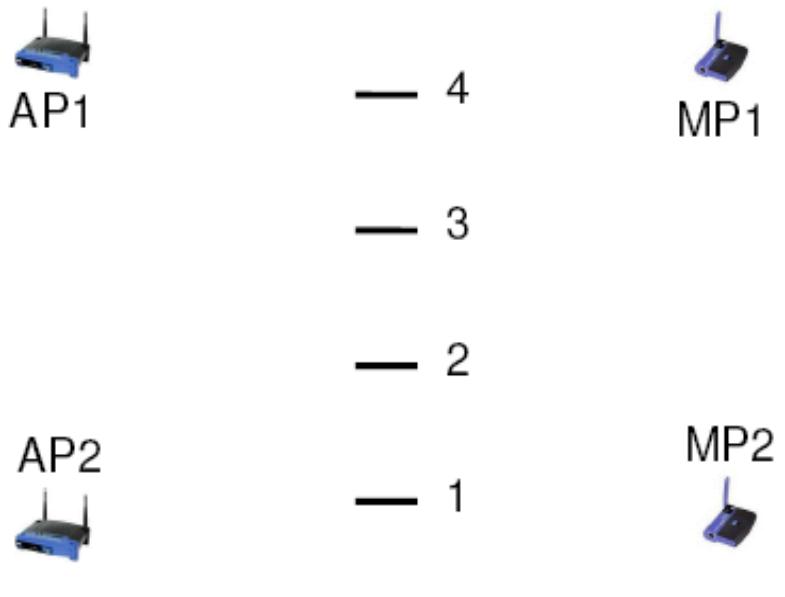
Feasibility Experiment – MobiCom'07

- 802.11b – 2.4GHz
- Cisco Aironet 350 Series APs
- Orinoco Silver cards
- Person pauses for 60 seconds at four positions
- Positions 3 feet apart
- Process repeated twice
- Total of 10 events

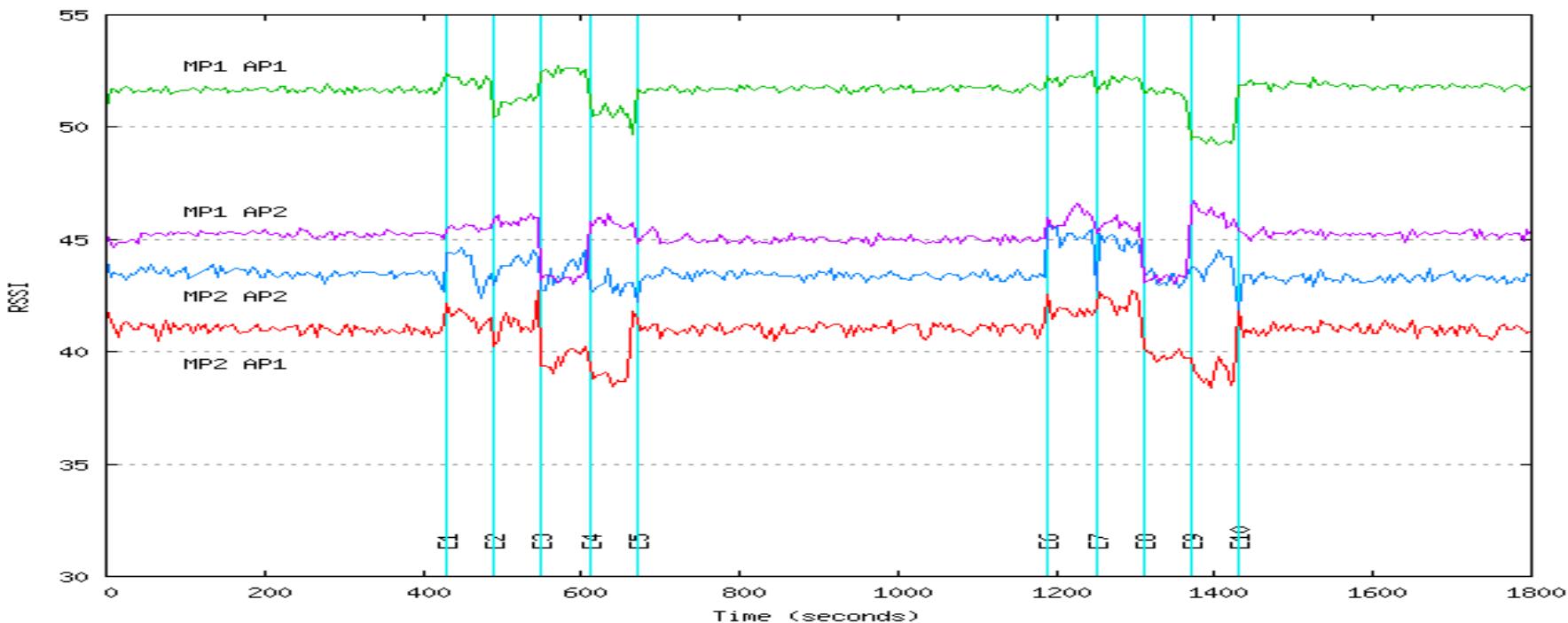


► All are CoS

Sample Streams



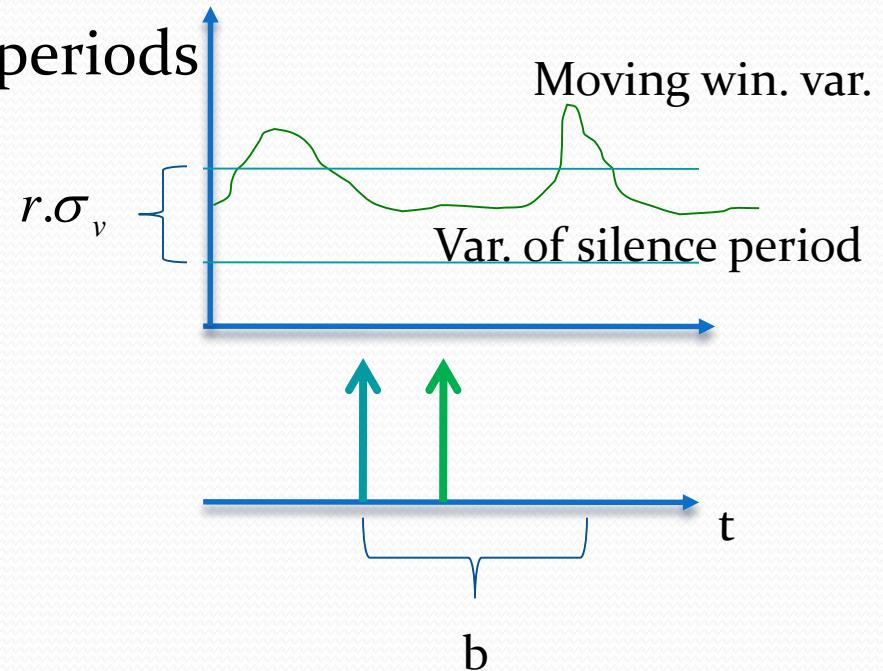
- Each stream is noisy
 - Large number of streams



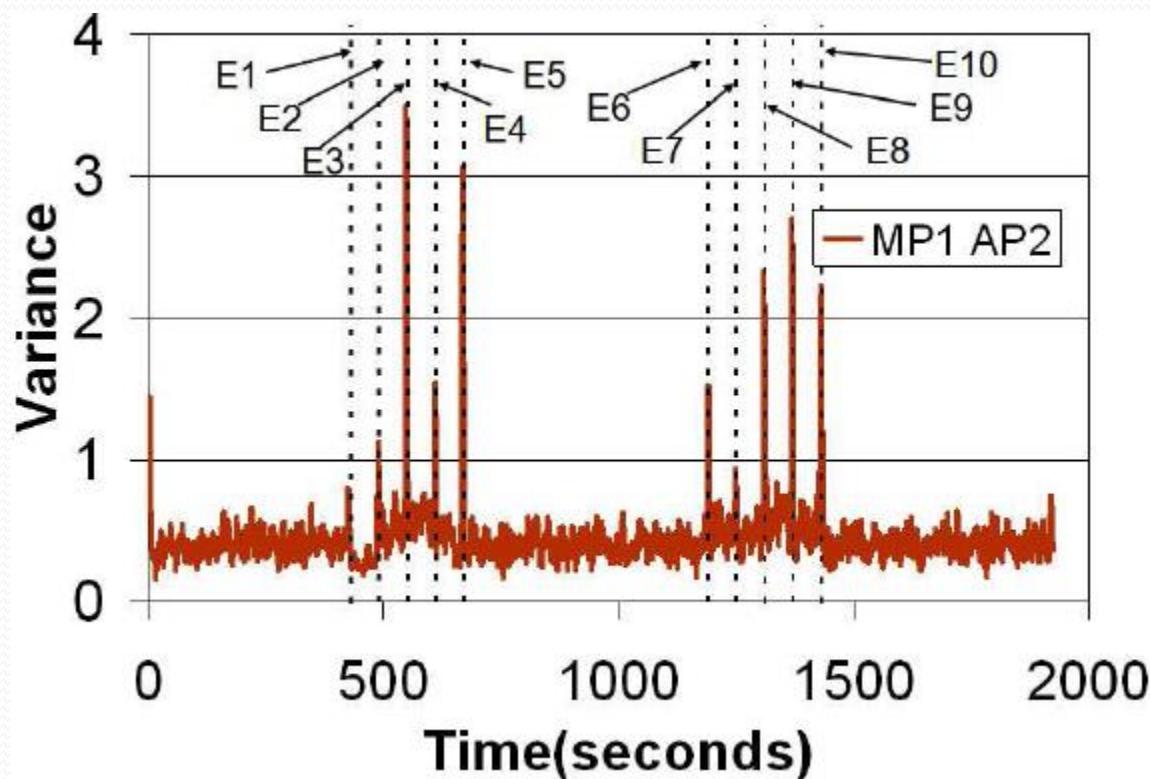
- Can we detect an event
 - i.e. changes in the environment?
- Moving variance technique

Moving Variance Technique

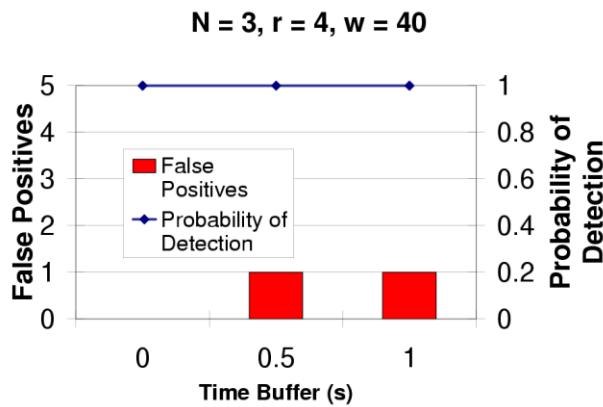
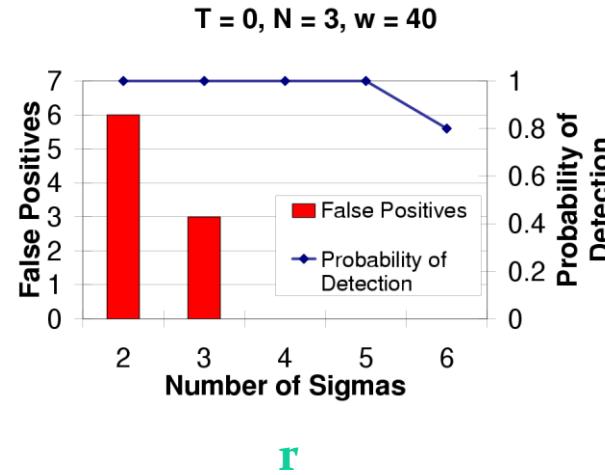
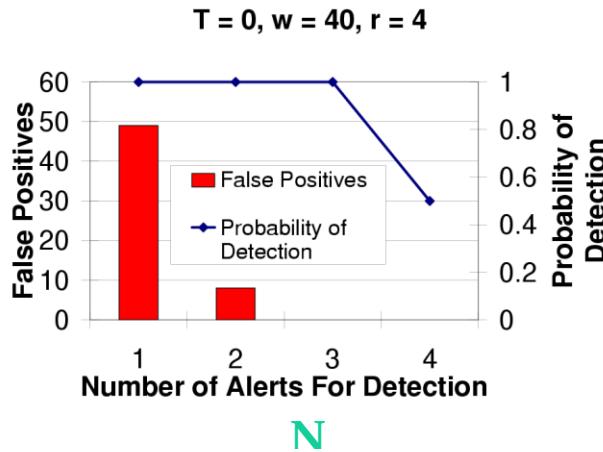
- Compare the variance of two periods
 - Window of size w (v_t)
 - Silence period (V_t)
- If $v_t > v_t + r \cdot \sigma_v$
 - Event detected
- Combine N of these alerts
 - Single stream is noisy
- Within time buffer b
- Parameters
 - w : Window size r : detection threshold
 - N : no. of alerts b : time buffer



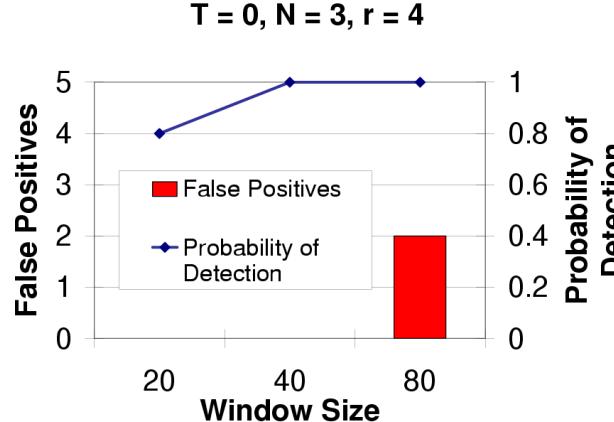
Detection Results



Detection Results



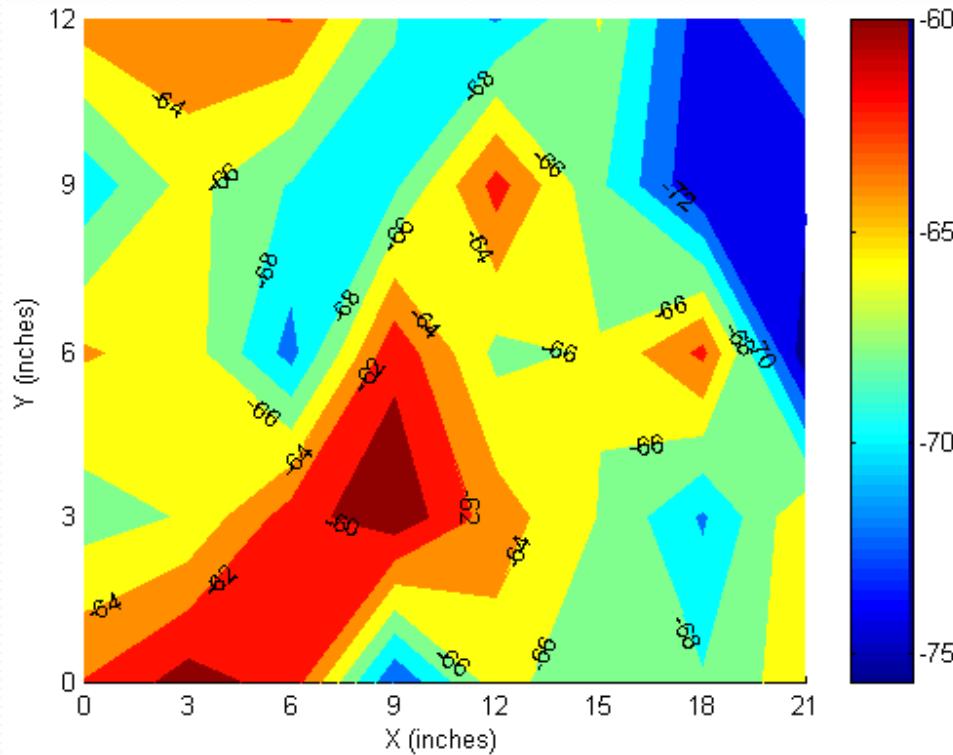
b



w

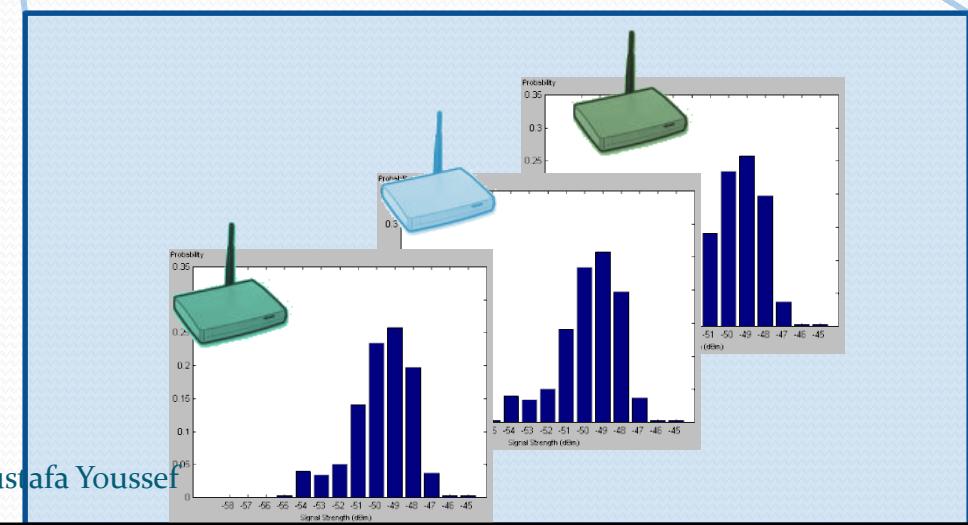
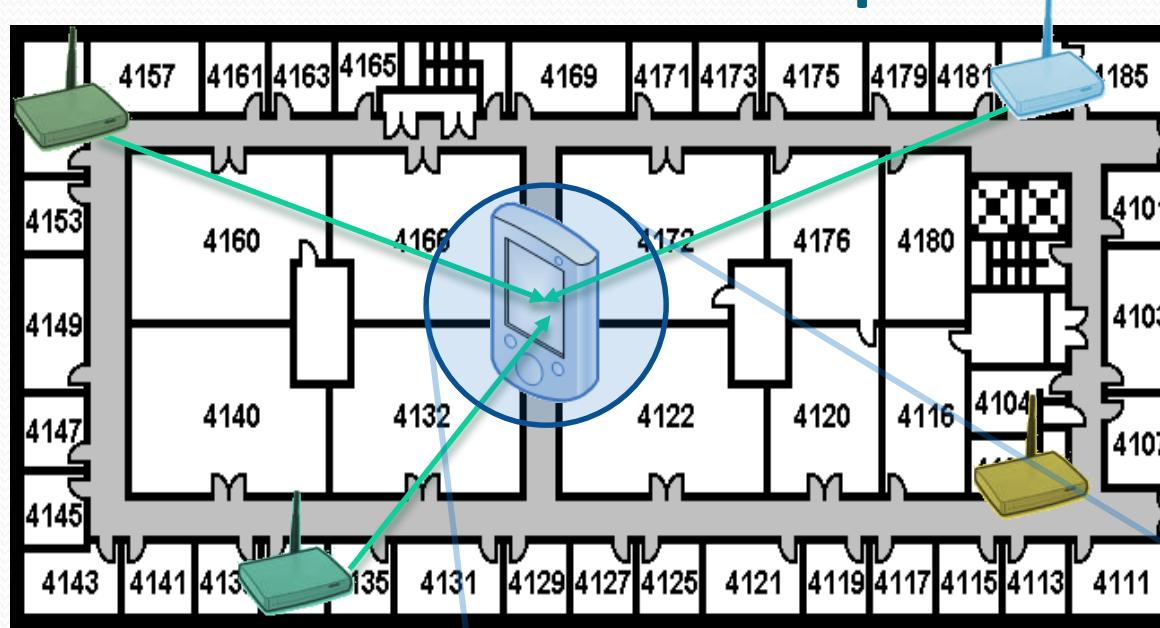
Tracking

Tracking

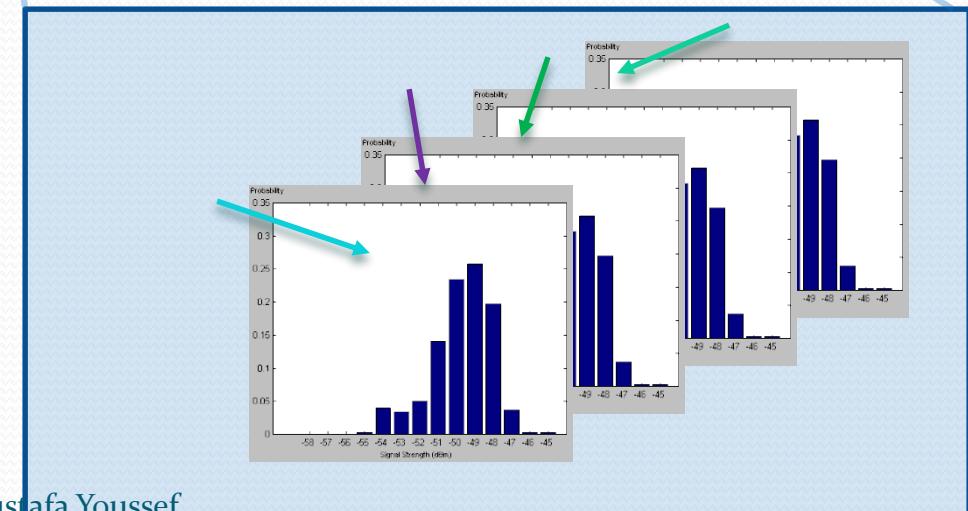
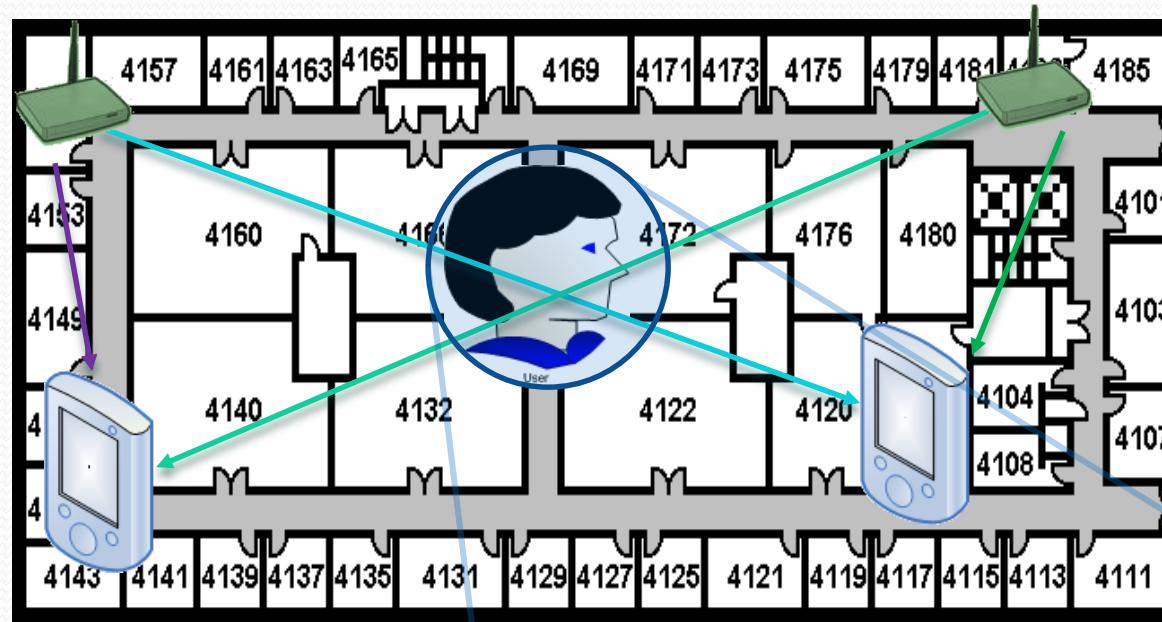


- We need a radio map
- Passive radio map construction
- Passive tracking

Device-based Radio Map Construction



Device-free Radio Map Construction



Device-Free Tracking

- Use passive radio map
- Use Bayesian inversion to calculate most probable

$$\begin{aligned}\arg \max_l P(l/\bar{s}) &= \arg \max_l P(\bar{s}/l) \cdot \frac{P(l)}{P(\bar{s})} \\ &= \arg \max_l P(\bar{s}/l) \cdot P(l)\end{aligned}$$

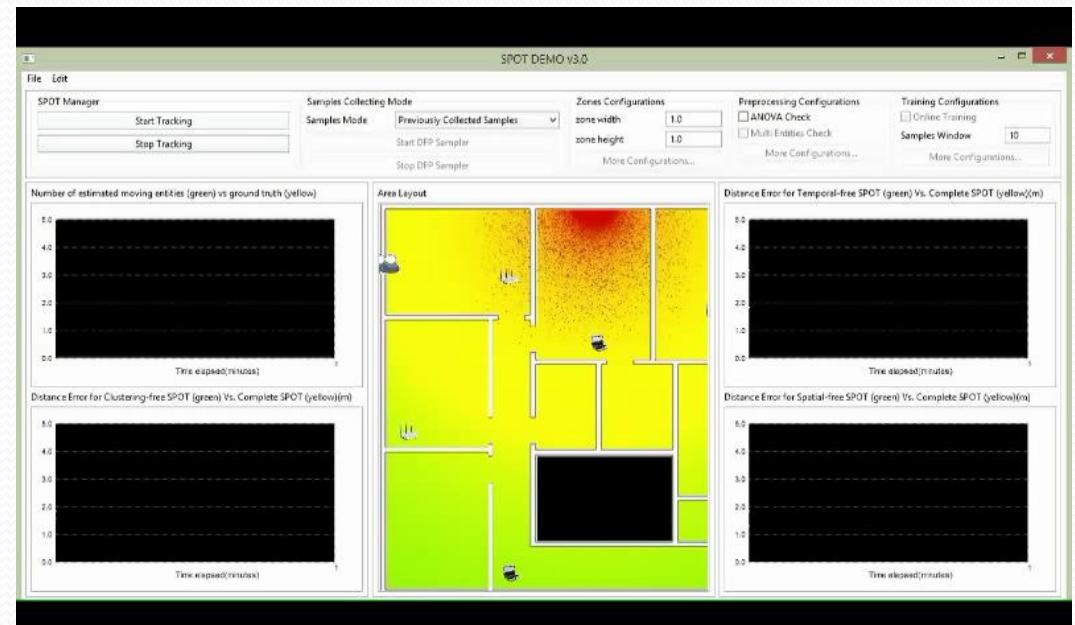
$$\arg \max_l P(l/\bar{s}) = \arg \max_l P(\bar{s}/l)$$

Tracking Results

Configuration	Exp. 1 as training	Exp. 2 as training
100% Accuracy	86.3%	89.7%
Average Accuracy	0.685 ft	0.515 ft

Progress on Identification and Tracking

- Robust detection
 - Rasid
- Multi-entity
- Single TX-RX
- Automatic fingerprint construction



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Sensor-less Sensing Identification

- Detecting the identity/characteristics of entities that caused the changes
 - Detecting the type of entity
 - Its identity
 - Its size, mass, shape, and/or composition
- Examples
 - Gesture recognition
 - Breathing rate detection
 - Traffic estimation
 - Fall detection
 - Wireless keyboard
 - Speech detection
 - Smoke detection
 - Material identification
 - ...

Sensor-less Sensing Identification

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 - **Gesture recognition**
 - **Breathing rate detection**
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 - Speech detection
 - ...

WiGest: A Ubiquitous WiFi-based Gesture Recognition System

Media coverage



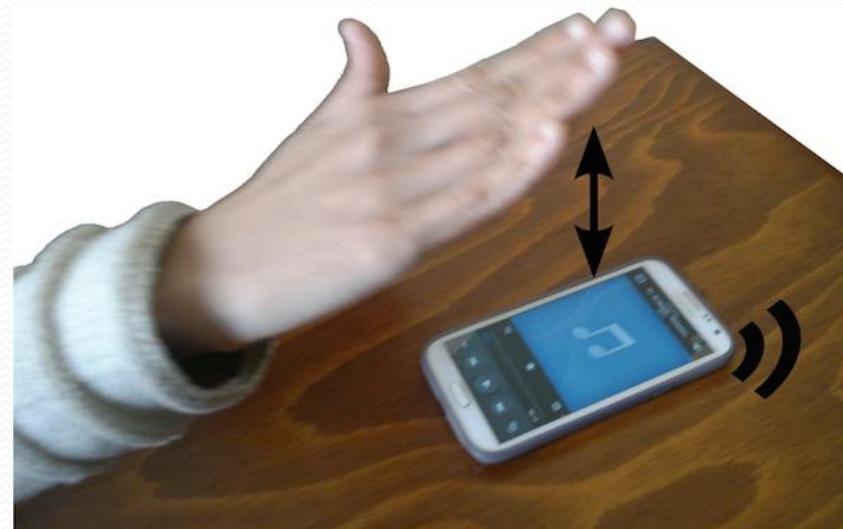
Motivation

- Touch input – user is wearing gloves
- **Wet/dirty hands.**
- Special sensors
 - E.g. Samsung Galaxy S9, S10



Contributions

- **Ubiquitous WiFi-based hand gesture recognition system**
- Works with **any WiFi-equipped devices**
- Challenges
 - **No need for training** or special devices
 - **Robust** to users interference
 - **Energy-efficient**



Basic Idea

Leveraging the impact of hand motion on the received WiFi on the phone to control WiFi-enabled devices

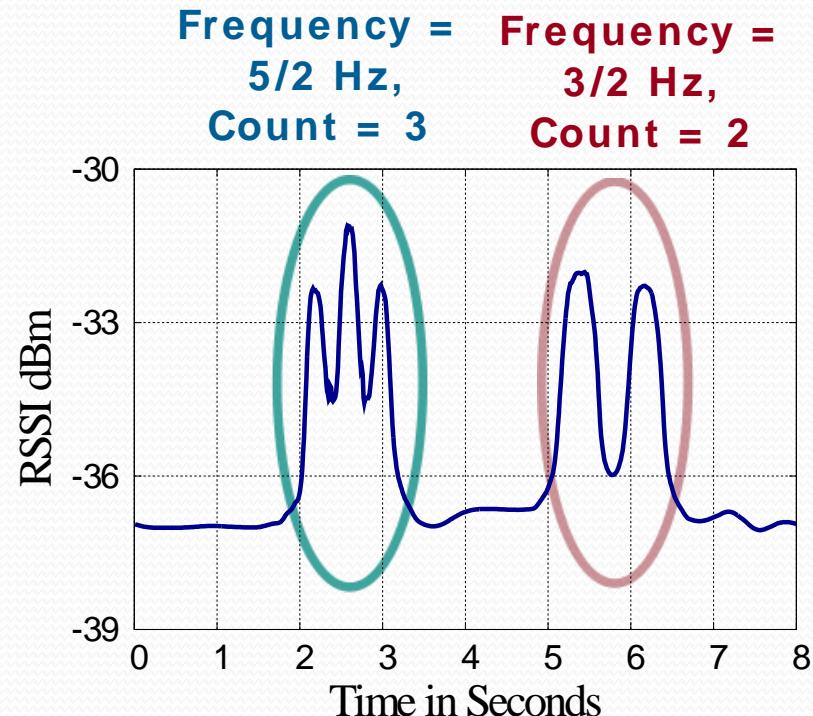
Count

- Number of gesture repetitions
- E.g. double click and single click

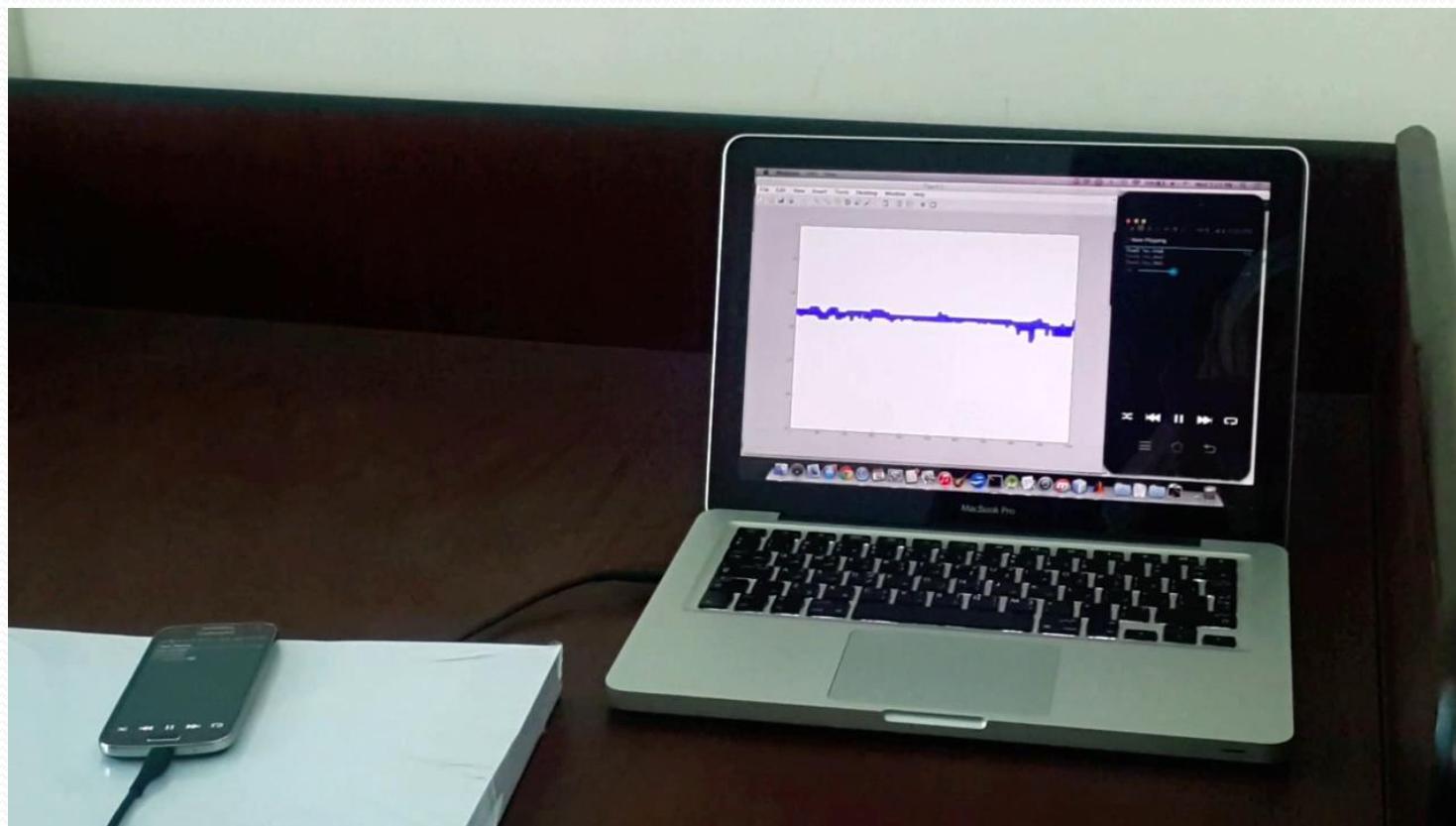


Frequency

- Number of gesture repetitions per unit time
- E.g. speed of basketball dribble

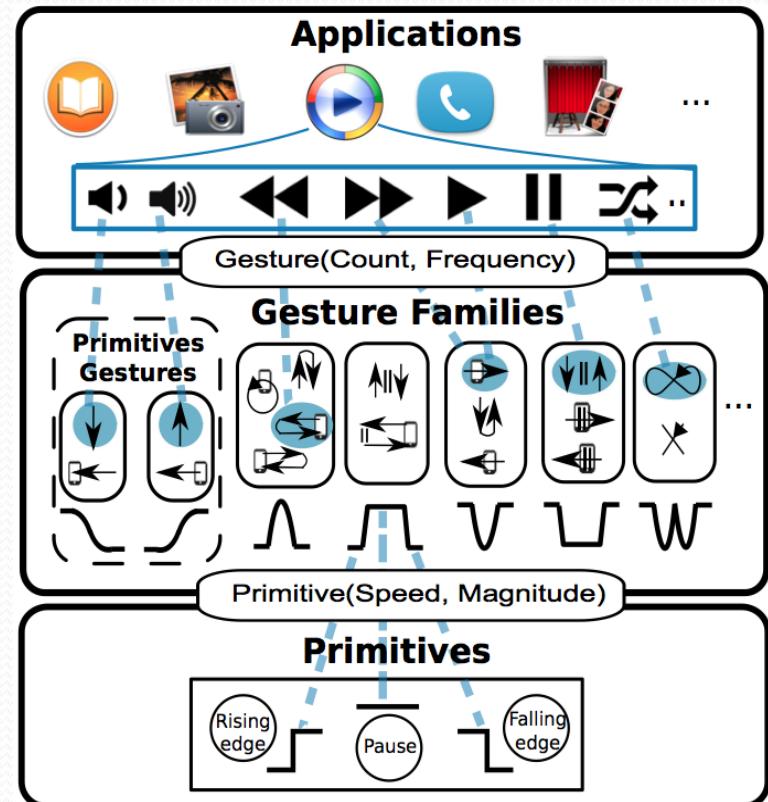


WiGest Demo – InfoCom 2015



WiGest

- Different signal change **primitives** are used to construct gesture **families** which mapped to **application** actions.
- WiGest has been evaluated in two different testbeds. It has accuracy of 96% using multiple APs.



UbiBreathe: A Ubiquitous non-Invasive WiFi-based Breathing Estimator

Motivation

- Monitoring breathing is an important predictor for **serious health problems**
 - SIDS
 - Apnea
 - Etc

Current Solutions

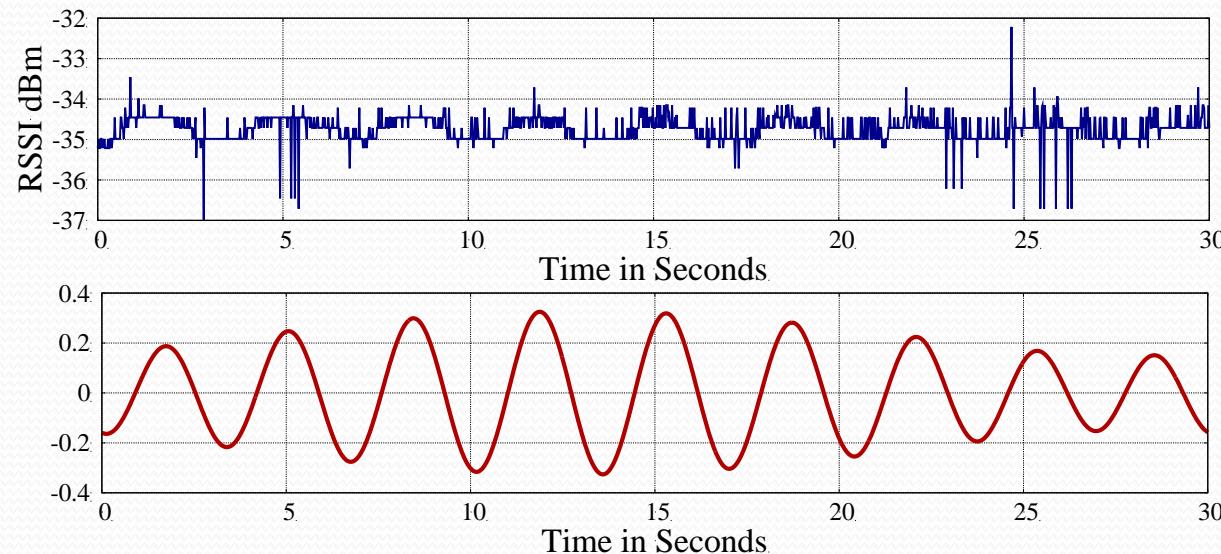
- Invasive
 - Not convenient
- Only in medical facilities
- Trained personnel
- Expensive dense equipment



Our Solution

- Based on WiFi signal
 - Leveraging the impact of breathing inhaling and exhaling motion on the received WiFi

WiFi Signal

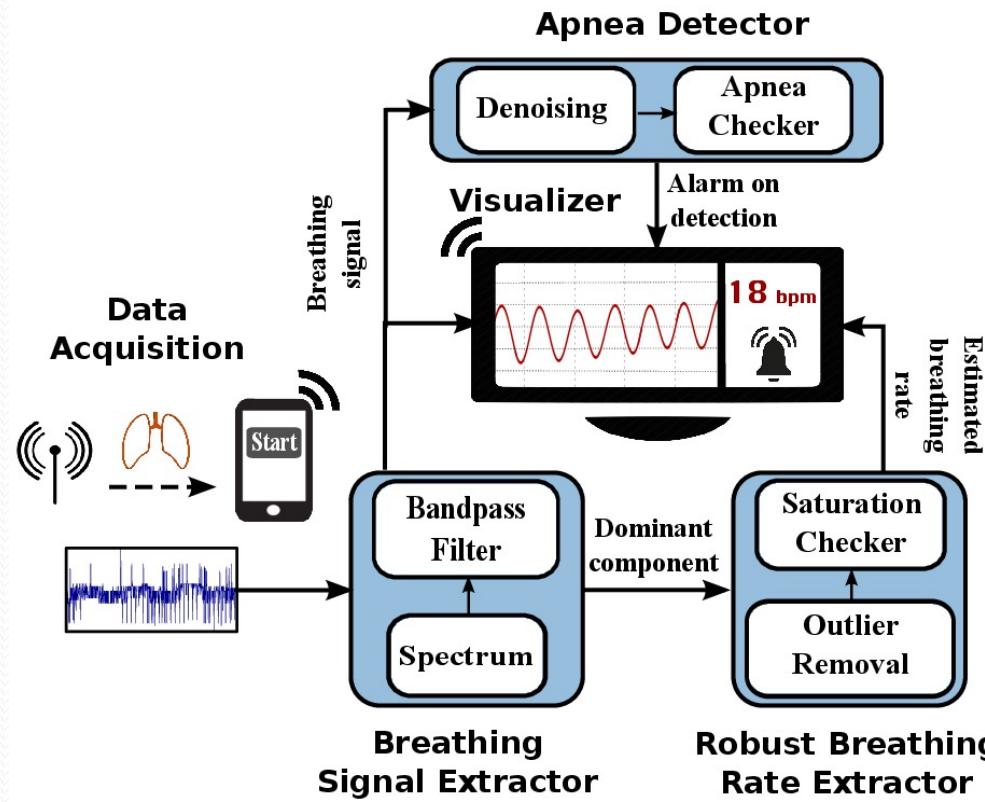


Breathing
Signal

Advantages

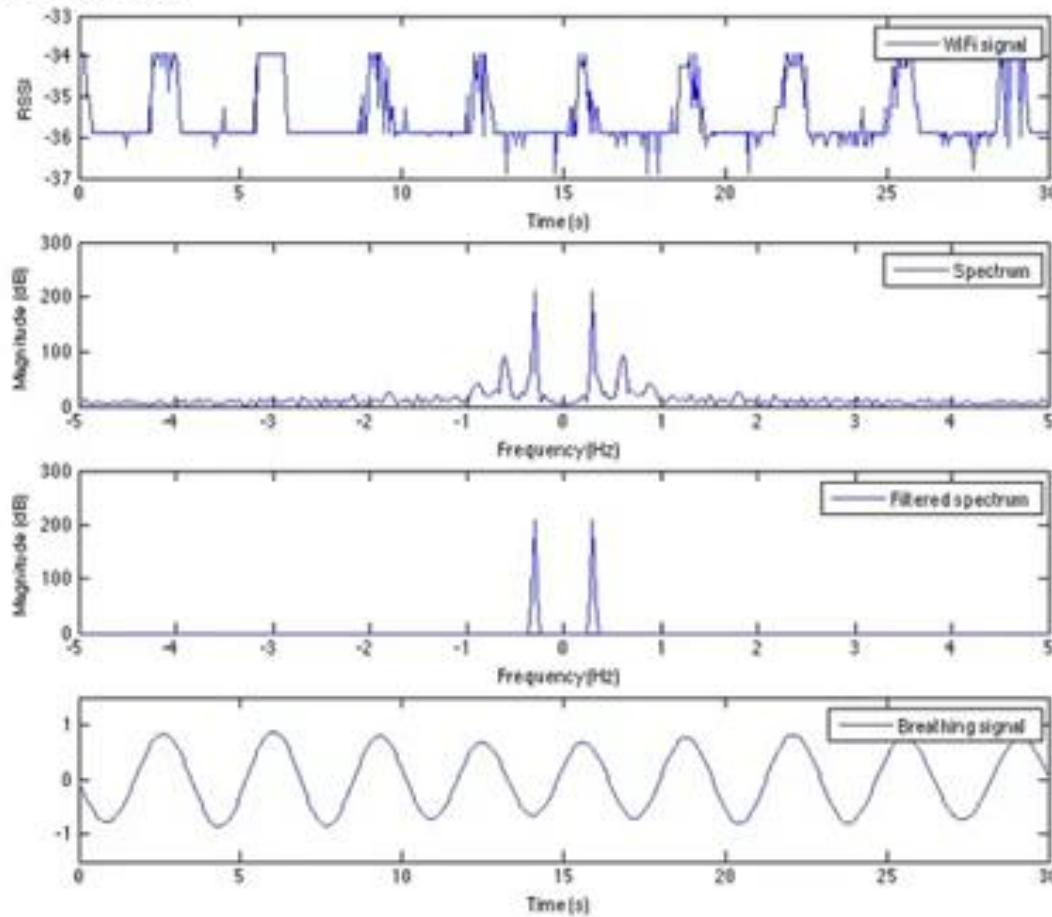
- Non-intrusive system for estimating breathing rates and detecting apnea
- Works with any WiFi-equipped devices
- Ubiquitous breath monitoring
 - Anywhere

UbiBreathe System



UbiBreathe Demo

WIBREATH



Actual breathing 18bpm

Instantaneous :
(Breathing Signal Extractor)
18.00bpm

Saturated :
(Robust Breathing Rate Extractor)
Calculating..



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Current Trends

- IoT
 - Scalable device-free detection, tracking, and identification
- Energy-free sensing
- Deep learning
- Wearable devices
 - Control
 - New biometric-based security for wearables
- Heterogeneity
 - Different technologies simultaneously
 - Different devices
- Novel applications!
 - Identification of subjects classes
 - Emotion recognition



Thank You



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