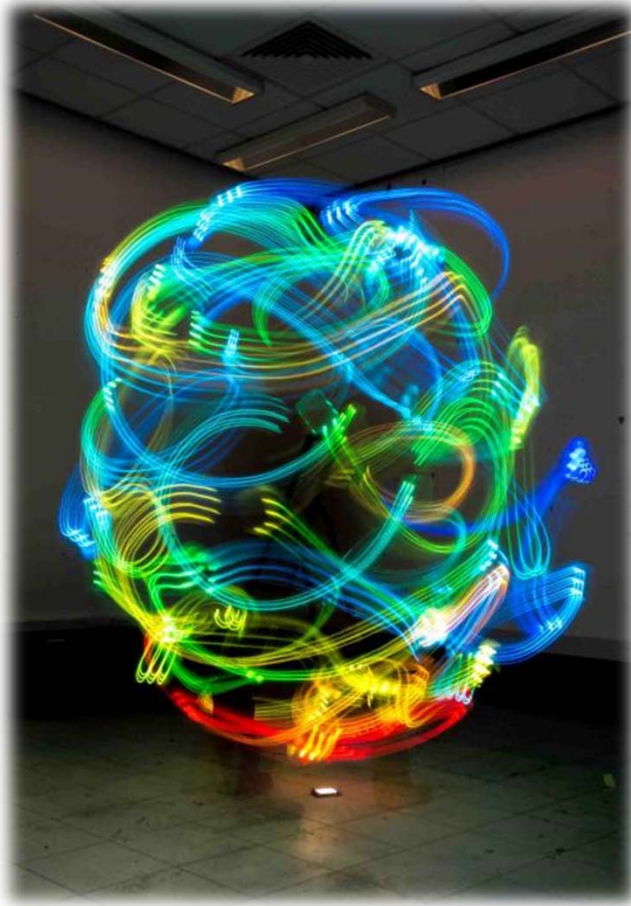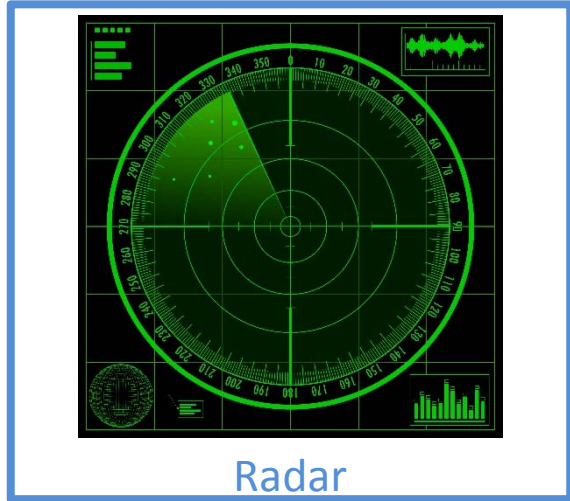# WiFi 雷达
无所不在的感知

杨 铮

清华大学软件学院

Outline

- **Introduction**
- Background
- Methods & Applications
- Conclusion

WiFi Signals Everywhere

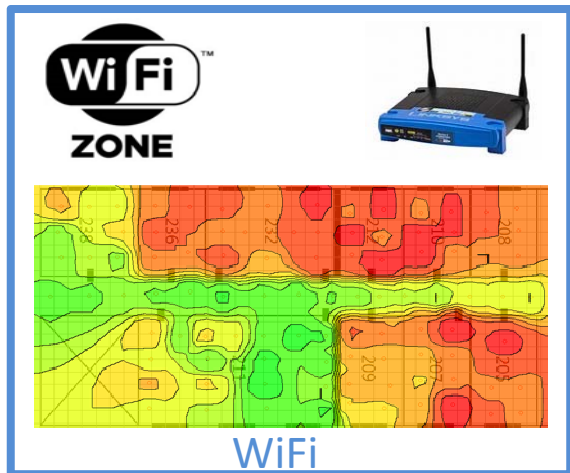Visualization of WiFi signals by Luis Hernan

WiFi as Radar?

Radar

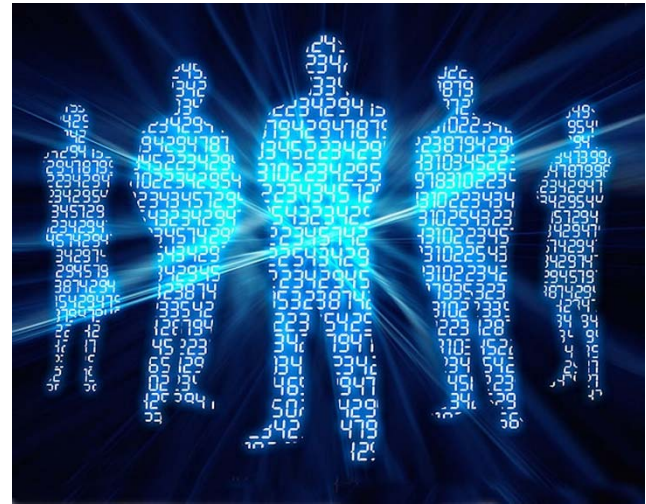+

WiFi

WiFi Radar
Omnipresent Sensing around You

WiFi Radar: Applications

Access Control

Asset Security

Intrusion Detection

Fall Detection

Sleep Quality Assessment

Healthcare

Whole-home Gaming

Remote Control

HCI

WiFi Radar: Benefits

- **Benefits:**
  - **Wireless** sensing without wires
  - **Sensorless** sensing without dedicated sensors
  - **Contactless** sensing without wearable sensors
  - Through-wall & Privacy Preserving

How to Enable
Sensoreless Sensing with WiFi?

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Detect Environment Dynamics

Signal Strength **+** LED **=**

- Capture environment dynamics via the fluctuation of radio signal
  - Received radio signal strength (RSSI)
- Is RSSI a Good Signal Feature?
  - In theory, it is. However …
  - In practice, sensing ability of RSSI is greatly weakened by rich multipath effects

Multipath: Enemy!

- Impacts of Multipath Effects:
  - Bound Accuracy of Ranging
  - Induce False Match in Fingerprinting

RSSI-based Ranging

RSSI-based Fingerprinting
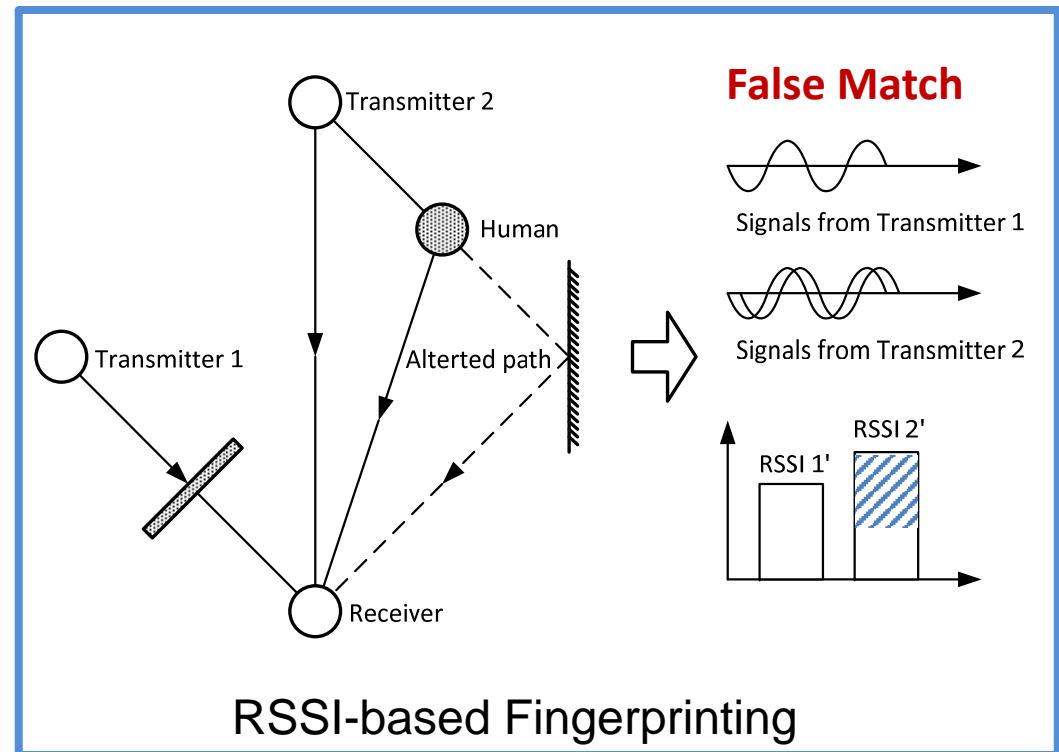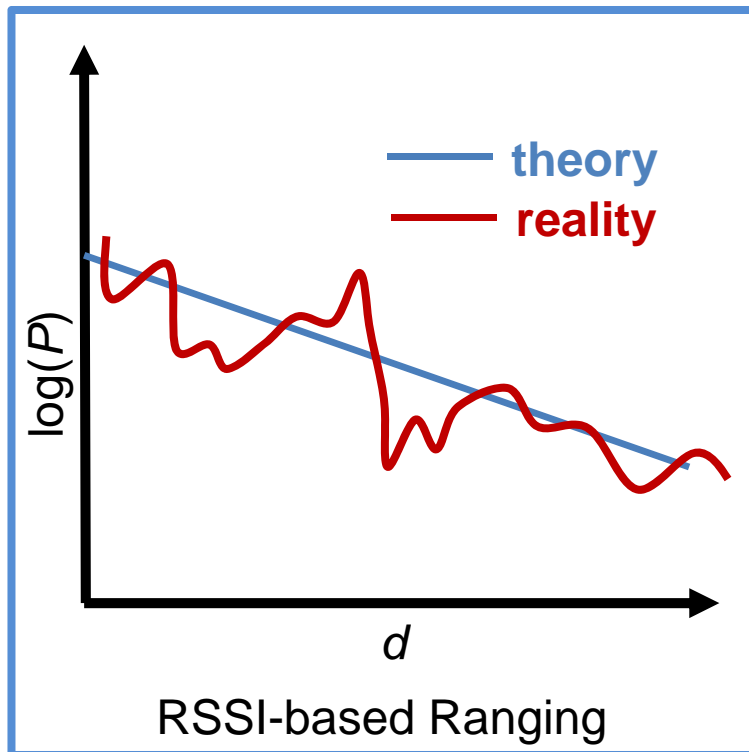
Multipath: Friend?!
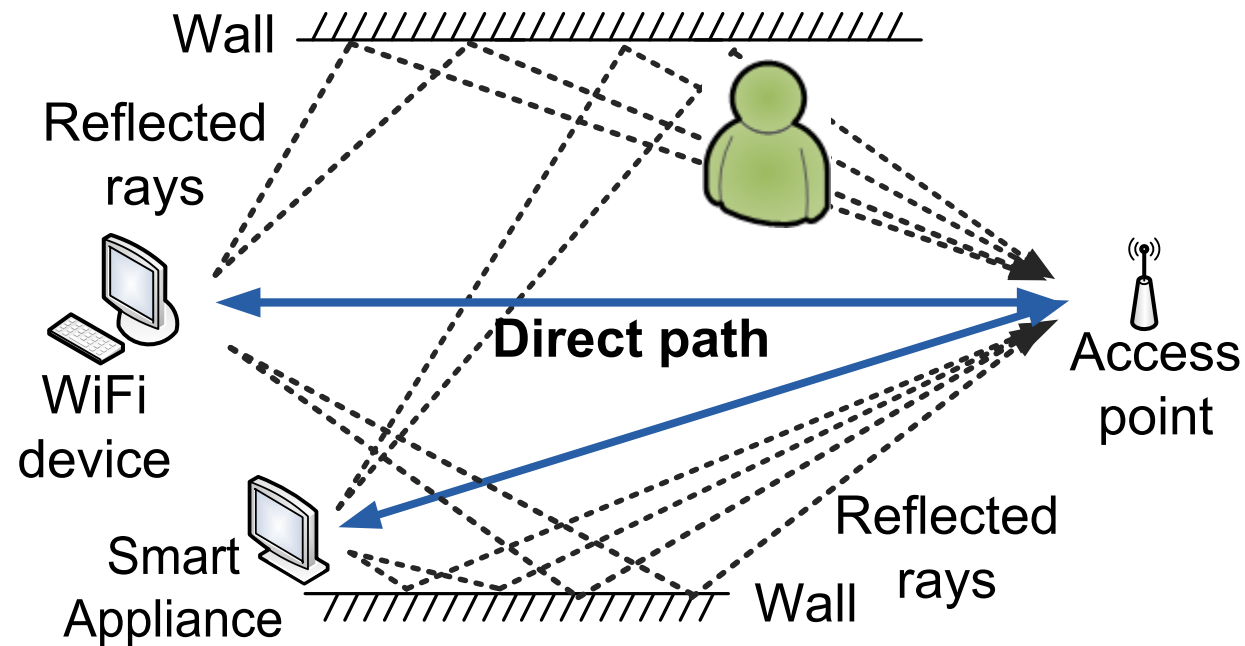
Multipath Propagation Conveys Rich Environment Information

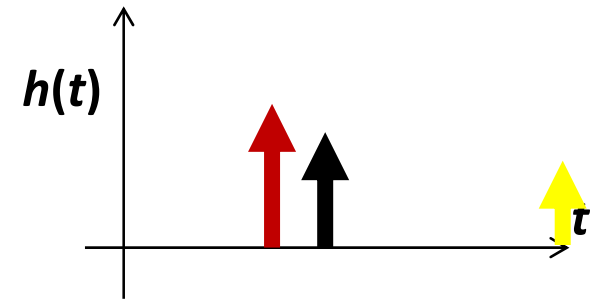# Characterizing Multipath

- Channel Impulse Response (CIR)
  - a set of attenuated, delayed impulse functions, depicting multipath

$$h(\tau) = \sum_{i=0}^{N-1} a_i \exp\left(-j\theta_i\right)\delta\left(\tau - \tau_i\right)$$

h(t)

τ

- Deriving Channel Response
  - VNA / SDR for precise measurement
  - Channel State Information (CSI): sampled version of channel response with OFDM at sub-carrier level
  - CSI on a single sub-carrier k: $H\left(f_k\right) = \left\|H\left(f_k\right)\right\| e^{j\sin(\angle H)}$

Channel State Information

Sub-carrier 1
Sub-carrier 2
Sub-carrier K

RSSI:
Sunbeam

OFDM:
Prism

CSI:
Dispersed Lights
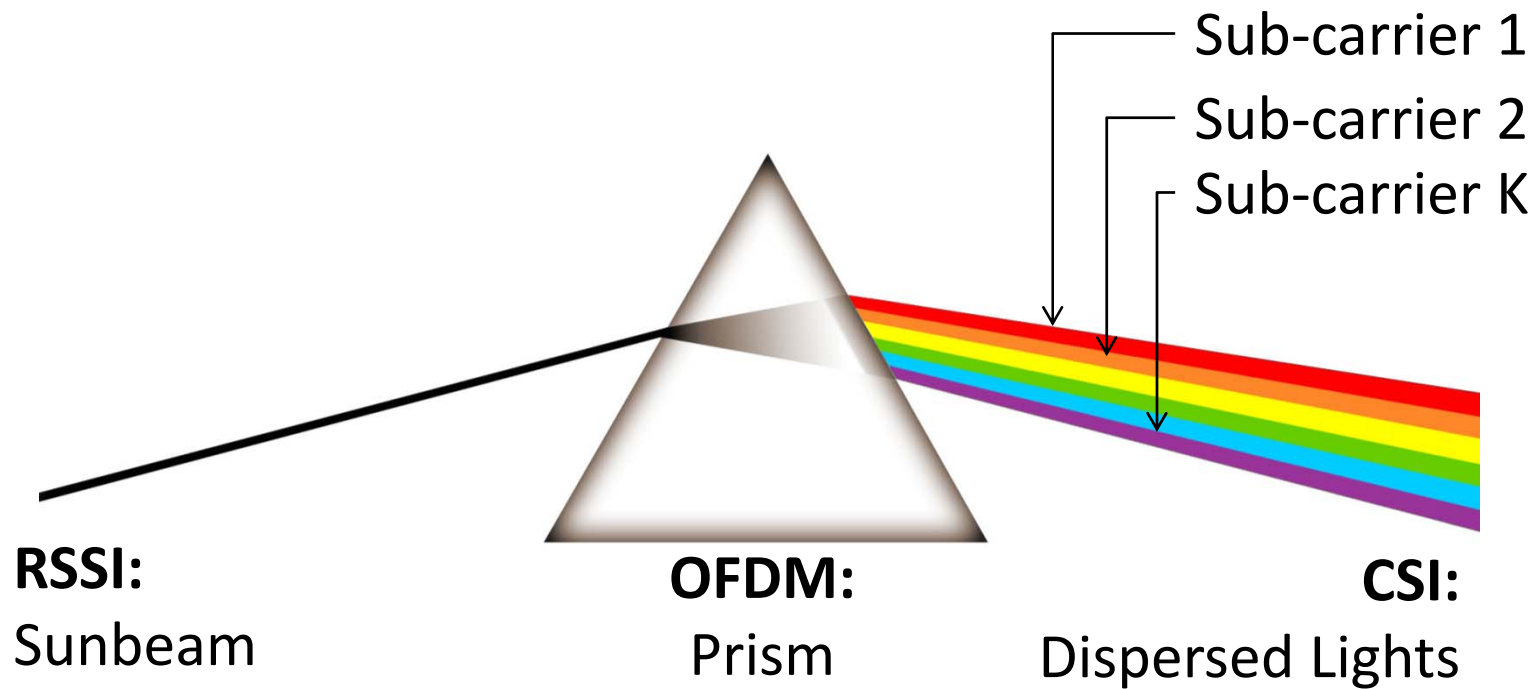
CSI vs. RSSI

| Category	RSSI	CSI
Layering	MAC layer	PHY layer
Time Resolution	Packet level	Multipath clusters
Frequency Resolution	N/A	Sub-carrier level
Stability	Low	High for CFR structure
Ubiquity	Handy access	Commercial Wi-Fi

How **CSI** Benefits **WiFi Sensing**?

Outline

- Introduction
- Background
- **Method & Application**
  - **Sensing Coverage**
  - **Sensing Human with Dynamic Speeds**
  - **Sensing Static Human**
- Conclusion

Passive Human Sensing

- **Objective:**
  - Detect, Count, Localize, Track, Identify
- **Emerging Trend:**
  - Sense Humans **Passively**

ground truth

| presence | count | location | track | identity |

TRUE

3

information
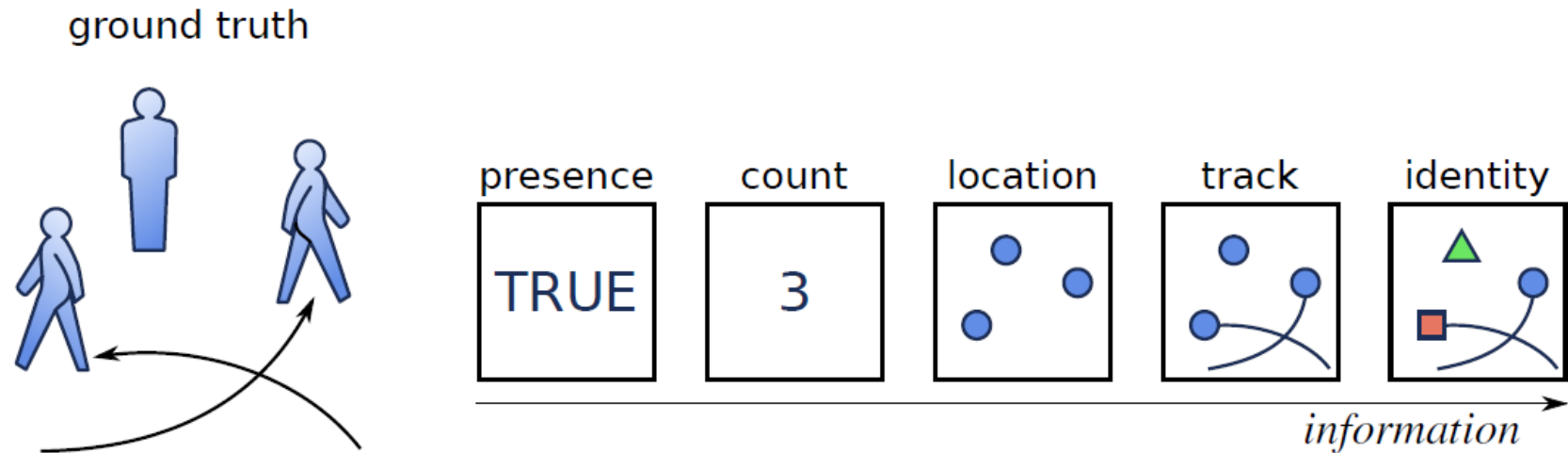
Passive Human Sensing

A Thief! Help!

I won't be detected.

Passive Human Sensing:
- Asset Security
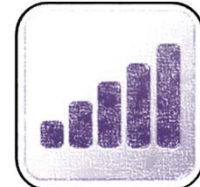- Emergency Response
- Smart Space
- ...

Existing Methods

High Cost

LOS, Smoke, Directional

- Pervasive, low cost
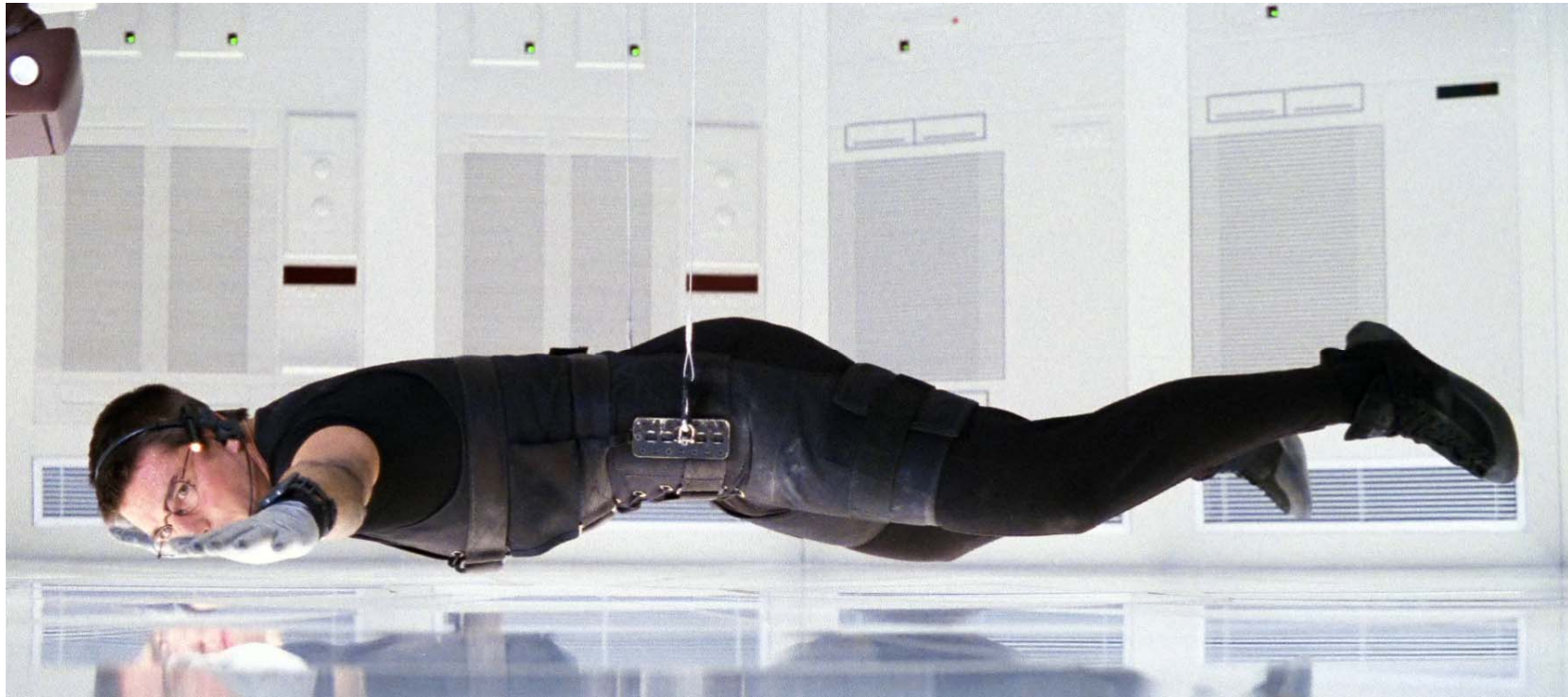- Penetrate walls and smoke
- No privacy issues

Limitation of Existing Methods

- Pressure Sensor

Limitation of Existing Methods

- Pressure Sensor

Limitation of Existing Methods

- Infrared Sensor

Limitation of Existing Methods

- Infrared Sensor

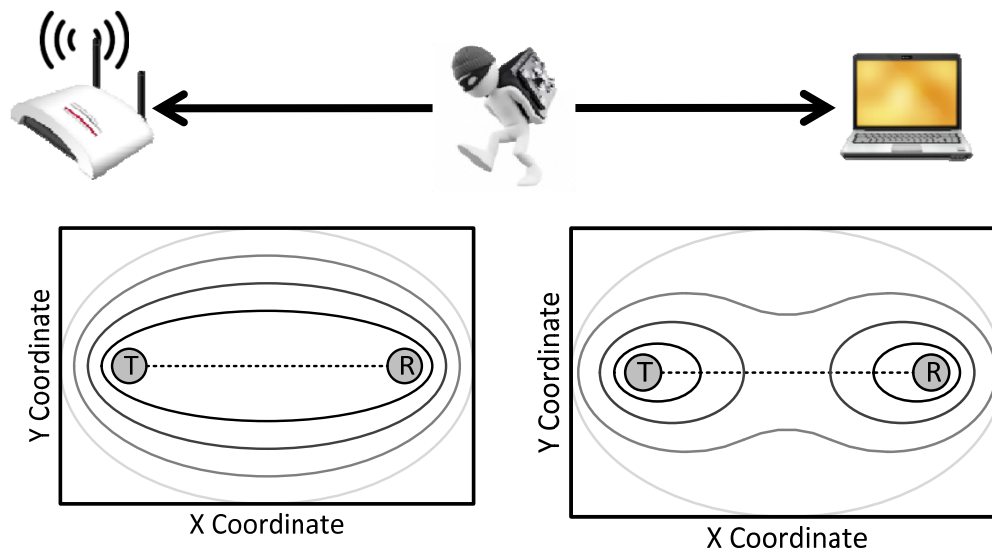# Limitation of Existing Methods

- Camera

Limitation of Existing Methods

- Camera

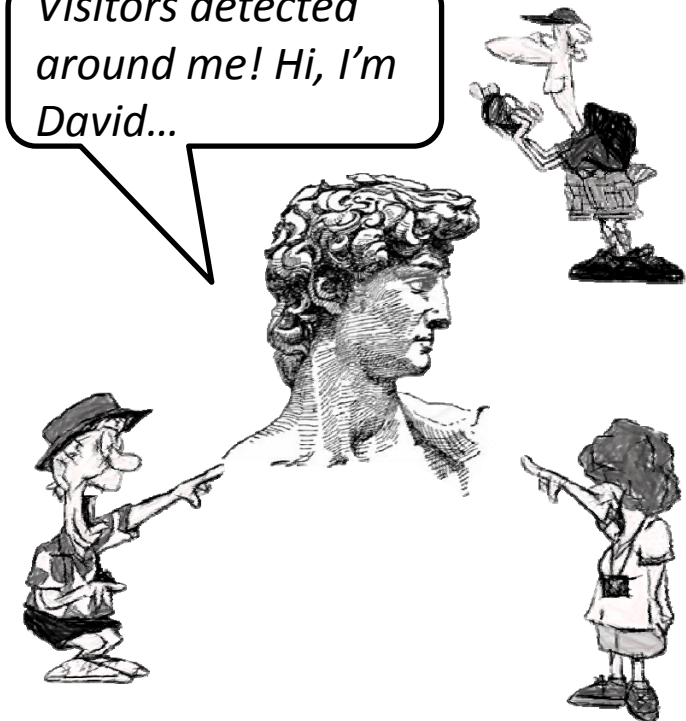# Link-centric Coverage Shape

- Most monitoring units demonstrate a **link-centric** property
- **Disk-like** coverage is also desired in theory and application

Visitors detected around me! Hi, I'm David...

Scattering Dominant

Reflection Dominant

Omnidirectional Coverage?

- **Objective:**
  - Omnidirectional coverage under link-centric structure

Original Detection
Rate Contour

**Envisioned Detection
Rate Contour**
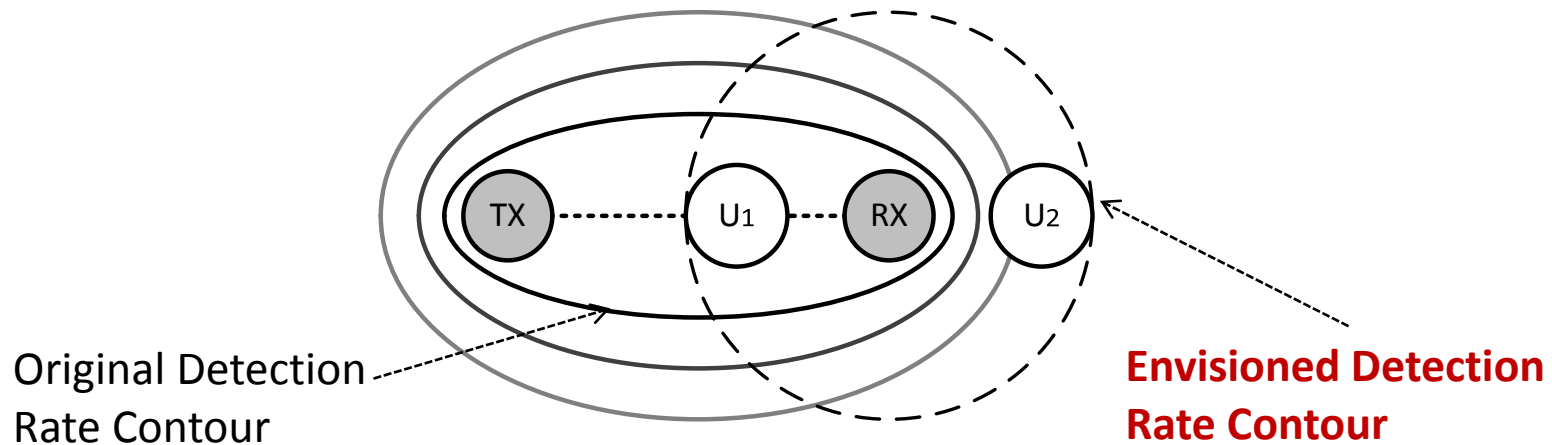
Insight: Exploit Multipath to Blur the Link-centric Coverage

Zhou et al, "Towards Omnidirectional Passive Human Detection ", IEEE INFOCOM, 2013

Fingerprinting Each Direction

- Requirements on the Fingerprints:
  - Sensitive to Human Presence **Nearby**
  - Resistant to Background Dynamics **Faraway**

Case 1: Normal Profile with No One Around

Case 2: Normal Profile with 3 Men Strolling
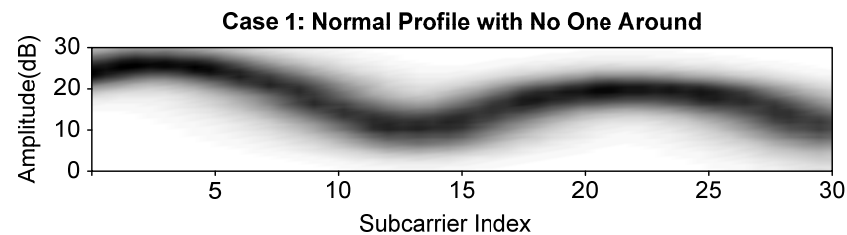
Stable under Dynamics **Faraway**
Disperse with **Nearby** Human Motions

Subcarrier Index

Moving Target Detection

- **Principle:**
  - Variance Reflects Changes

Subcarriers
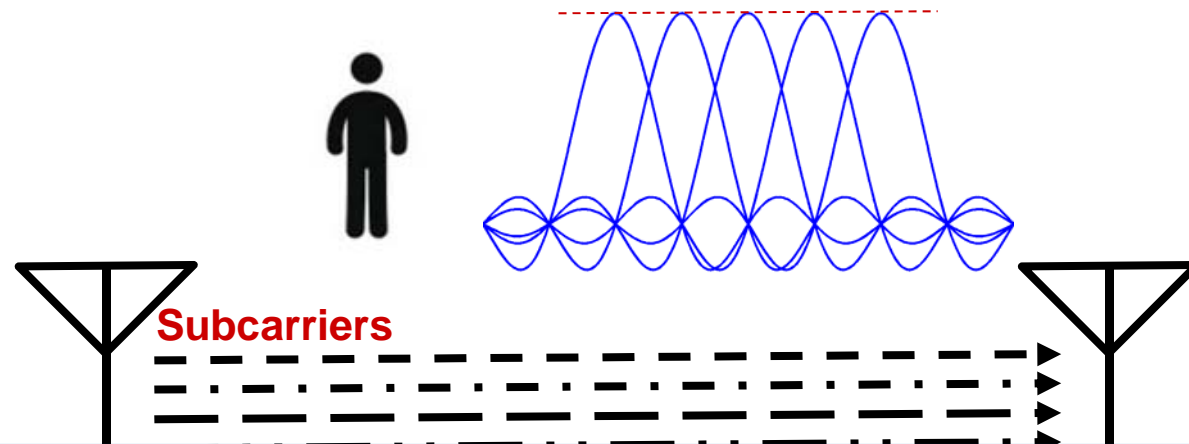
Slow Motions May be **Missed**
Due to **Low Sensitivity**

Coping with Dynamic Motion Speeds

- **Rationale:**
  - Variances of both phase and amplitude reflect changes

Subcarrier 10 — Subcarrier 20

Qian et al, "PADS: Passive Detection of Moving Targets with Dynamic Speed using PHY Layer Information", IEEE ICPADS, 2014   27
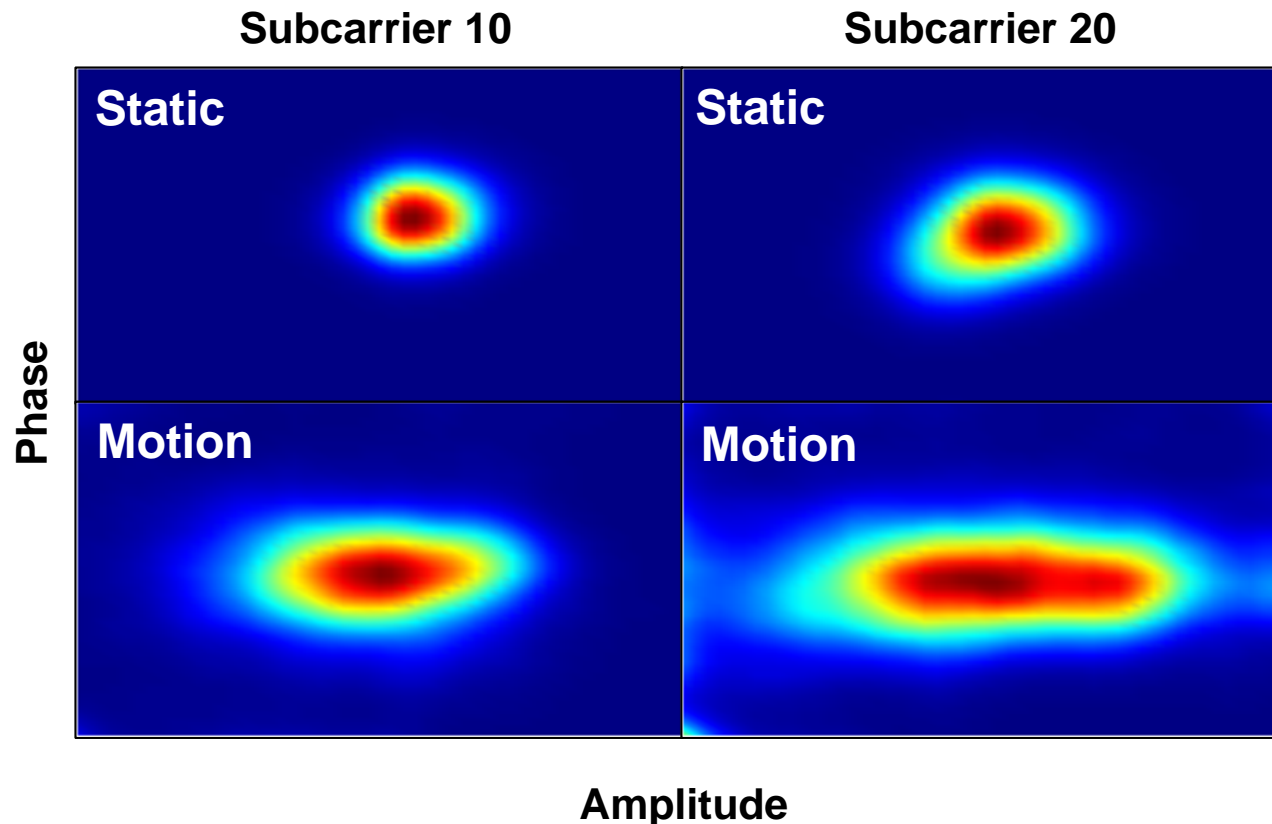
Demo

优酷：http://v.youku.com/v_show/id_XODQ4MTY3MjY0.html

Youtube: http://youtu.be/As5JexOeOYY

Sensing Static Humans
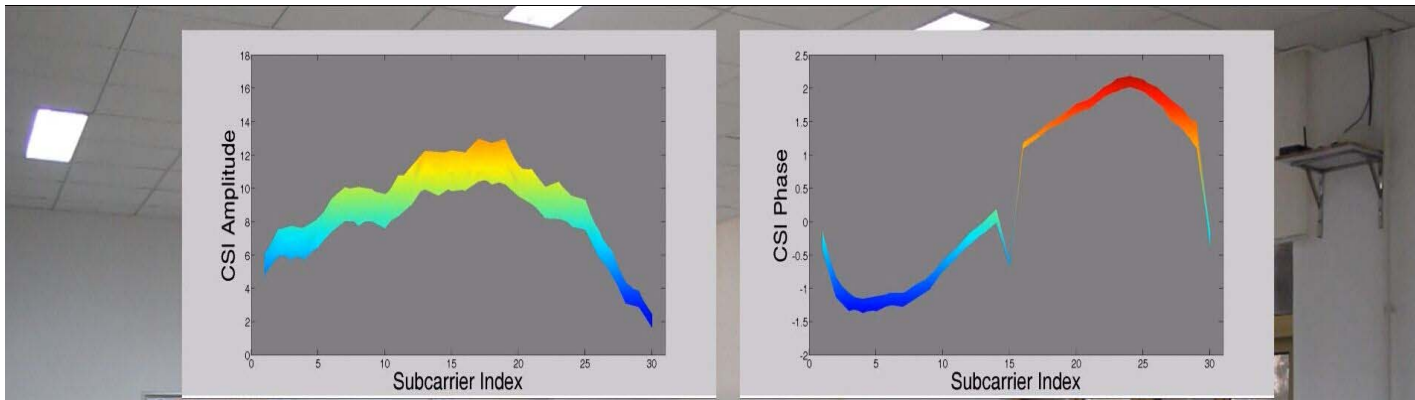
Cannot Sense Static Humans

Static Human

Do not Move, Yet Breathe!

Breathing Induces **Rhythmic** Chest Motions!

➢ Detect Static Humans via Breathing-induced Signals

➢ A Unified Scheme for Detection of Moving and Stationary Humans

➢ Converges the advantages of purely WiFi-based, scenario-specific calibration free, and non-invasive together

Design & Challenges
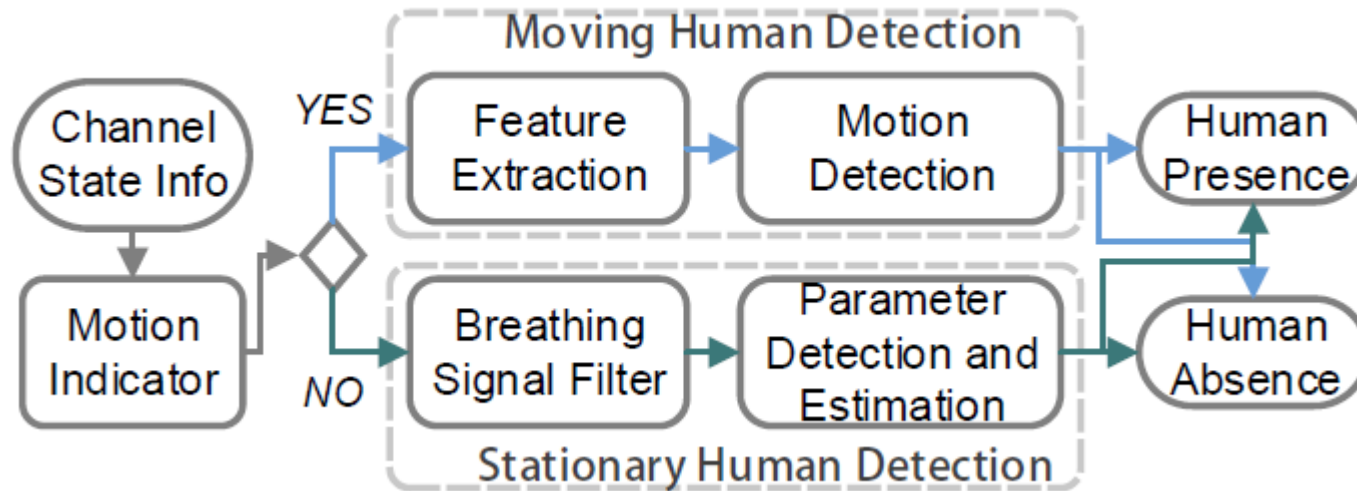
A **unified** framework for **static & moving** human detection (**minute breathing-induced chest motion** vs **significant body motions**)

Identify **weak human breathing patterns** from wireless signals with environmental noises

Detect static humans **without fingerprinting**

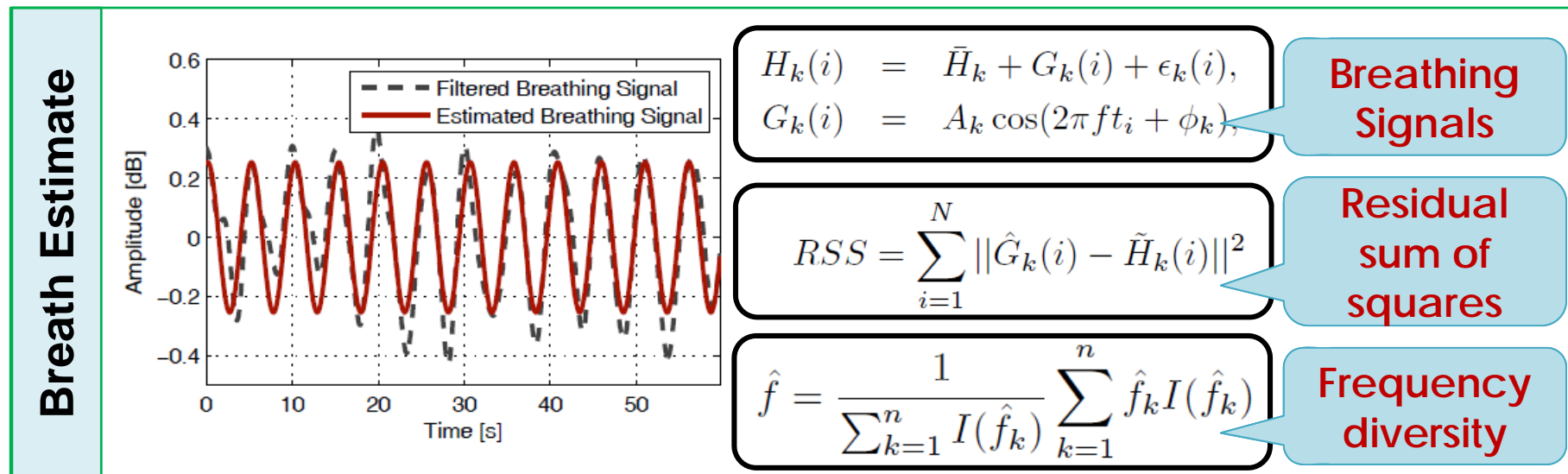# Static Human Detection

Measurements

Breathing Freq.
[0.167, 0.667] *Hz*

Bandpass filter

Breath Estimate

$$H_k(i) = \bar{H}_k + G_k(i) + \epsilon_k(i),$$
$$G_k(i) = A_k \cos(2\pi f t_i + \phi_k),$$

Breathing Signals

$$RSS = \sum_{i=1}^{N} ||\hat{G}_k(i) - \tilde{H}_k(i)||^2$$

Residual sum of squares

$$\hat{f} = \frac{1}{\sum_{k=1}^{n} I(\hat{f}_k)} \sum_{k=1}^{n} \hat{f}_k I(\hat{f}_k)$$

Frequency diversity
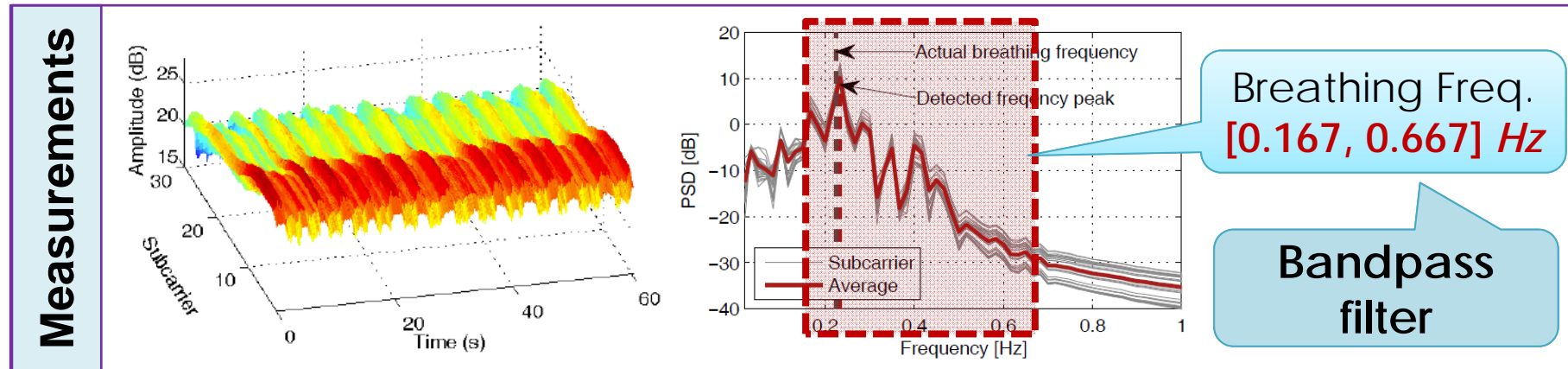
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Summary

CSI, the fine-grained channel response accessible on commodity WiFi devices, acts as an essential upgrade of RSSI.

WiFi-Radar enables WiFi to sense wirelessly, sensorlessly, and contactlessly.

Due to its worldwide deployment, WiFi can be seen as the world's largest sensor network.

WiFi-Radar, together with emerging PHY layer information, initializes the pulse on next-generation mobile computing.

Look ahead

以前在电视剧中总能看到这样的场景，当几个人做坏事或者密谋做坏事的时候，一般会选择一个密室，关好门拉上窗帘，有经验的还会检查桌子下面是否有窃听器，完事后还要仪式性地念叨一句"天知地知，你知我知"。

今后，别忘了还要把Wi-Fi 关掉。

Reference

- Zimu Zhou, et al., "Sensorless Sensing with WiFi", Tsinghua Science and Technology, Vol. 20, No. 1, pp. 1–6, 2015.

- Zheng Yang, et al., "From RSSI to CSI: Indoor Localization via Channel Response", ACM Computing Surveys, Volume 46, No. 2, 2014.

- Chenshu Wu, Zheng Yang, et al., "Non-invasive Detection of Moving and Stationary Human with WiFi", IEEE JSAC.

- Qian et al, "PADS: Passive Detection of Moving Targets with Dynamic Speed using PHY Layer Information", IEEE ICPADS, 2014.

- Zimu Zhou, Zheng Yang, et al., "Omnidirectional Coverage for Device-free Passive Human Detection", IEEE Transactions on Parallel and Distributed Systems (TPDS), Volume 25, Issue 7, Pages 1819 – 1829, July 2014.

- Zimu Zhou, Zheng Yang, et al., On Multipath Link Characterization and Adaptation for Device-free Human Detection, IEEE ICDCS, 2015.

- 杨铮、吴陈沭、刘云浩，《位置计算：无线网络定位与可定位性》，清华大学出版社，2014

- WiFi雷达主页：http://tns.thss.tsinghua.edu.cn/wifiradar/

WiFi雷达实验平台

- "WiFi雷达"实验平台包括微型工控机、TNS-CSI Tool、Visual CSI软件等，可实时显示无线信道状态信息（振幅与相位），并能同步存储观测数据，方便使用者观察和分析环境变化对信道状态的影响。

- WiFi雷达主页：
http://tns.thss.tsinghua.edu.cn/wifiradar/

Thanks!
Q&A