From Fresnel Diffraction Model to Contactless Sensing with Commodity Wi-Fi Devices

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Outline

1. **Background**

2. **Fresnel Diffraction Model**

3. **Applying the Model for Human Respiration Sensing**

4. **Applying the Model for Human Activity Sensing**

5. **Summary**

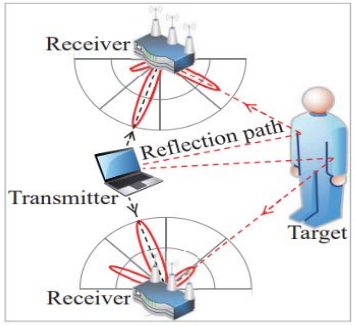
1. Background

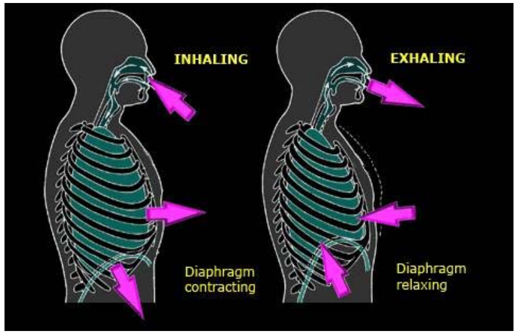
Wi-Fi based device free sensing

■ **Application:**

- **Coarse-grained:** **Localization, Fall detection**
- **Fine-grained:** **Keystroke detection, Respiration sensing**

Advantage : non-intrusive, cost-effective, privacy friendly





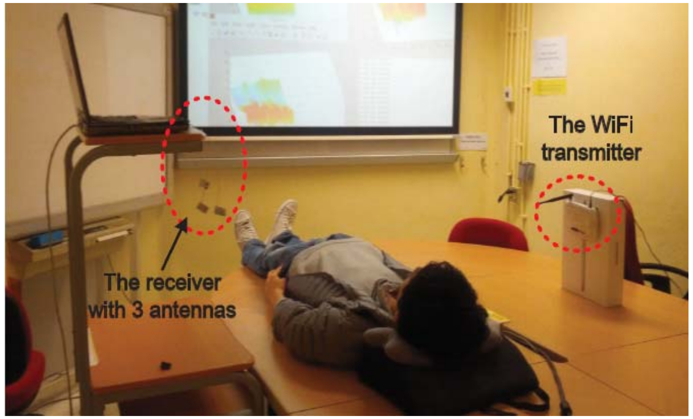
Localization **Fall detection** **Keystroke detection** **Respiration sensing**

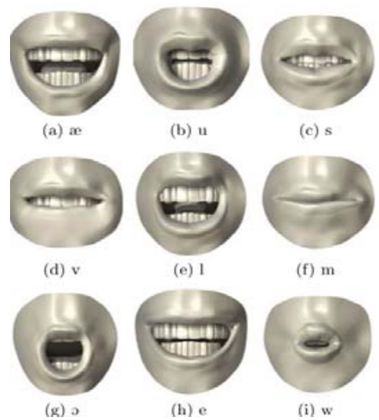
Coarse-grained

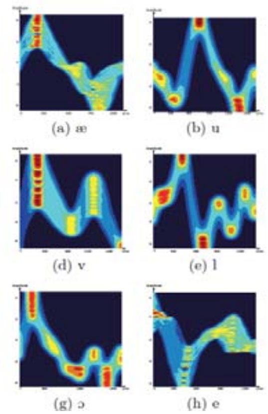
Fine-grained

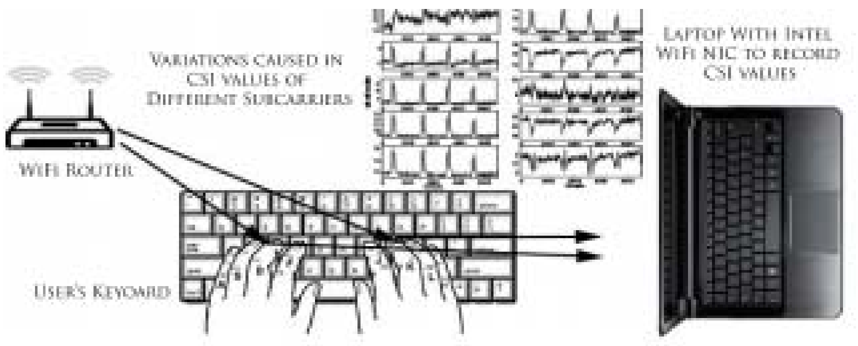
Existing work

- Most of the existing work employ pattern-based approaches using a trial-and-error methodology. It lacks lack of theoretical foundation for wireless sensing.
- Our group first proposes Fresnel refection model out first Fresnel zone (FFZ) in 2016 (Ubicomp paper). It explains when the human respiration can be detected using reflection signal.





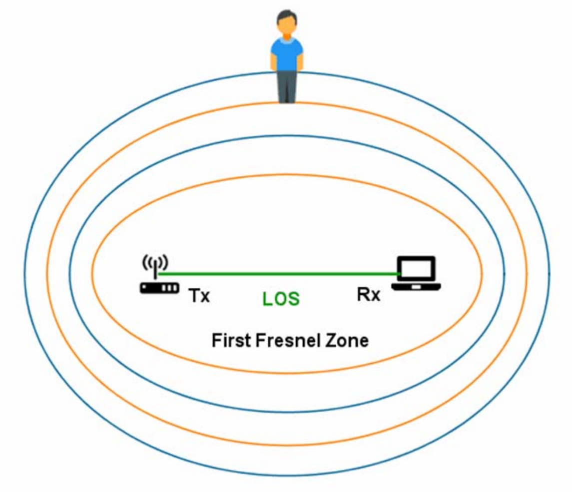




Motivation

The inner most zone between transmitter and receiver remains a mystery for researchers.

1. **What's the theory behind sensing human activities in the FFZ?**
2. **How to detect human activity when the target located in the FFZ?**



2. Fresnel Diffraction Model

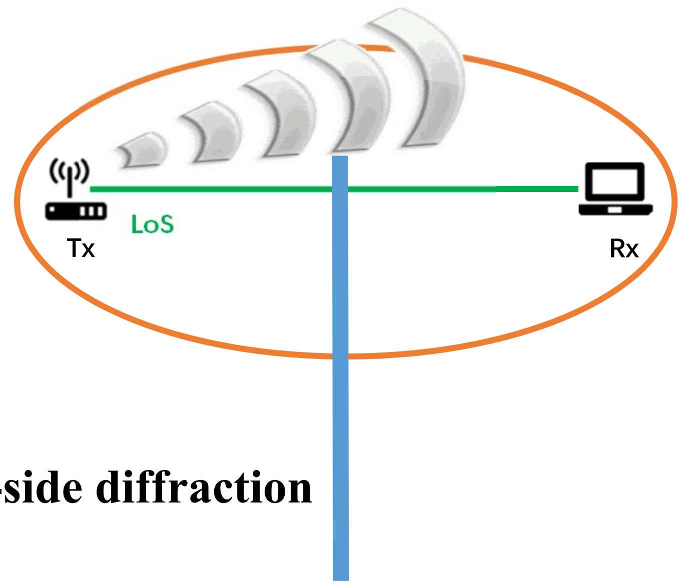
The Basics of Fresnel Zone Model

- **Fresnel Zones refer to the concentric ellipses with foci in a pair of transceivers** $|TxQ_n| + |RxQ_n| - |TxRx| = n\lambda/2$

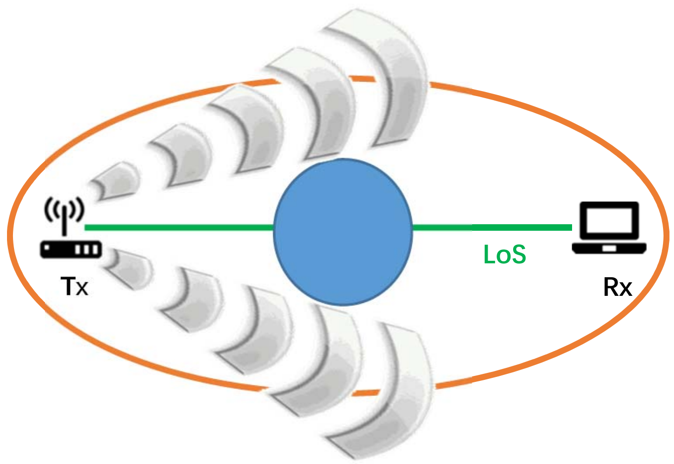
More than 70% of the energy is transferred via FFZ

Diffraction Phenomenon

- **Case1: one-side diffraction.** **Signals have diffractions at one side, corresponding to an infinite-size target presented in the FFZ.**
- **Case2: double-side diffraction.** **Signals have diffractions at both sides of the target, corresponding to a finite-size target presented in the FFZ.**



Case1: one-side diffraction



Case2： double-side diffraction

Diffraction Based Sensing Model

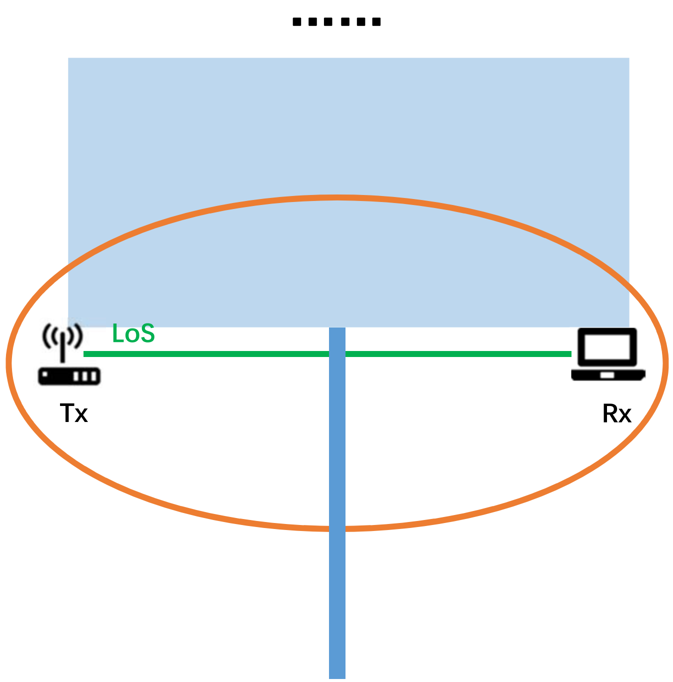
(1) One side diffraction model

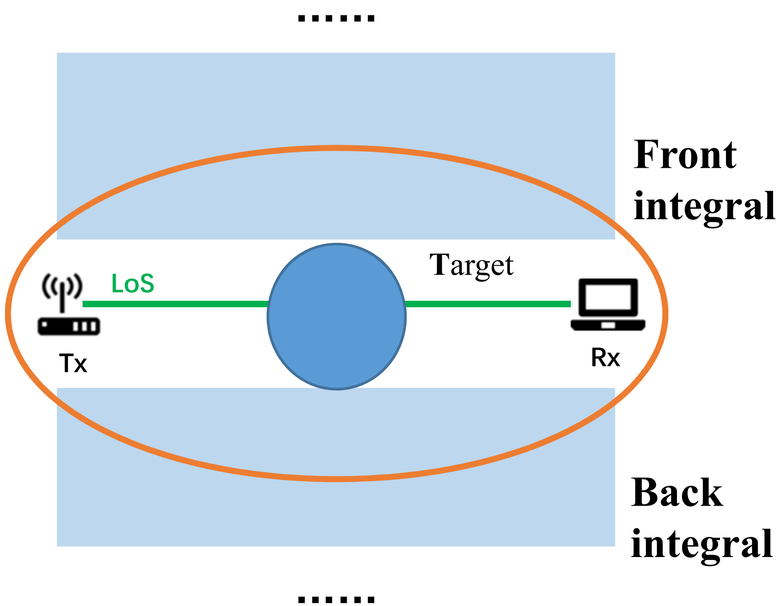
$$F(v)=\frac{1+j}{2}\cdot\int_{v}^{\infty}\exp\left(\frac{-J.\pi Z^2}{2}\right)dz$$

(2) Double side diffraction model

$$F(v)=|F(v_{front})+F(v_{back})|$$

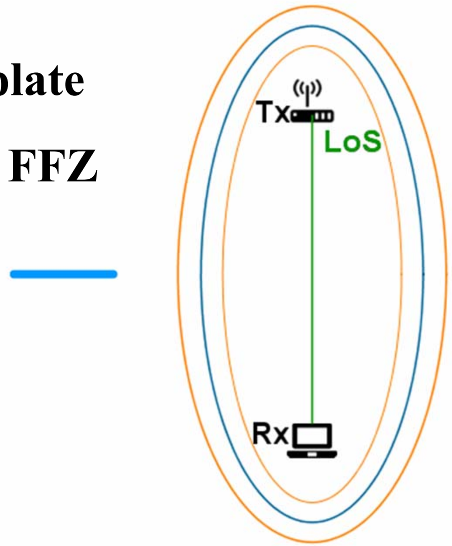
- Front integral: $F(v_{front})=\frac{1+j}{2}\cdot\int_{V_{front}}^{\infty}exp\left(\frac{-J.\pi Z^2}{2}\right)dz$
- Back integral: $F(v_{back})=\frac{1+j}{2}\cdot\int_{-\infty}^{V_{back}}exp\left(\frac{-J.\pi Z^2}{2}\right)dz$



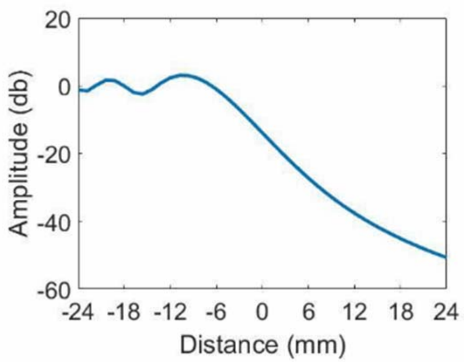


Example: diffraction signal with target moving across the FFZ

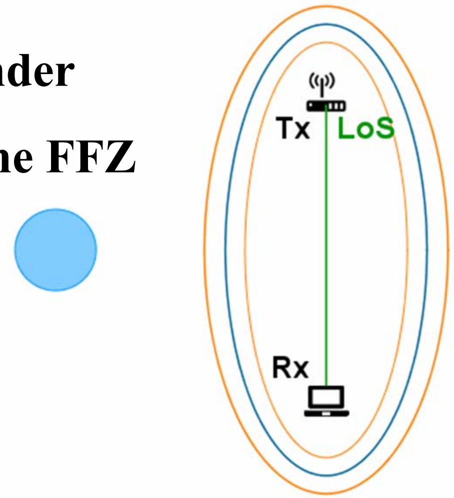
A infinite metal plate moves across the FFZ



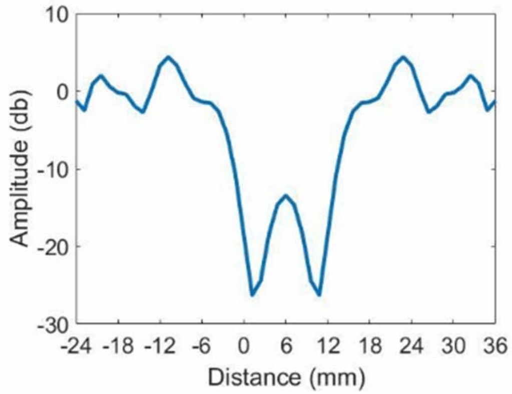
- Last peak appears around the boundary of FFZ
- monotonic decrease in FFZ



A circular cylinder moves across the FFZ



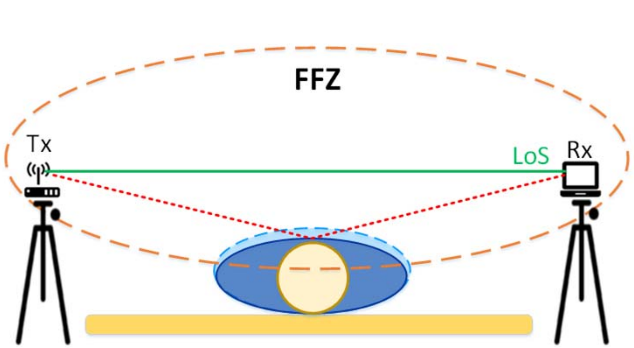
- Signal appears "W" like wave
- non-monotonous in FFZ



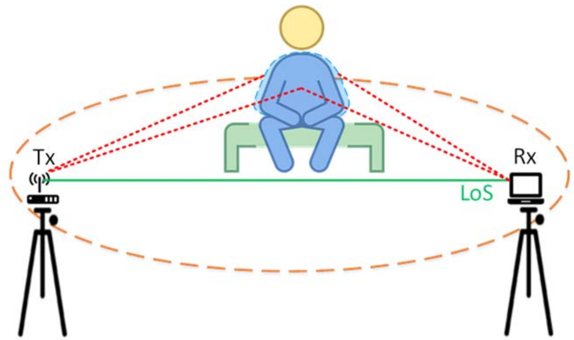
3. Applying the Diffraction Sensing Model for Human Respiration Detection

Scenario: detecting respiration while sitting and lying

- **Case1： while subject lying, it corresponds to one-side diffraction, signals have diffractions at one side**
- **Case2： while subject sitting, it corresponds to double-side diffraction, signals have diffractions at double side**



Lying： one side diffraction



Sitting: double side diffraction

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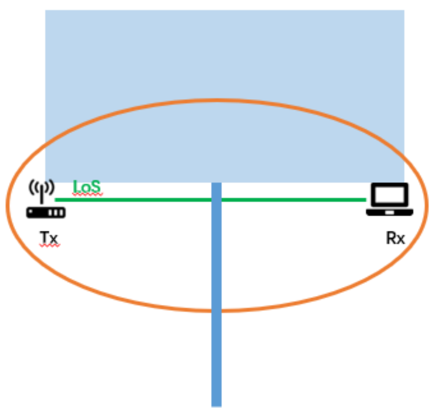

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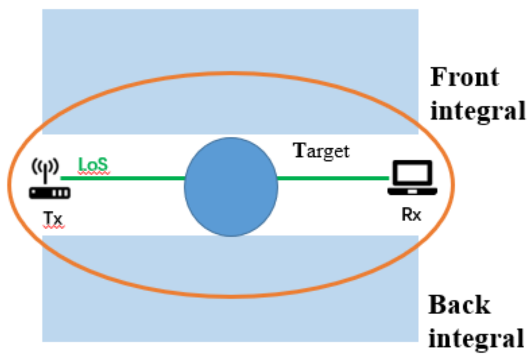

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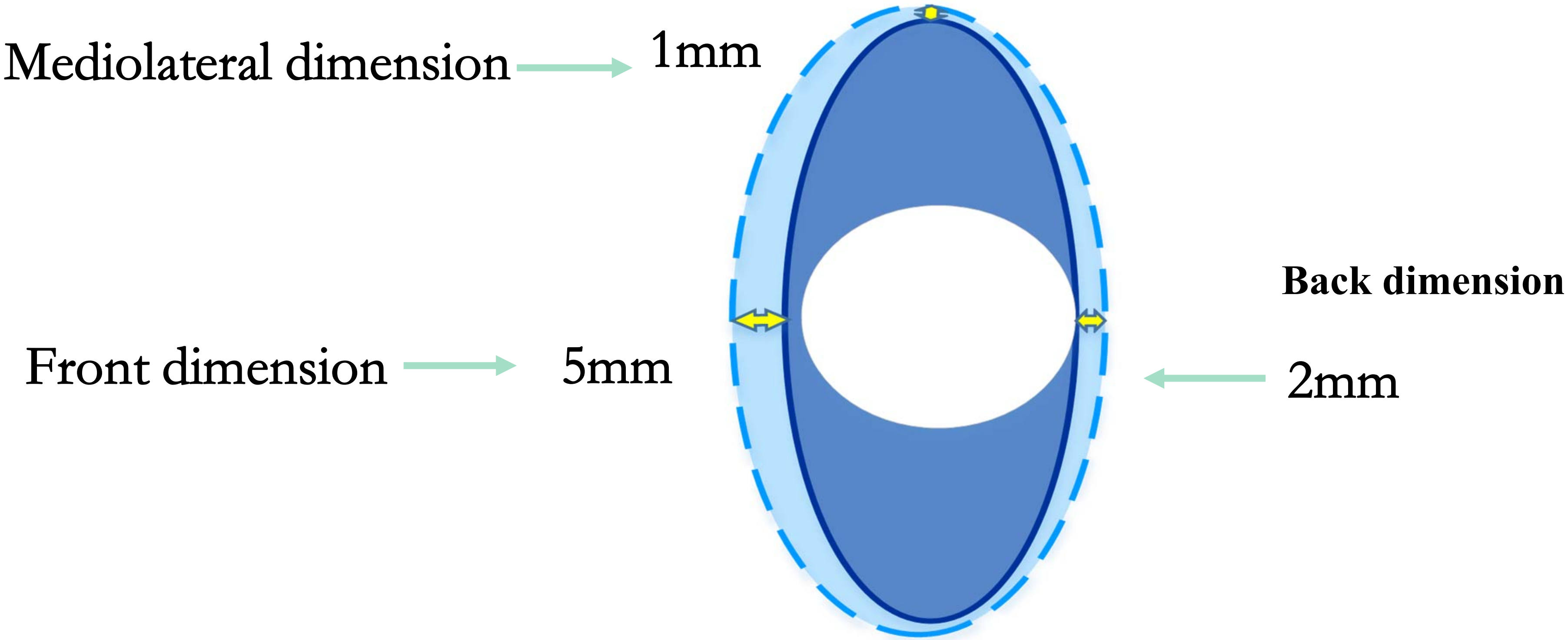
Modeling human respiration

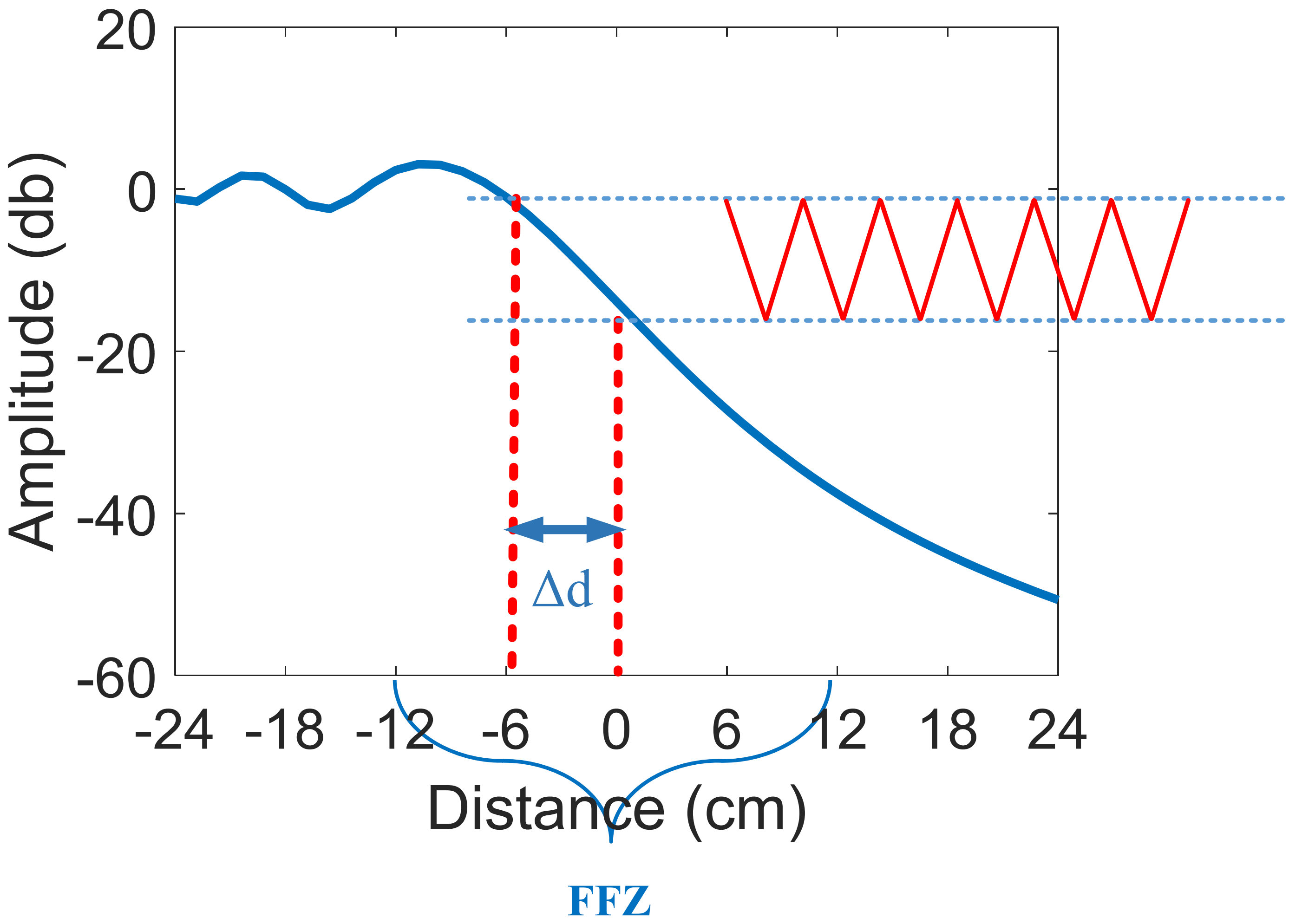
- **Human body is modeled as a varying size flat-cylinder**



1. C Lowanichkiattikul, M Dhanachai, C Sitathanee, S Khachonkham, and P Khaothong. *Impact of chest wall motion caused by respiration in adjuvant radiotherapy for postoperative breast cancer patients*. SpringerPlus 5, 1 (2016), 1–8.
2. Anders N Pedersen, Stine Korreman, Håkan Nyström, and Lena Specht. *Breathing adapted radiotherapy of breast cancer: reduction of cardiac and pulmonary doses using voluntary inspiration breath-hold*. Radiotherapy and oncology 72, 1 (2004), 53–60.

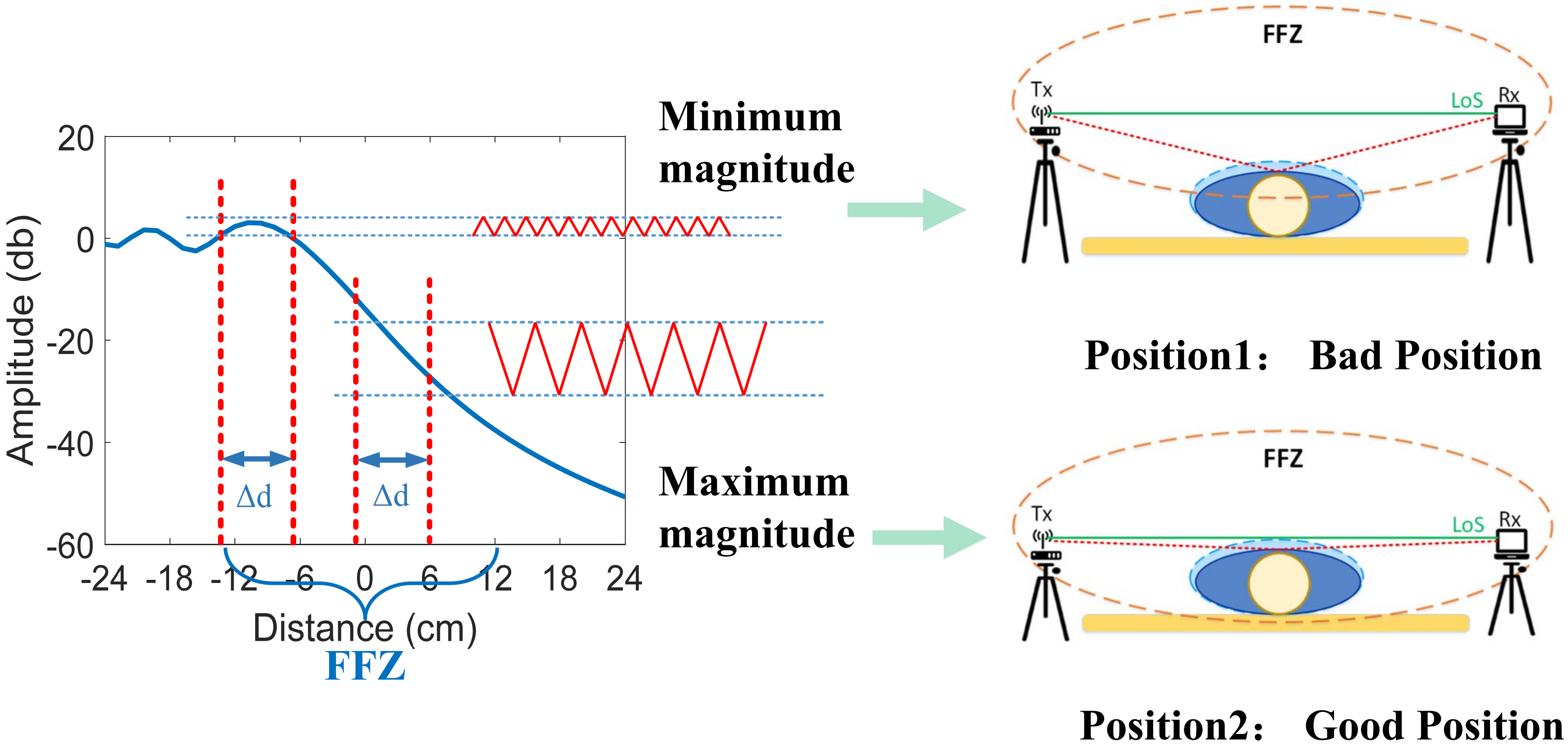
Extracting sensing signal of respiration

- **The chest displacement Δd causes a fragment of the whole received signal**



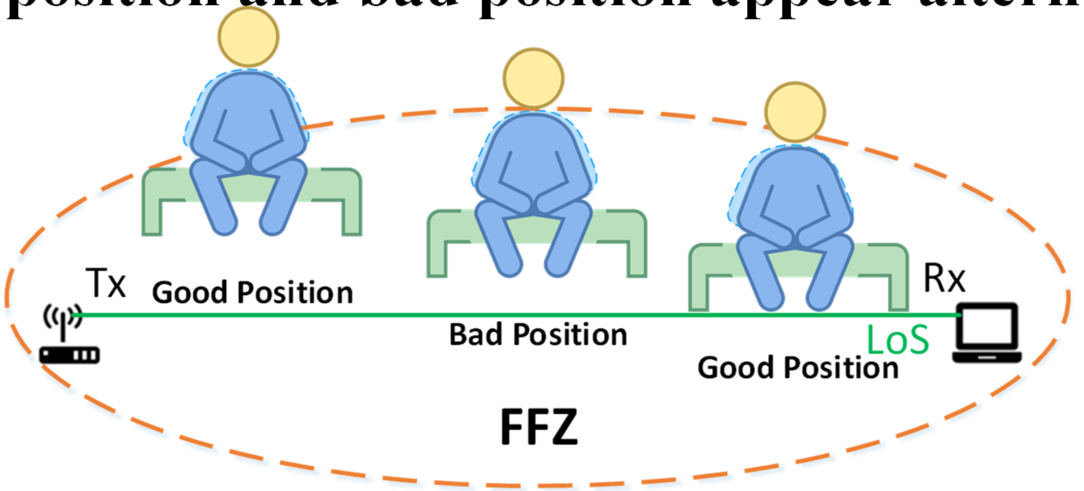
Chest location vs. signal variation（Lying）

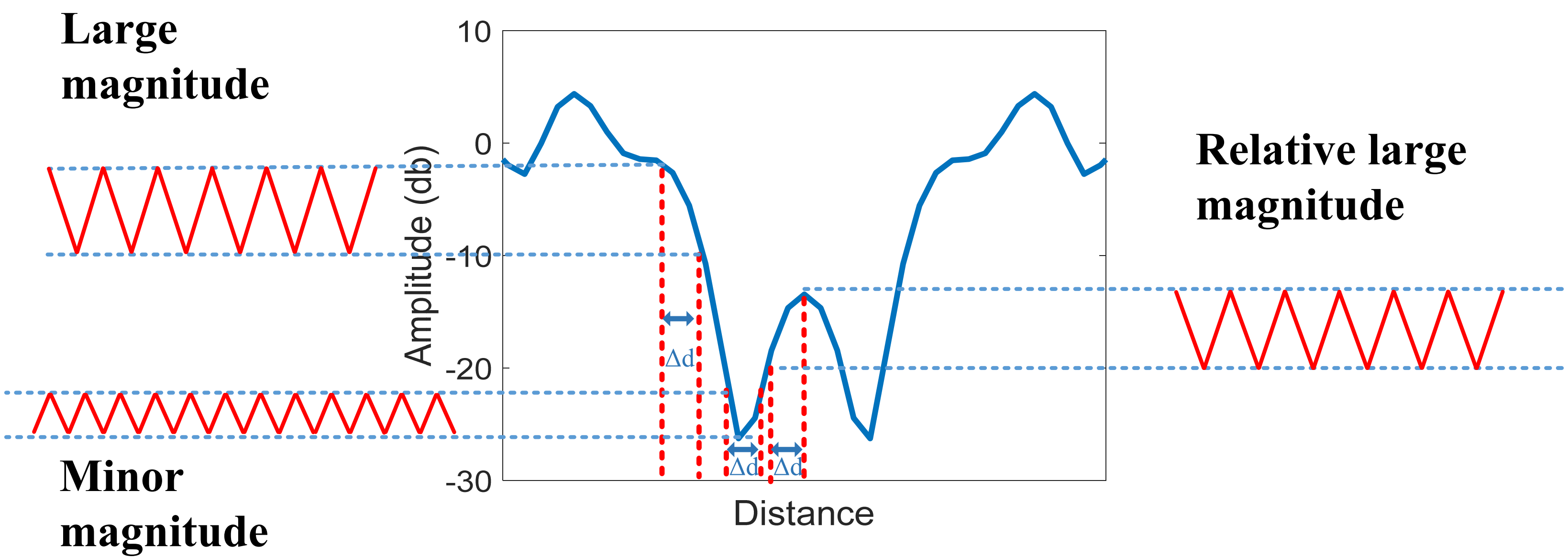
- **Same amount of chest displacement causes different amplitude variations**



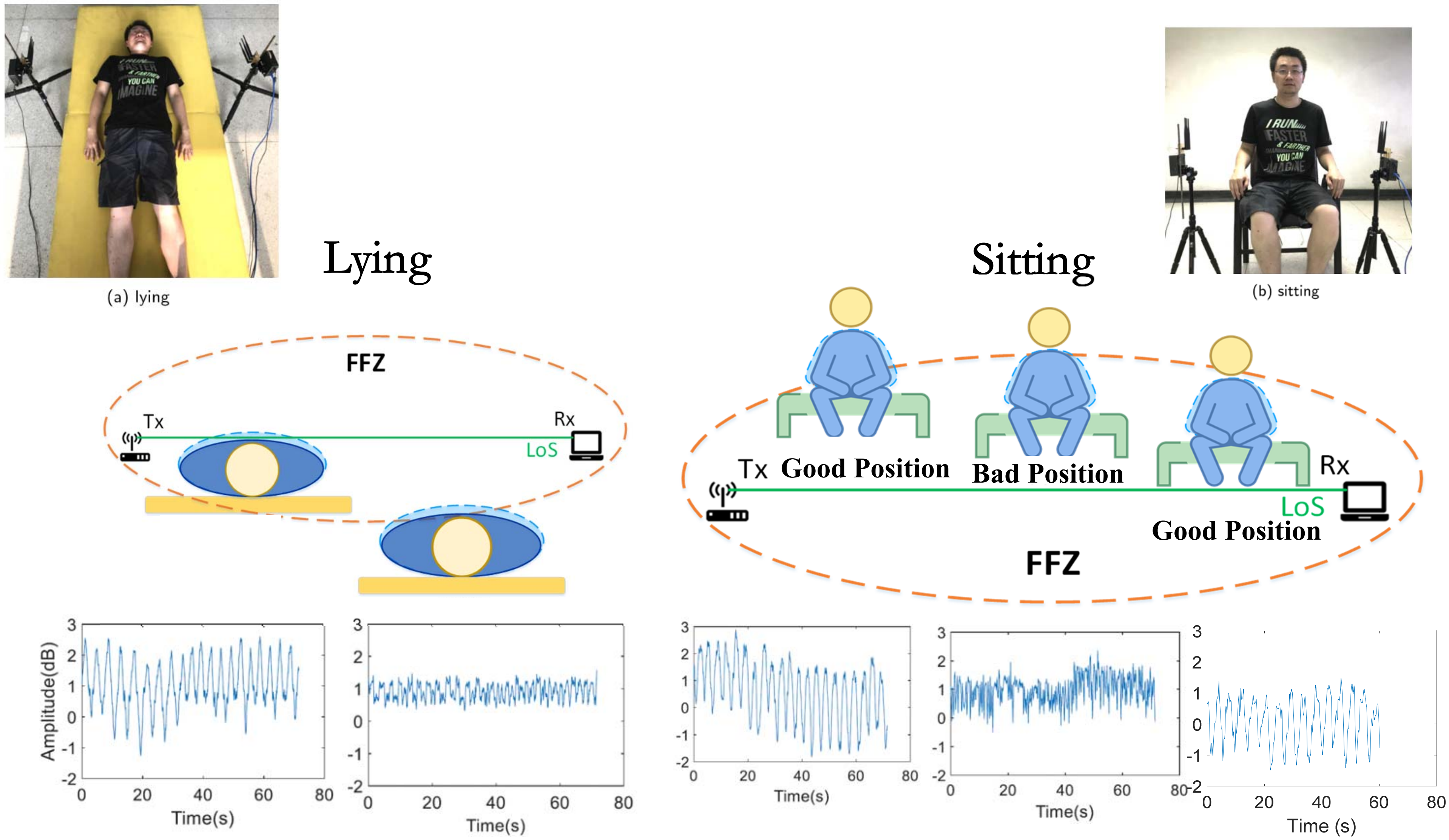
Chest location vs. signal variation（Sitting）

- The received Wi-Fi signal waveform takes the form of ‘W’
- The good position and bad position appear alternatively





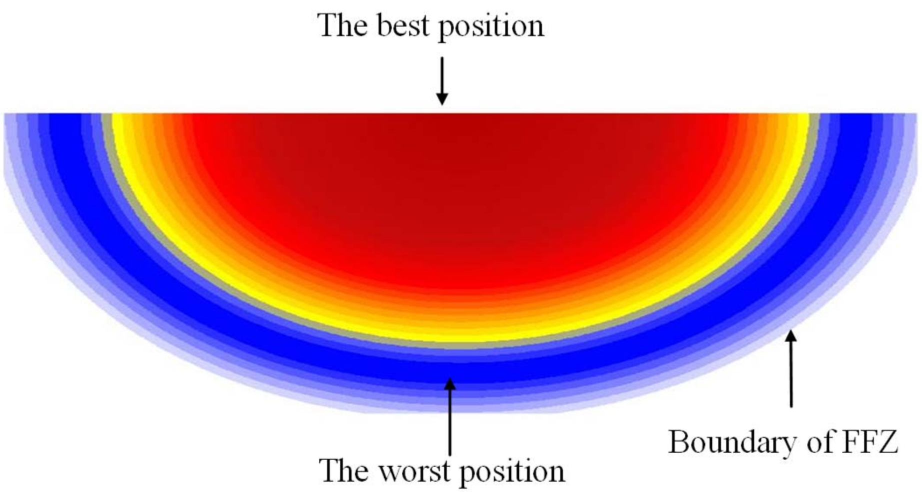
Typical good and bad position for Lying and sitting



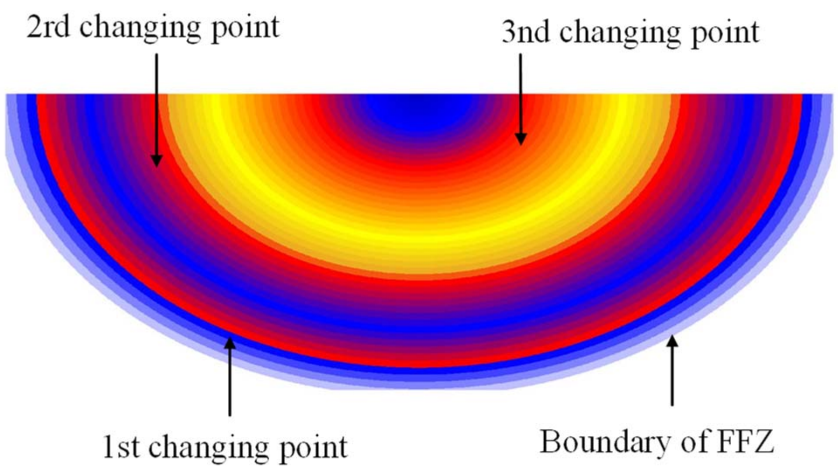
Good Position **Bad position** **Good Position** **Bad Position** **Good Position**

Detection Heat Map (Lying and Sitting)

- **Lying： the boundary of FFZ is bad position, whereas the most inner positions are good position (stable performance)**
- **Sitting： the interleaving of good and bad positions in FFZ（unstable performance）**



Lying



Sitting

4. Applying the Diffraction Sensing Model for Human Fitness Activity Sensing

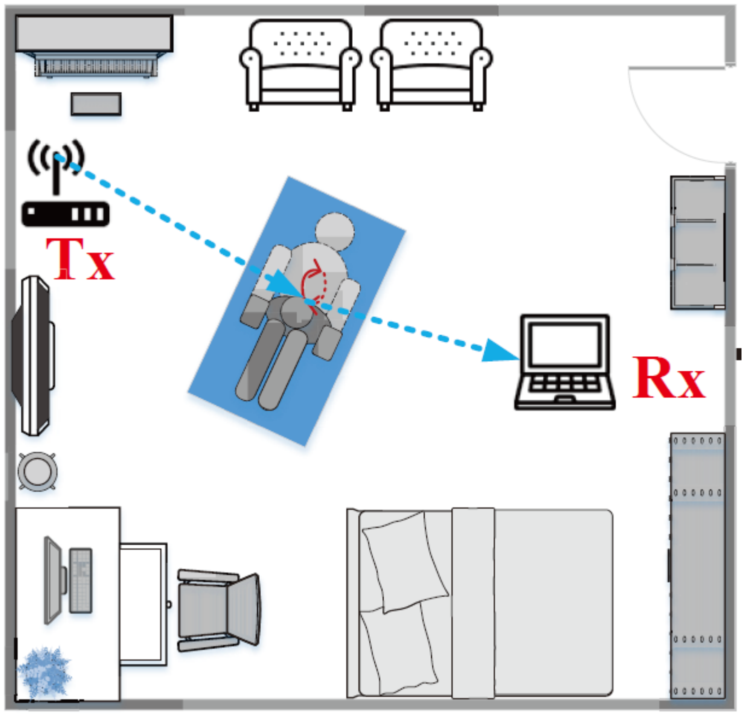
Wi-Fi based human fitness activity sensing

- **Home exercises** have the great advantage as well-rounded workouts to keep people healthy.
- We utilize Wi-Fi signals to provide **non-intrusive** exercise monitoring, and show how the **diffraction model** give guidance of activity sensing.

Push-up

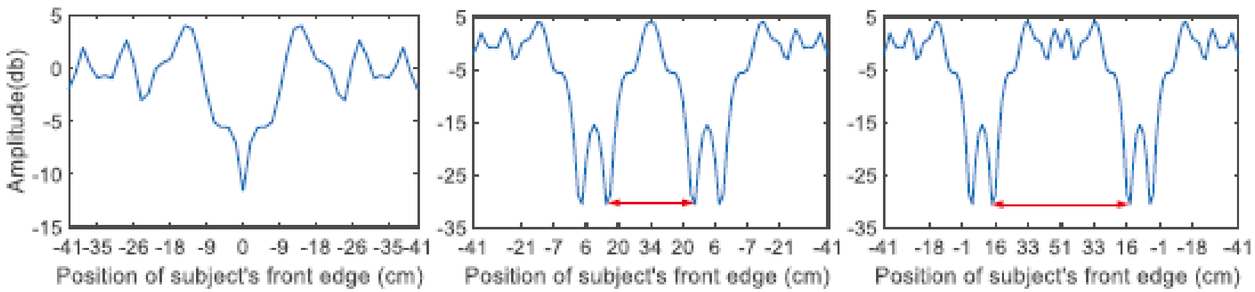
Sit-up

Walkout

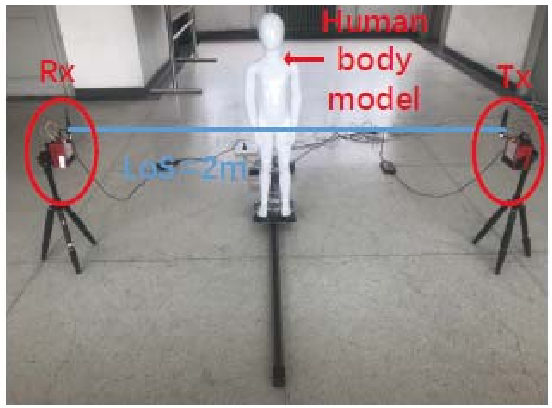


Fresnel diffraction model for large-scale motion

- Considering a target moves into the FFZ, stops and then moves back to the original position.
- Based on the diffraction model, we obtain unique signal patterns with different stopping positions.

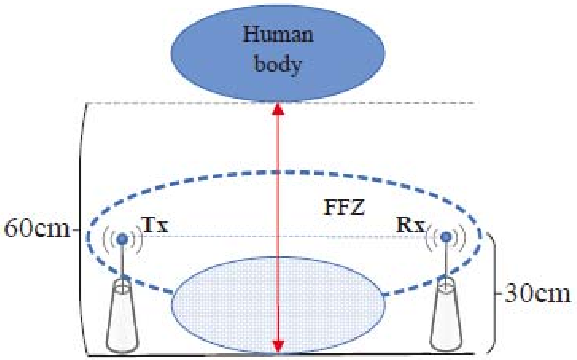


(a) Case 1: stop at $u_{front} = 0$ (b) Case 2: stop at $u_{front} = 2$ (c) Case 3: stop at $u_{front} = 3$

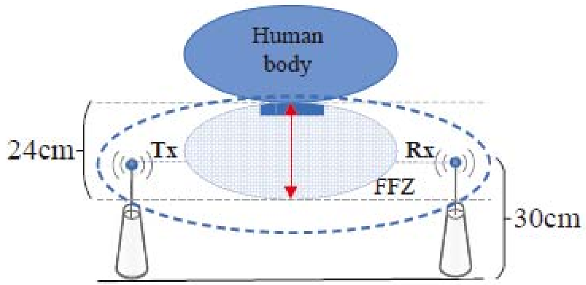


Model Guides Activity Recognition

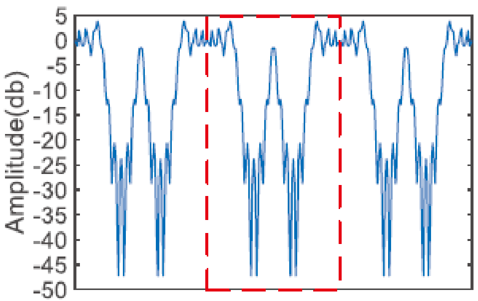
- We use sit-up and push-up as an example to demonstrate how we identify different exercise activities without training.



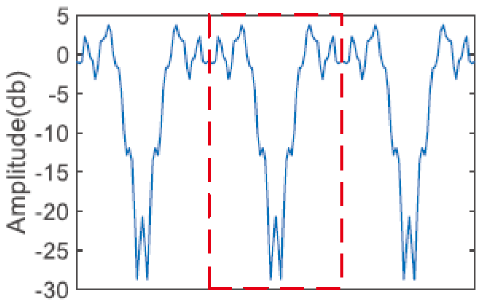
(a) Sit-ups



(b) Push-ups



(a) Sit-ups



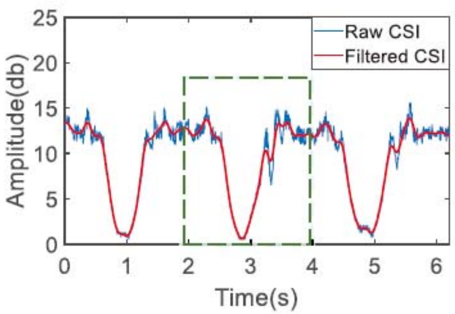
(b) Push-ups

Sensing results

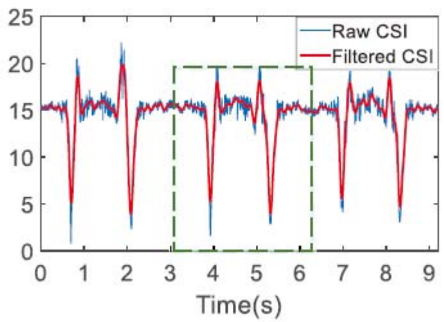
(a) Push-up

(b) Sit-up

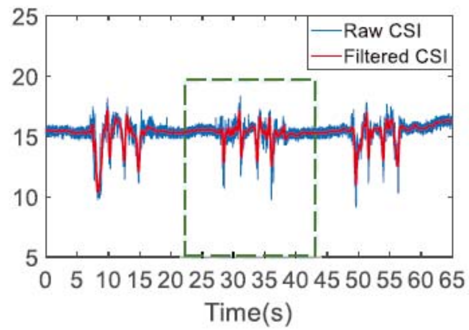
(c) Walkout



(d) Push-up

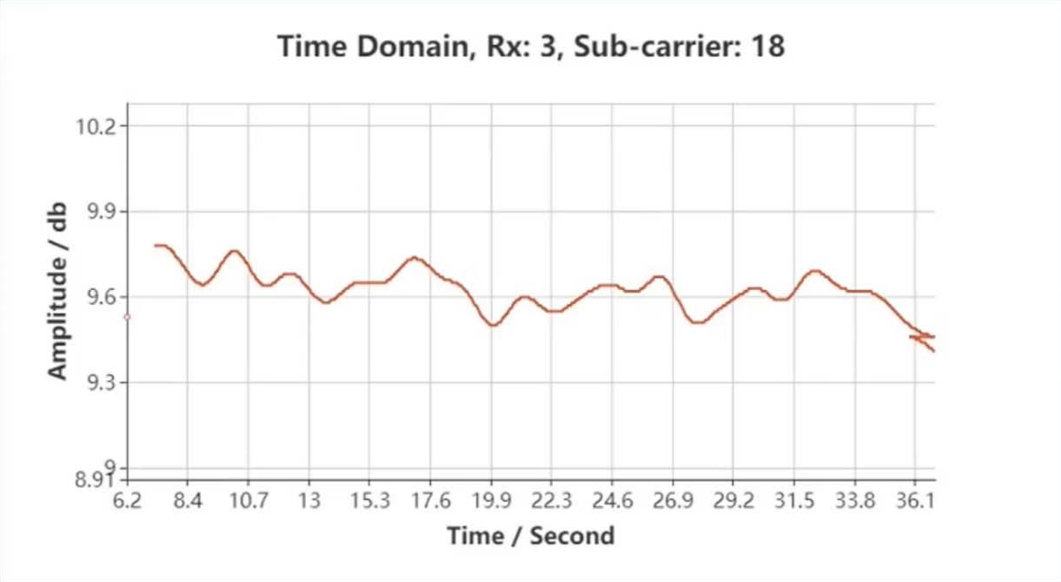


(e) Sit-up



(f) Walkout

Demo


Time Domain, Rx: 3, Sub-carrier: 18
Amplitude / db
10.2
9.9
9.6
9.3
9
8.91
6.2
8.4
10.7
13
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17.6
19.9
22.3
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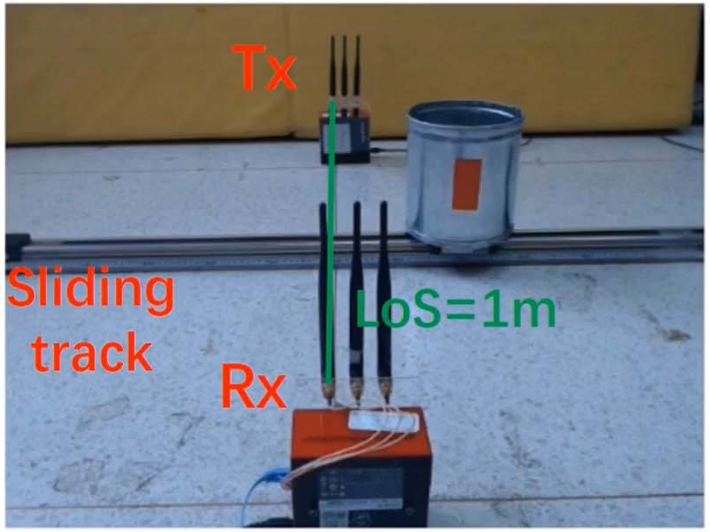
26.9
29.2
31.5
33.8
36.1
Time / Second


Tx
Sliding
track
LoS=1m
Rx

Summary

- **We develop diffraction-based wireless sensing theory in the FFZ with commodity Wi-Fi devices.**
- **We apply sensing model for fine-grained human respiration, and coarse-grained human fitness activity sensing.**
- **We believe this model can be used to guide other wireless sensing applications**

Publication

1. **Fusang Zhang,** Kai Niu, Jie Xiong, Beihong Jin, Tao Gu, Yuhang Jiang, Daqing Zhang. *Towards a Diffraction-based Sensing Approach on Human Activity Recognition*, **UbiComp 2019**, September 8-13, 2019, LONDON, UK.
2. Kai Niu, **Fusang Zhang**, Yuhang Jiang, Zhaoxin Chang, Leye Wang, Daqing Zhang. *A Contactless Morse Code Text Input System Using COTS WiFi Devices*, **UbiComp 2019**, Demo, September 8-13, 2019, LONDON, UK.
3. Kai Niu, **Fusang Zhang**, WiMorse: A Contactless Morse Code Text Input System using Ambient WiFi Signals, **IoT Journal**, Aug, 2019.
4. **Fusang Zhang,** Daqing Zhang, Jie Xiong, Hao Wang, Kai Niu, Beihong Jin, Yuxiang Wang. *From fresnel diffraction model to fine-grained human respiration sensing with commodity wi-fi devices,* **UbiComp 2018**, October 8-12, 2018, SINGAPORE.
5. Kai Niu, **Fusang Zhang,** Zhaoxin Chang, Daqing Zhang. *A Fresnel Diffraction Model Based Human Respiration Detection System Using COTS Wi-Fi Devices,* **UbiComp 2018**, Demo, October 8-12, 2018, SINGAPORE.
6. Kai Niu, **Fusang Zhang**, Jie Xiong, Xiang Li, Enze Yi, *Daqing Zhang. Boosting fine-grained activity sensing by embracing wireless multipath effects,* **CoNext 2018,** December 4-7, 2018, Heraklion/Crete, Greece.

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