Sense Me on the Ride:

Accurate Mobile Sensing over a LoRa Backscatter Channel

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Tsinghua University

Wireless Sensing

- **Wireless Sensing has become a key enabling technology for ubiquitous Internet of Things applications.**

Acoustic

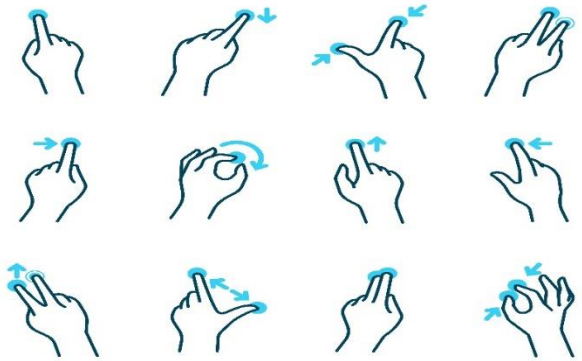
RFID

Wi-Fi

LoRa

mmWave

Wireless Sensing



motion and activity sensing

mobility measurement

environmental sensing

material sensing

How to Sense a Long-Range Mobile Target?

Long-Range Mobile Target

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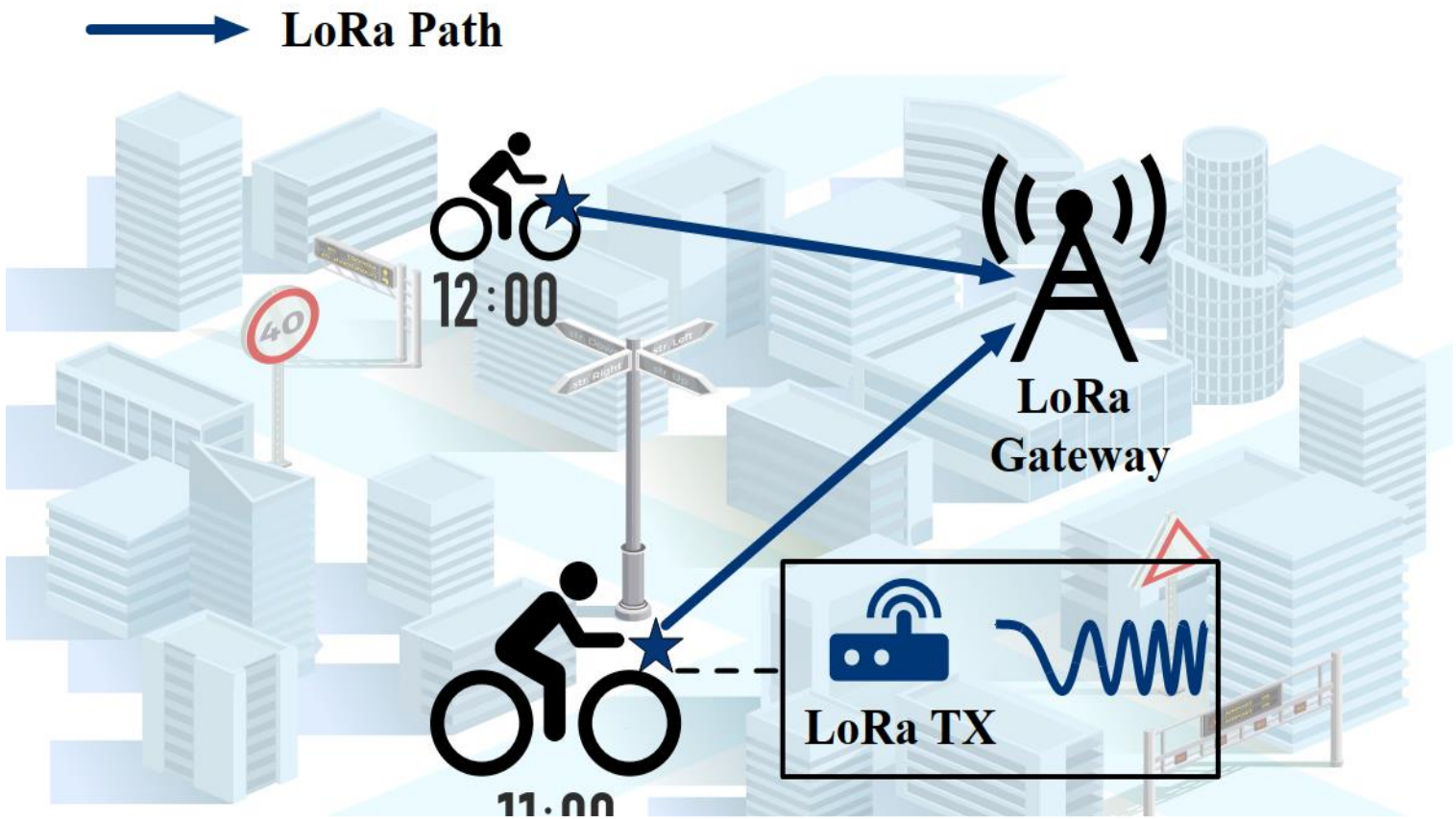
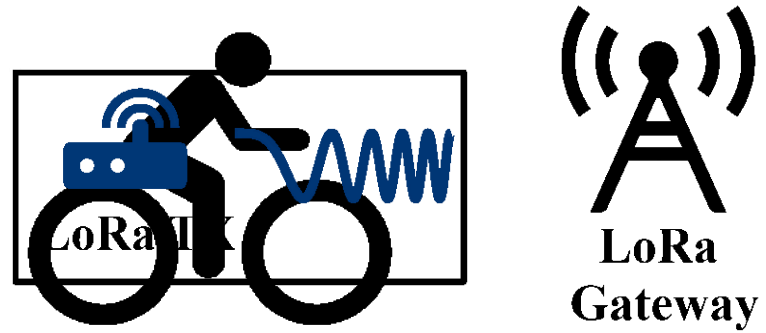
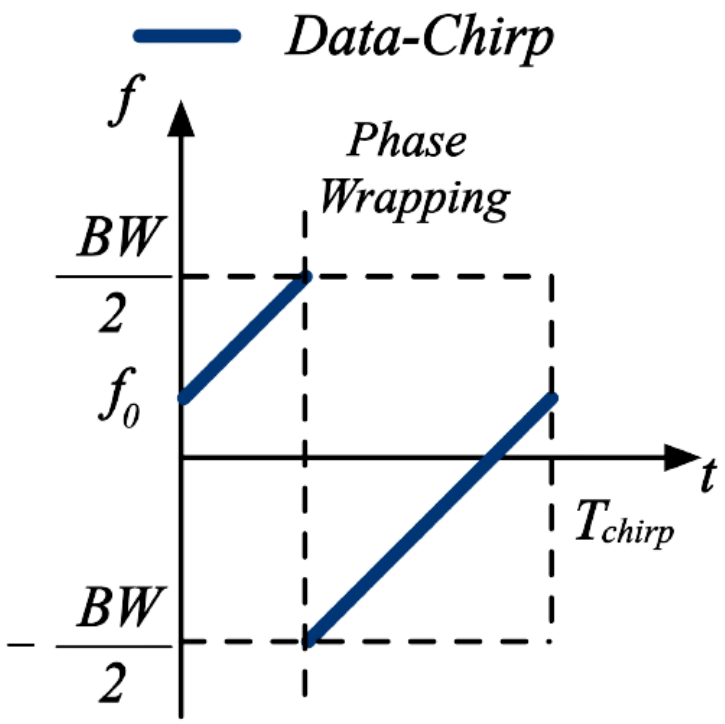
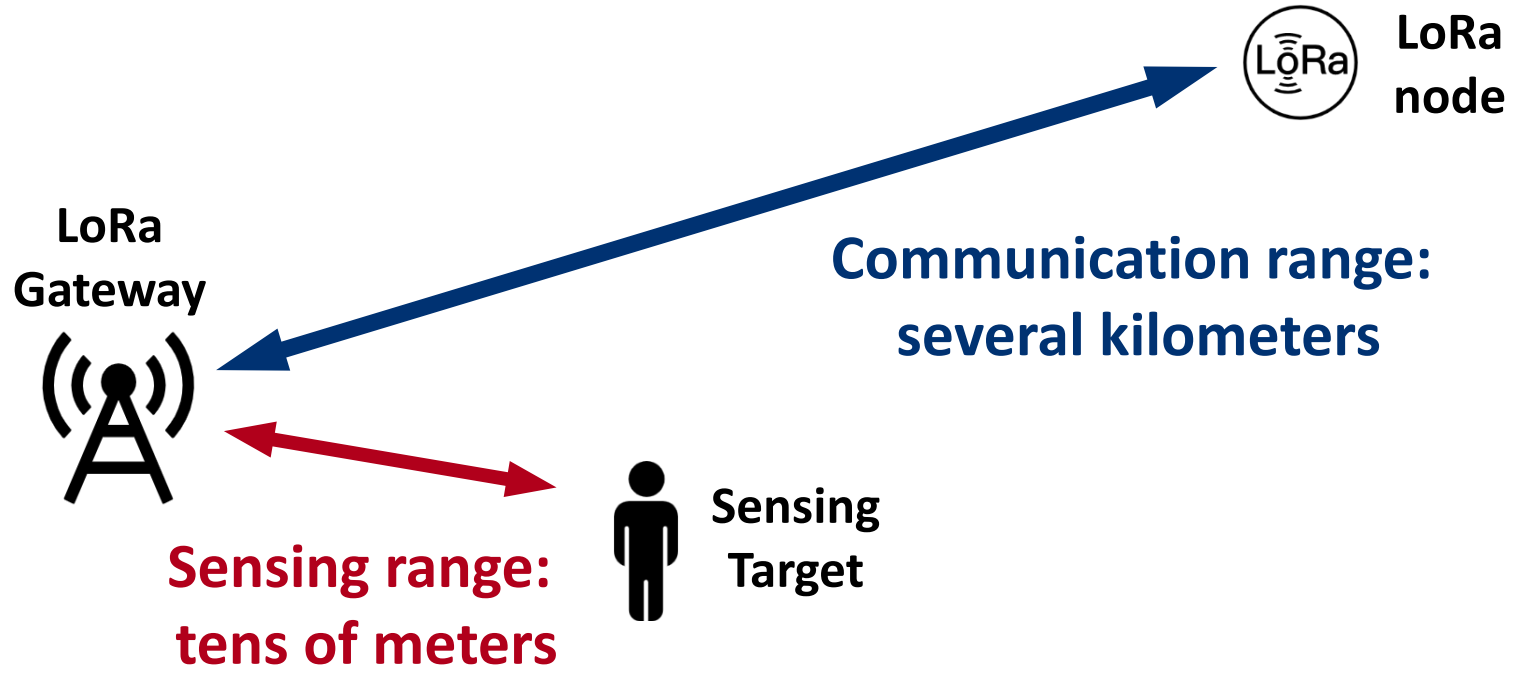




How to Sense a Long-Range Mobile Target?



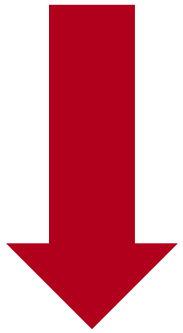
CSS modulation of LoRa



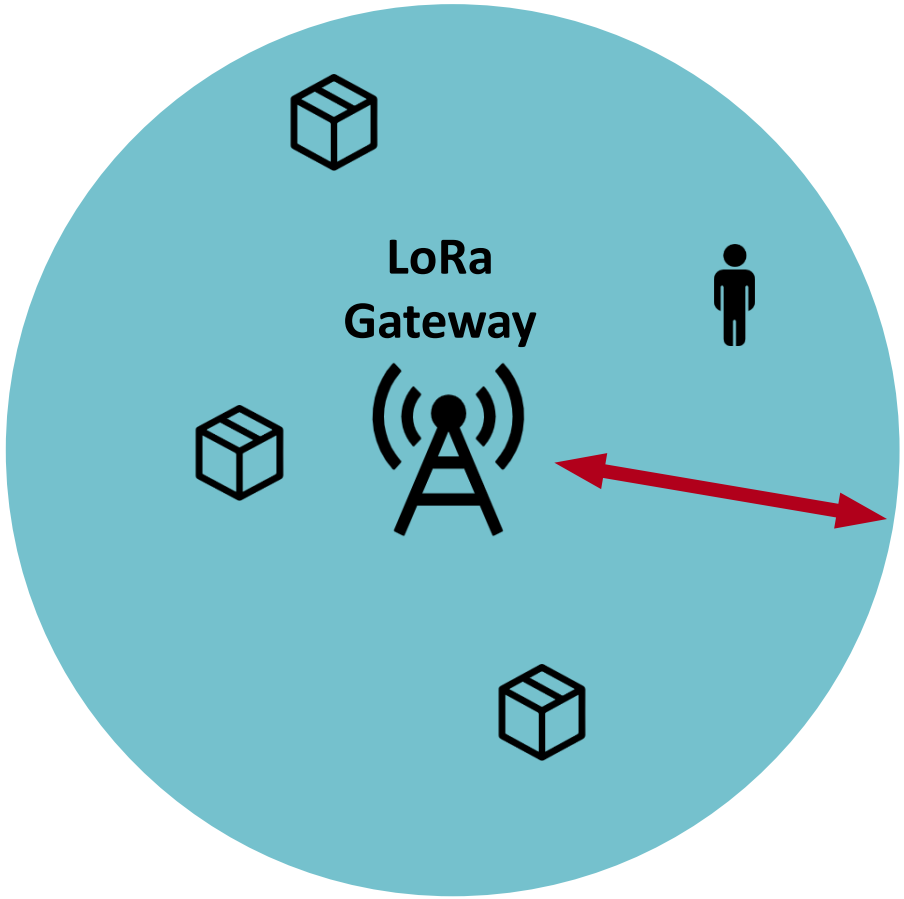
* Fusang Zhang, Zhaoxin Chang, Kai Niu, Jie Xiong, Beihong Jin, Qin Lv, and Daqing Zhang. 2020. Exploring LoRa for Long-range Through-wall Sensing. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 4, 2, Article 68 (June 2020), 27 pages

How to Sense a Long-Range Mobile Target?

Long Sensing Range



More Moving Targets

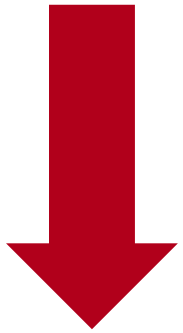


Sensing Target

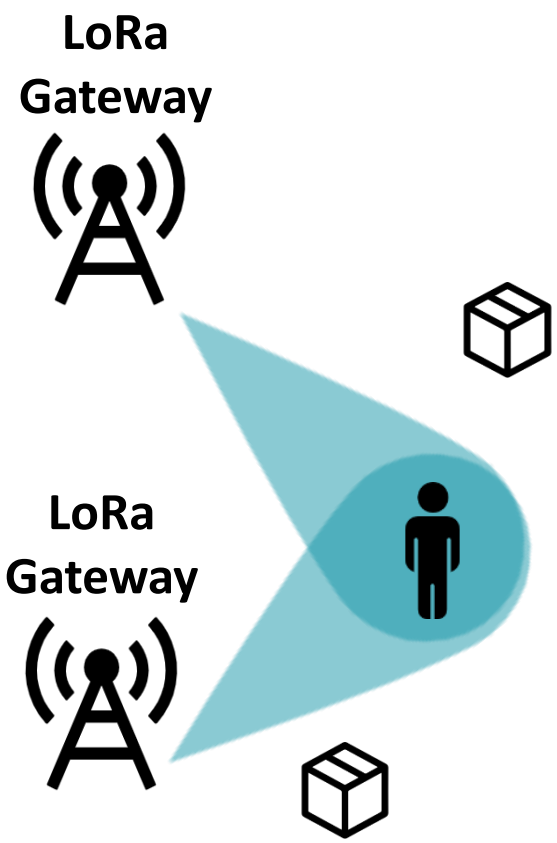
Other Moving Target

How to Sense a Long-Range Mobile Target?

Beamforming



Stationary Target



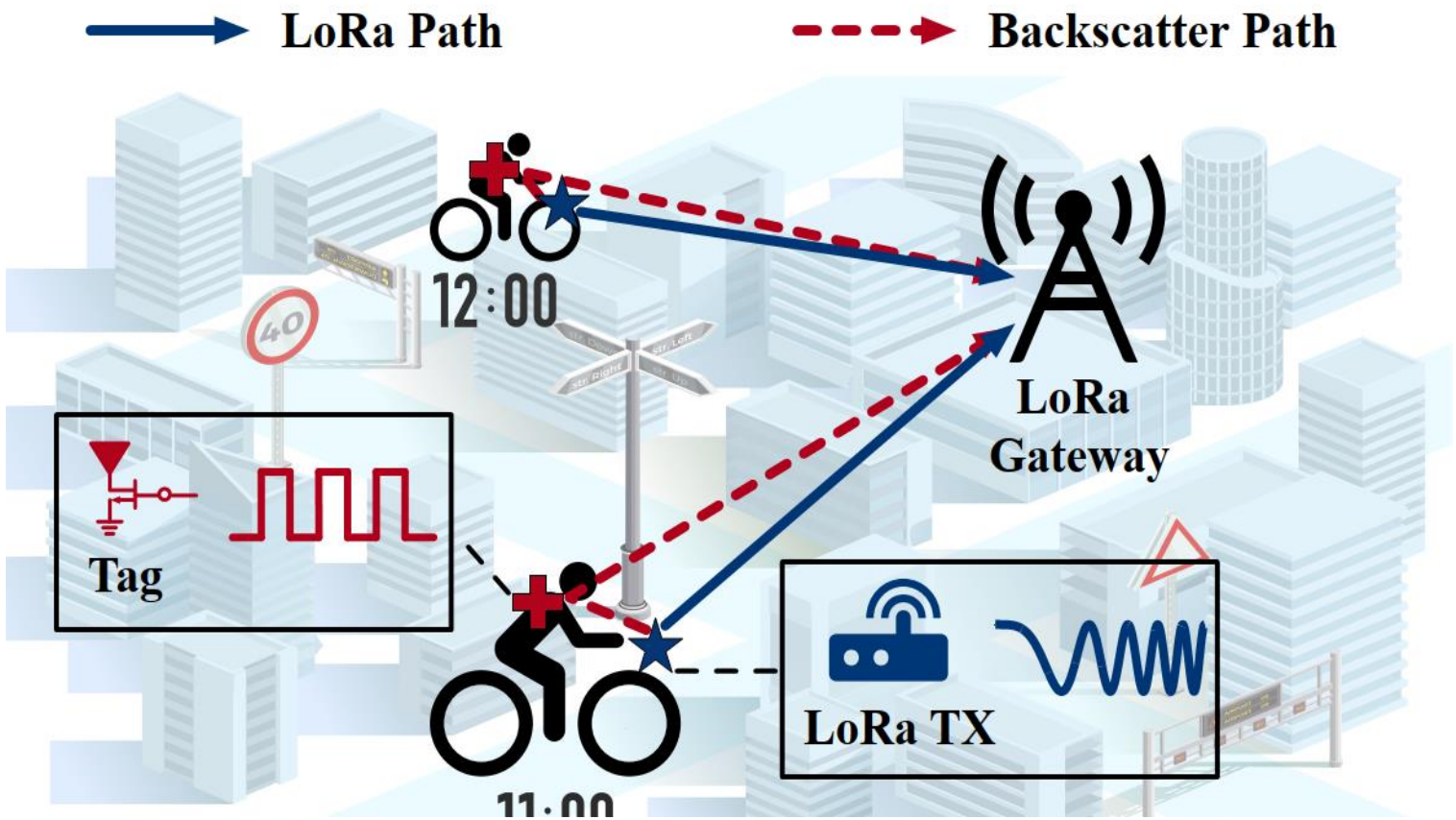
Sensing Target

Other Moving Target

Fail to sense mobile target

* Binbin Xie and Jie Xiong. 2020. Combating interference for long range LoRa sensing. In Proceedings of the 18th Conference on Embedded Networked Sensor Systems (SenSys '20).

Palantir : LoRa Backscatter-Based Sensing



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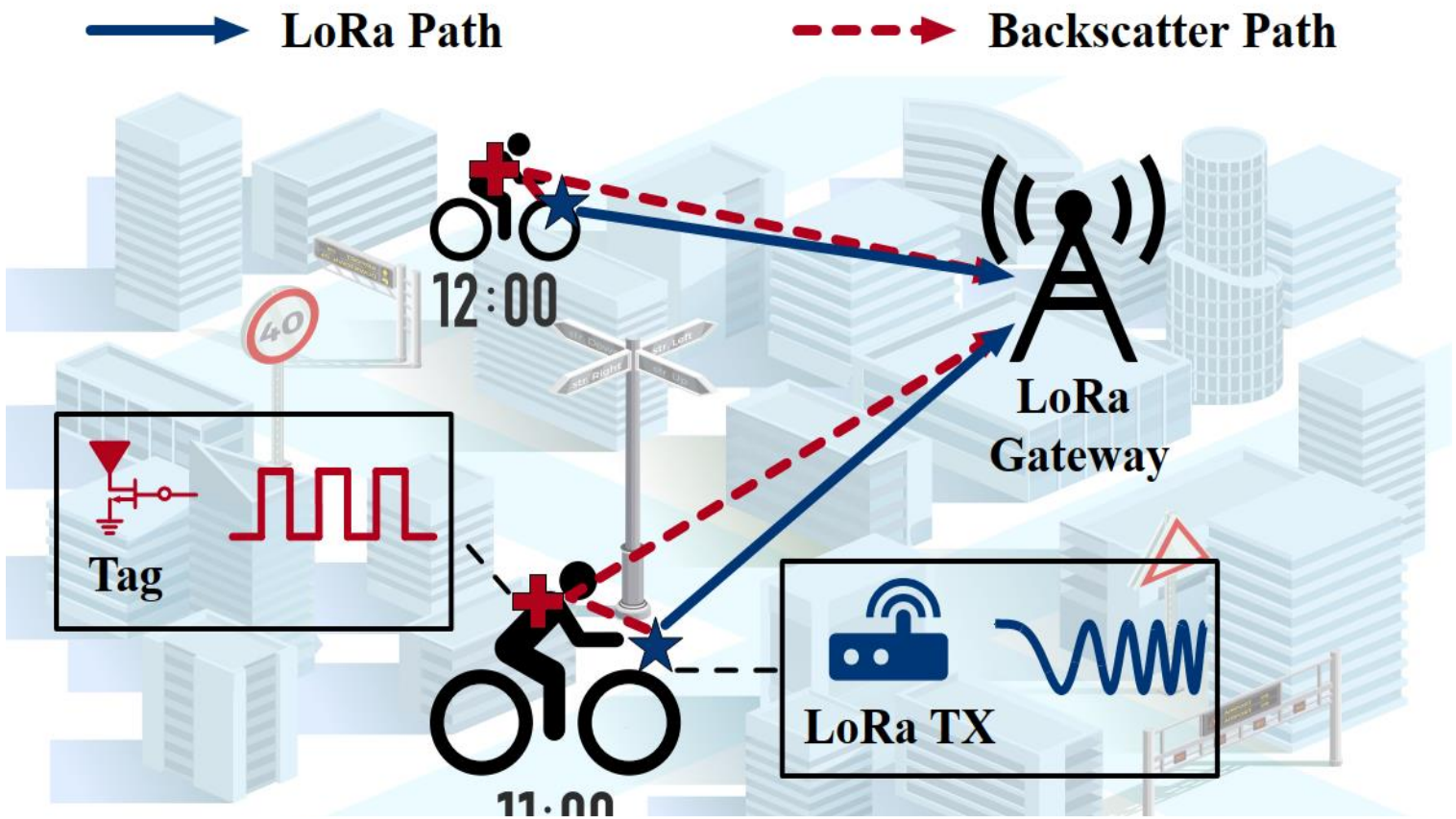
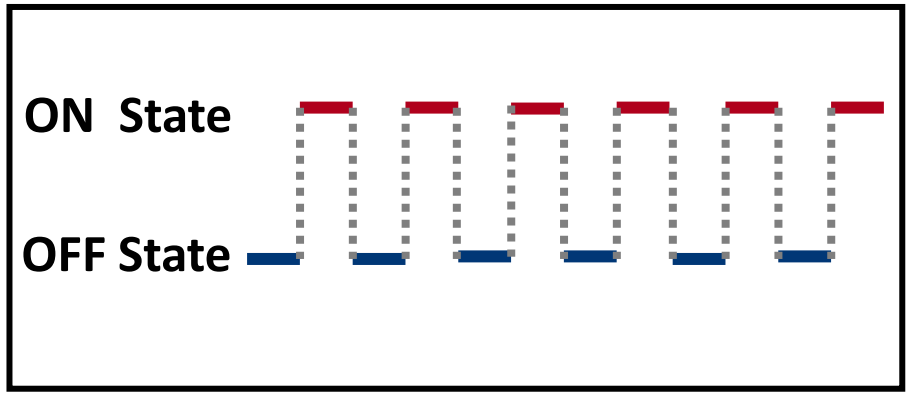


- Sensing with Side-Channel
- 100-Meter Sensing Range
- Battery-Free Tag
- Condition of Mobile Target

Palantir : Overview

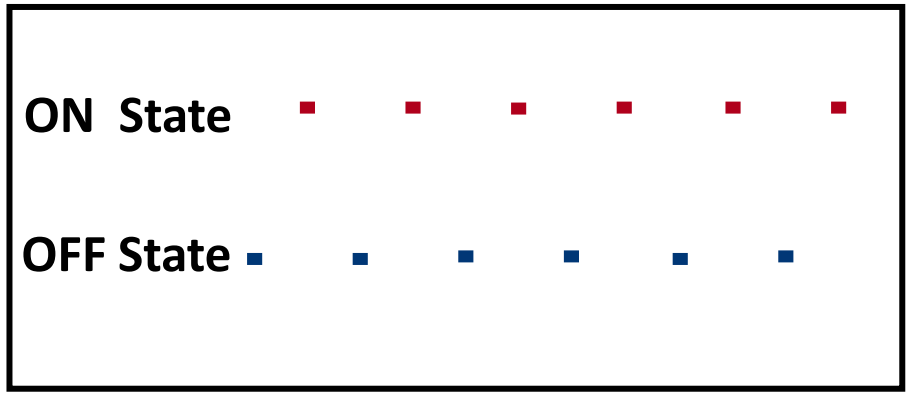
- **OOK-modulation**
  - **Two states in the time domain**



OOK modulation of Backscatter

Palantir : Overview

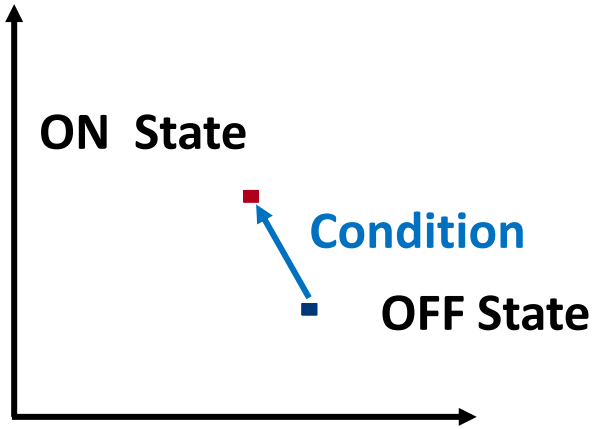
- **OOK-modulation**
  - **Two states in the time domain**
- **Stabilization**
  - **Remove the modulation of CSS**



OOK modulation of Backscatter

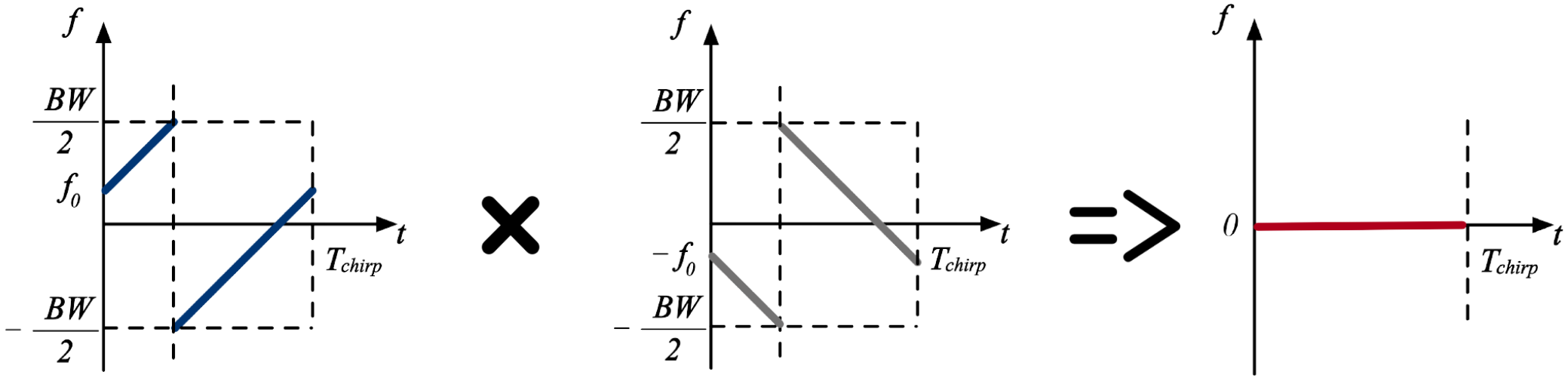
Palantir : Overview

- **OOK-modulation**
  - **Two states in the time domain**
- **Stabilization**
  - **Remove the modulation of CSS**
- **Sensing**
  - **OFF State acts as a reference**



Palantir : Theoretical Sensing Model

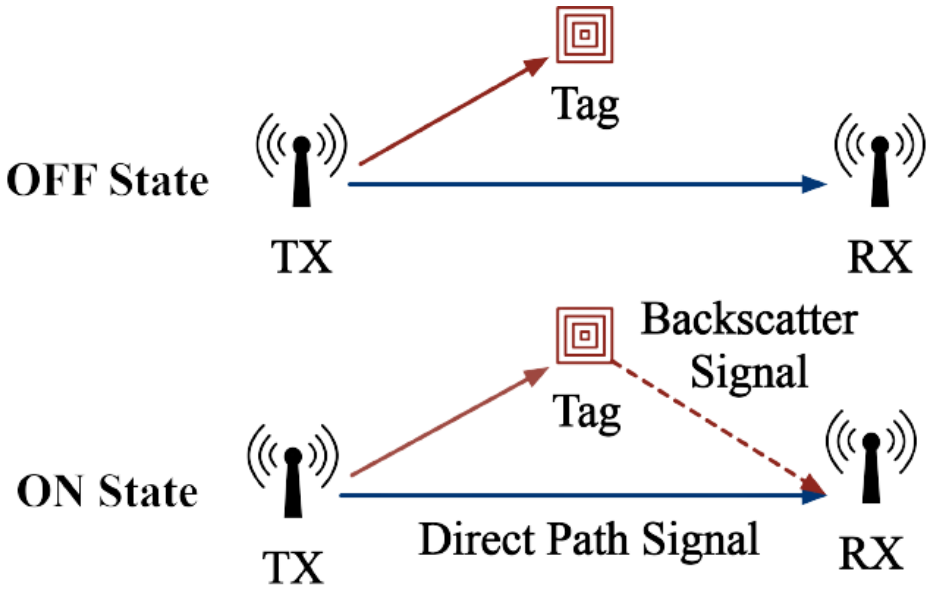
- **Stabilization : Conjugate multiplication**

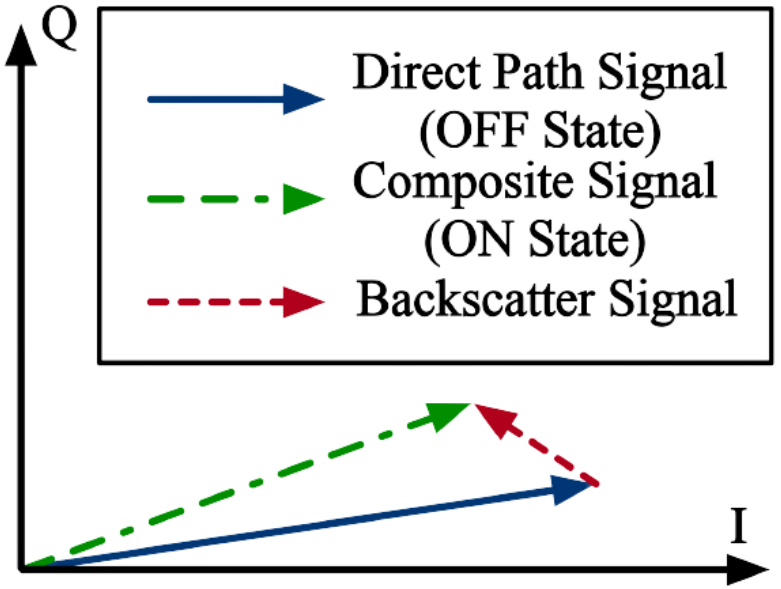


Data Chirp **Conjugate Chirp** **Stabilized Signal**

Palantir : Theoretical Sensing Model

- **Sensing : OFF State acts as a reference**





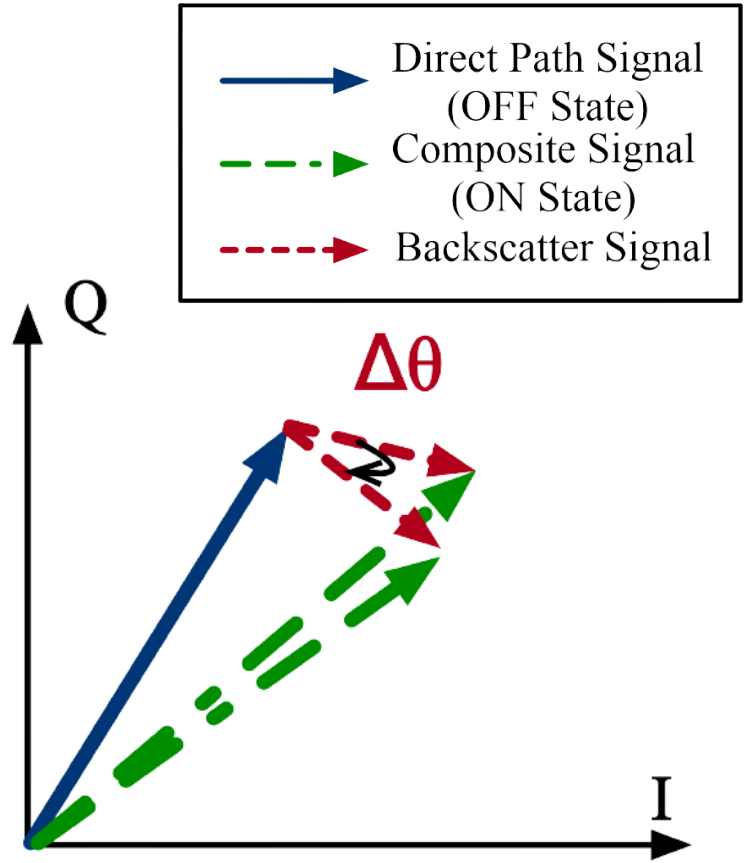
Palantir : Theoretical Sensing Model

- **Sensing : Movement of target**

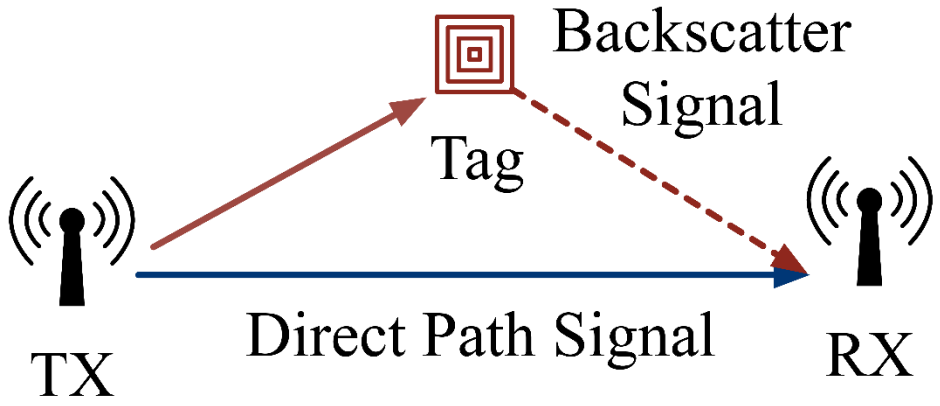
Rotation of backscatter signal $\Delta\theta$

$$\Delta d = \frac{c}{2\pi f_{Carrier}} \Delta\theta$$

Movement of target Δd



Palantir : Challenges



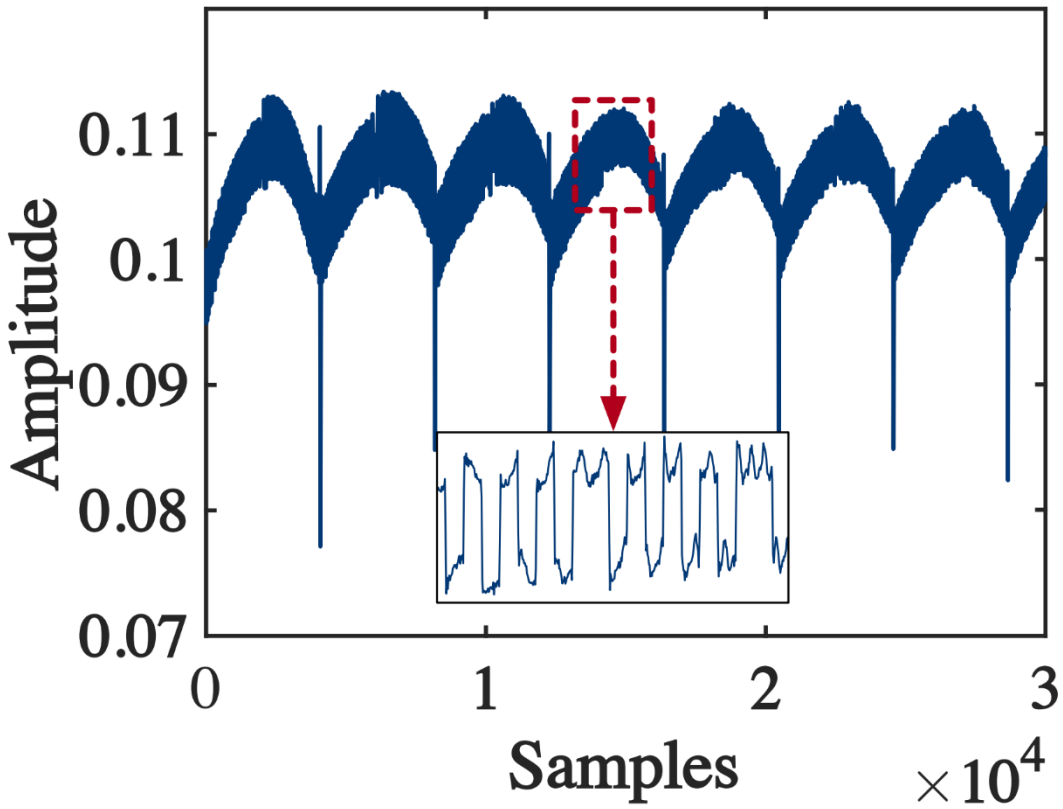
Communication ✓

Sensing ✗

Sensing sets higher requirements on channel quality than communication

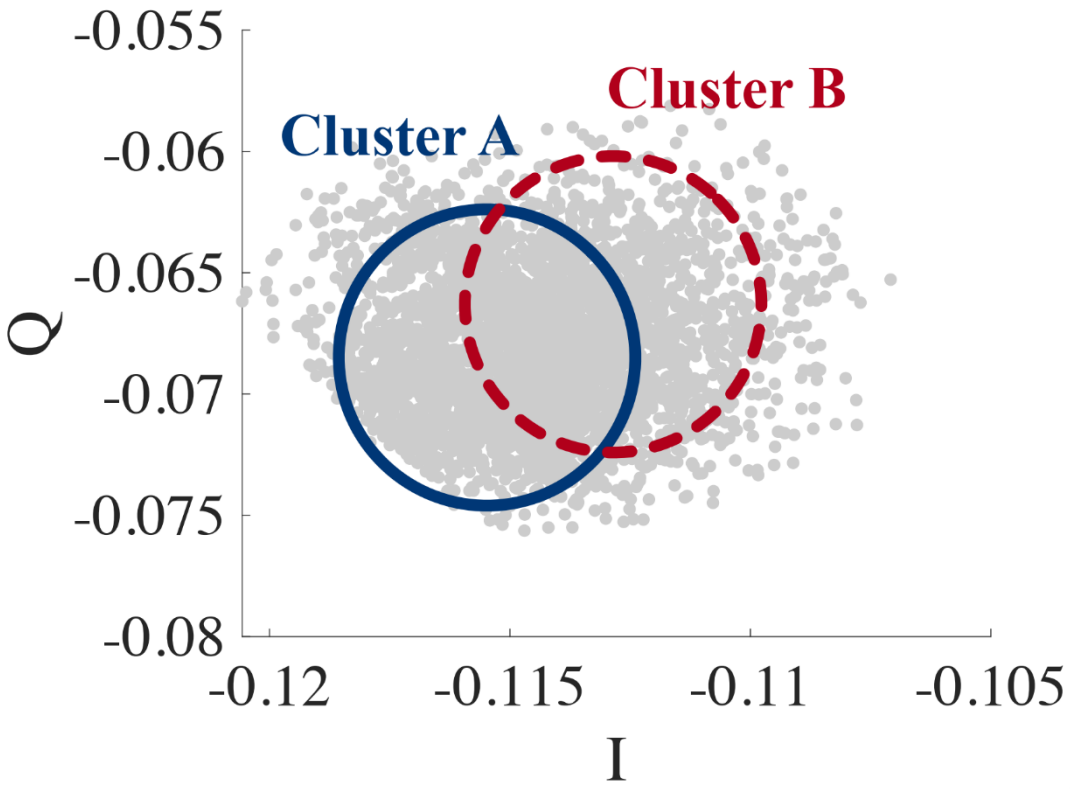
Palantir : Challenges

- **Amplitude Instability**



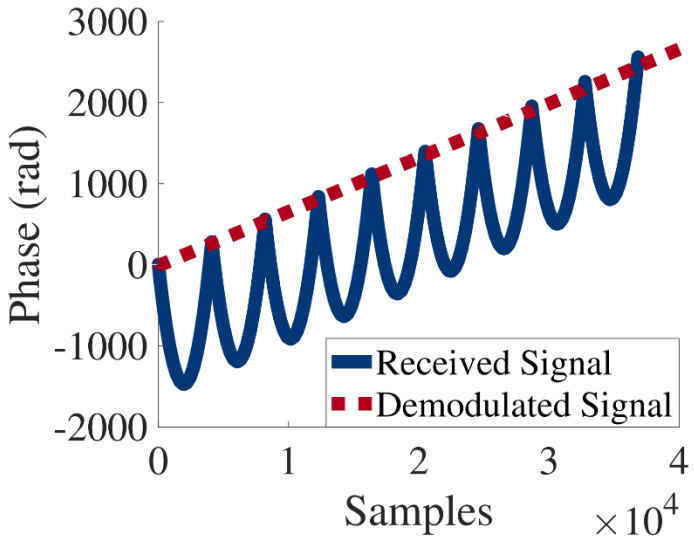
Palantir : Challenges

- **Amplitude Instability**
  - **State changes are submerged.**

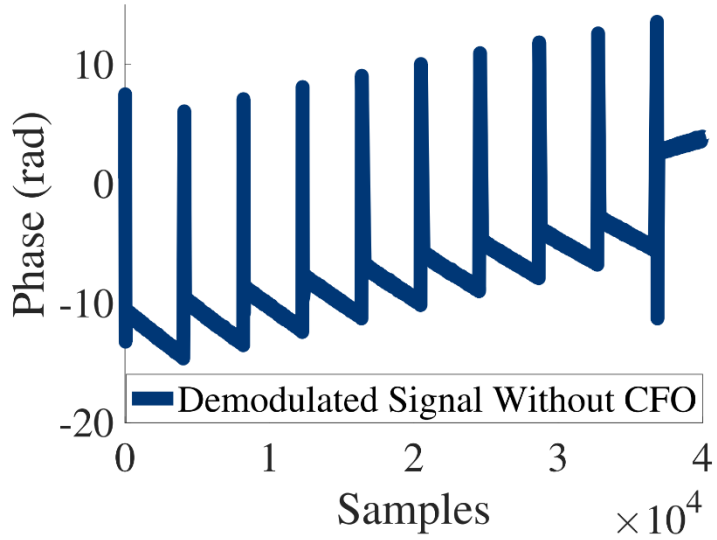


Palantir : Challenges

- **Amplitude Instability**
  - **State changes are submerged.**
- **Offset and Drift**



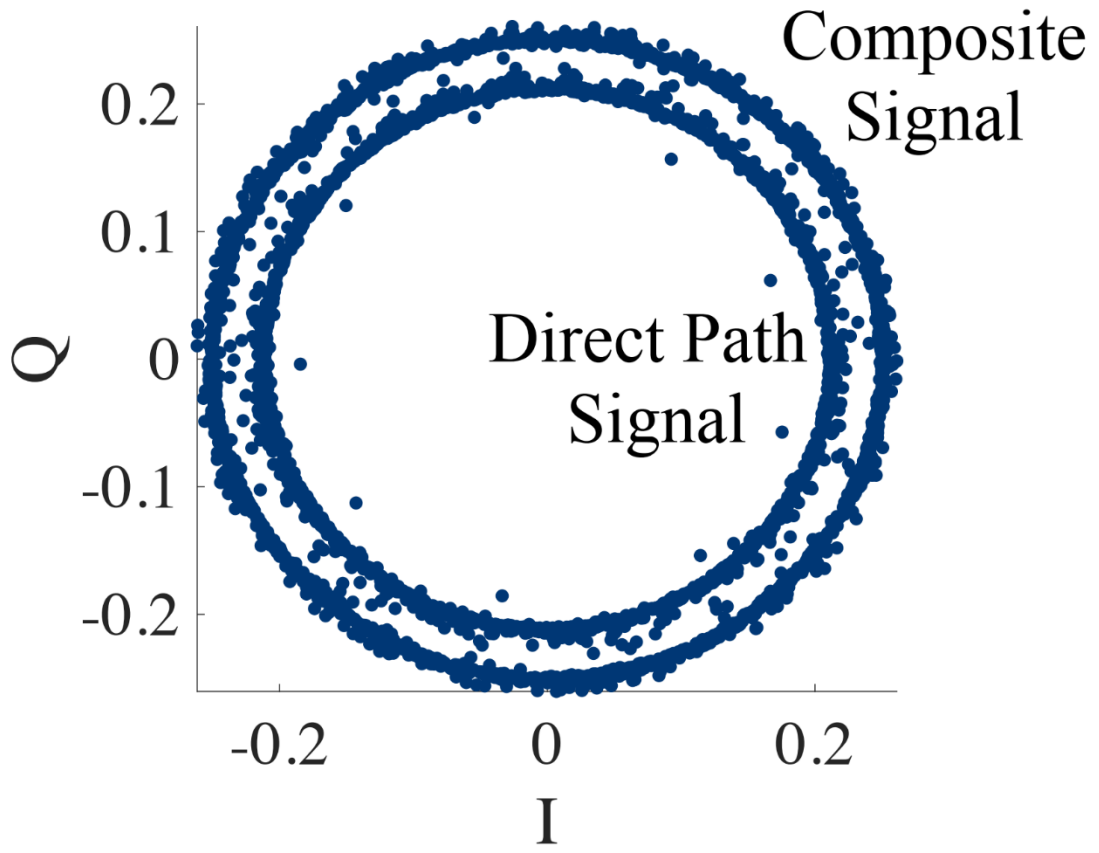
Carrier Frequency Offset



Sample Time Offset

Palantir : Challenges

- **Amplitude Instability**
  - **State changes are submerged.**
- **Offset and Drift**
  - **Phases are distorted.**



Palantir : Challenges

- **Amplitude Instability**
  - **State changes are submerged.**
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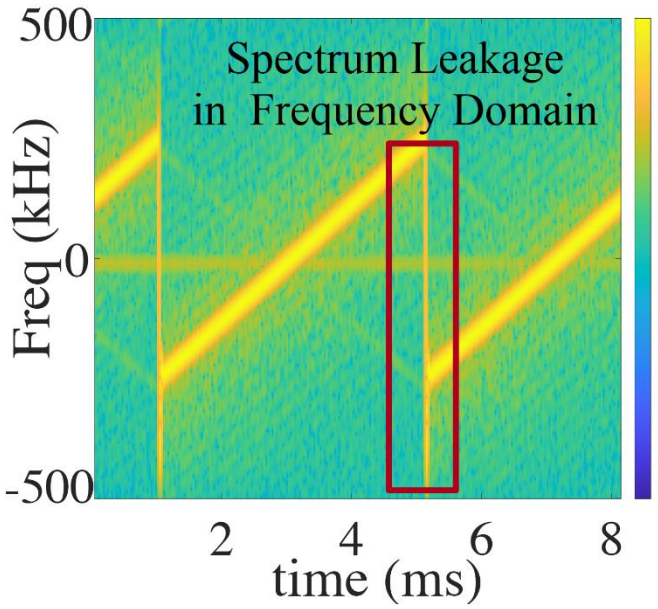
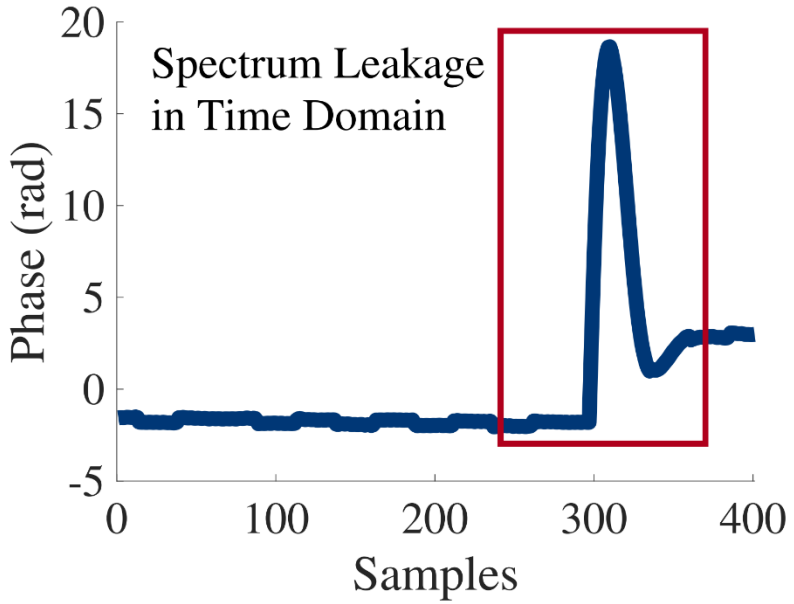
  - **Phases are distorted.**
- **Spectrum Leakage**
  - **Signal are broken into pieces.**





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- **Amplitude Instability**
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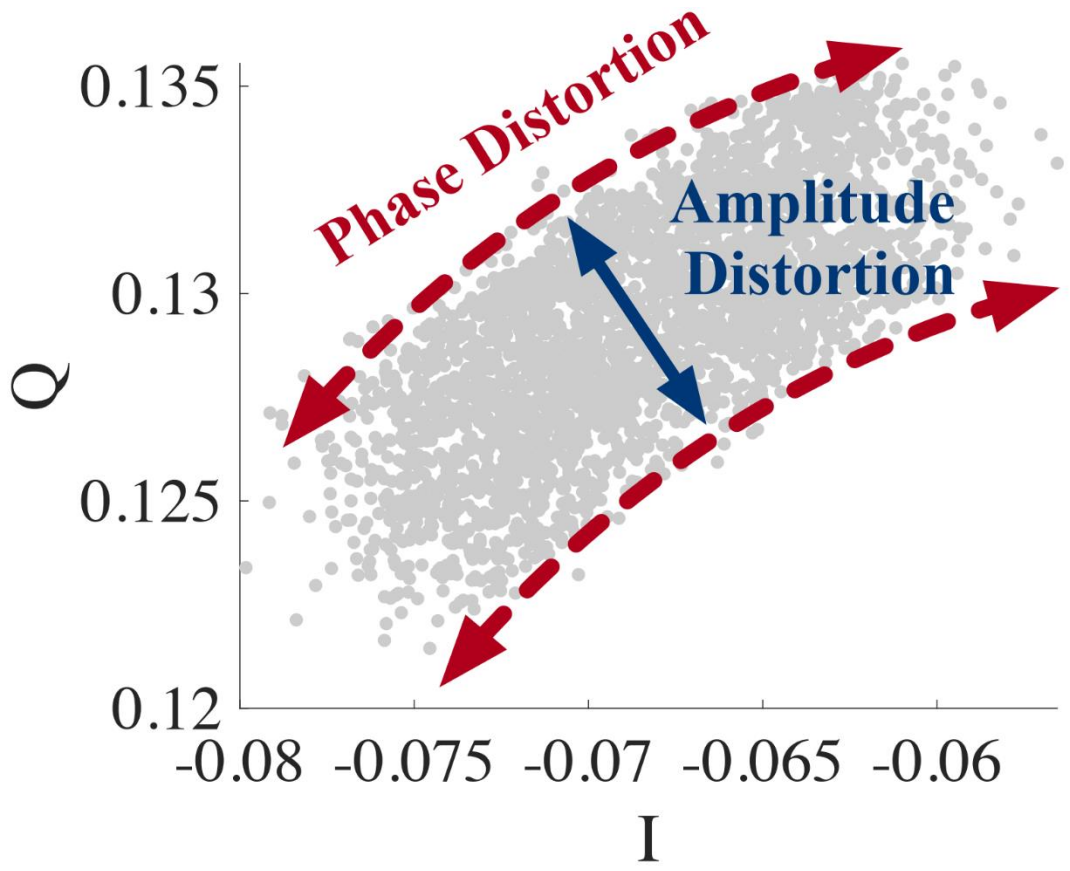
- **Multiplicative Noise**



Palantir : Challenges

- **Amplitude Instability**
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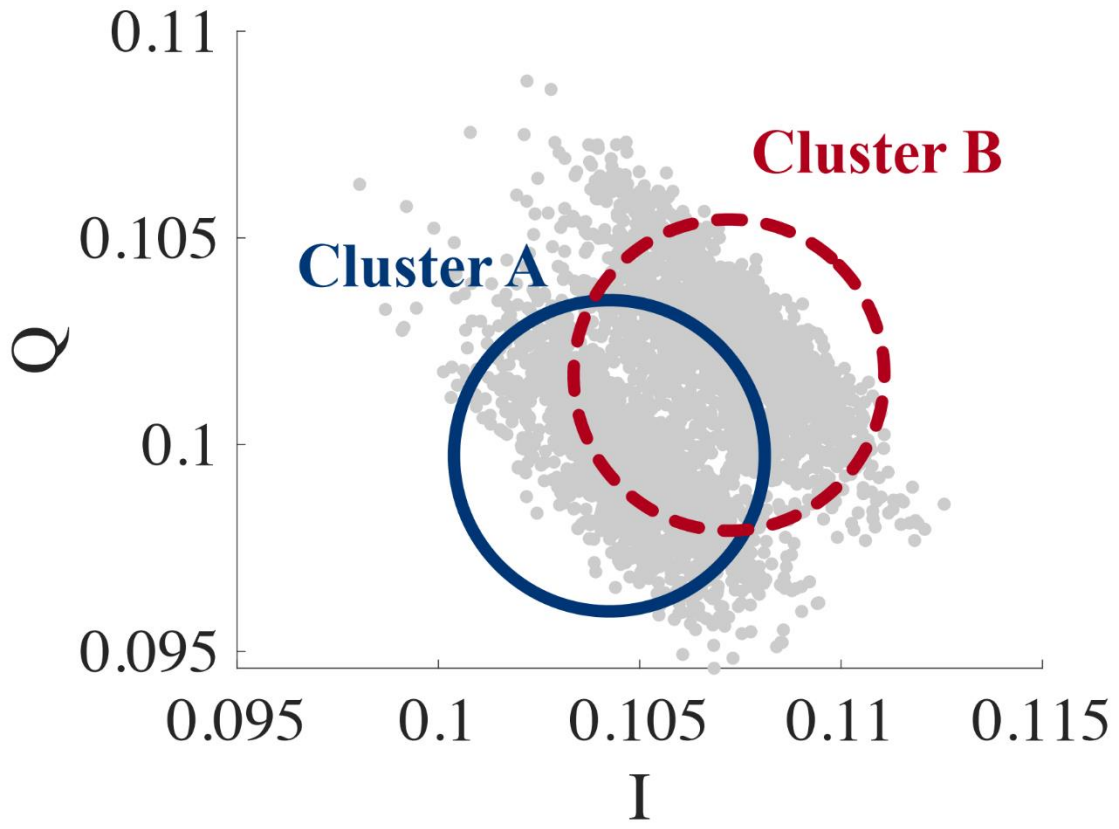
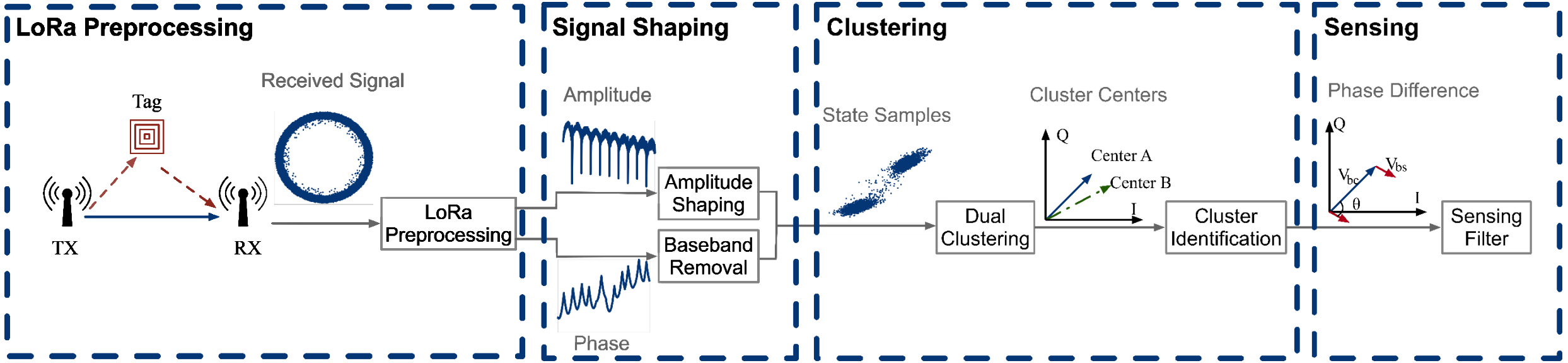
- **Offset and Drift**
  - Phases are distorted.
- **Spectrum Leakage**
  - Signal are broken into pieces.
- **Multiplicative Noise**
  - Clustering algorithm is disturbed.

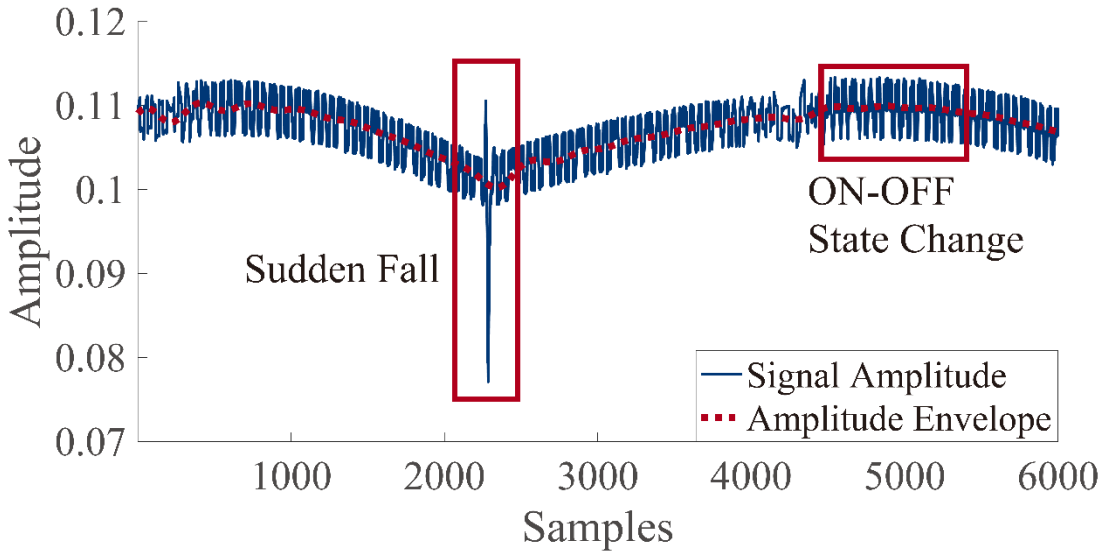


Palantir : System Design



Palantir : System Design

● Amplitude Envelope

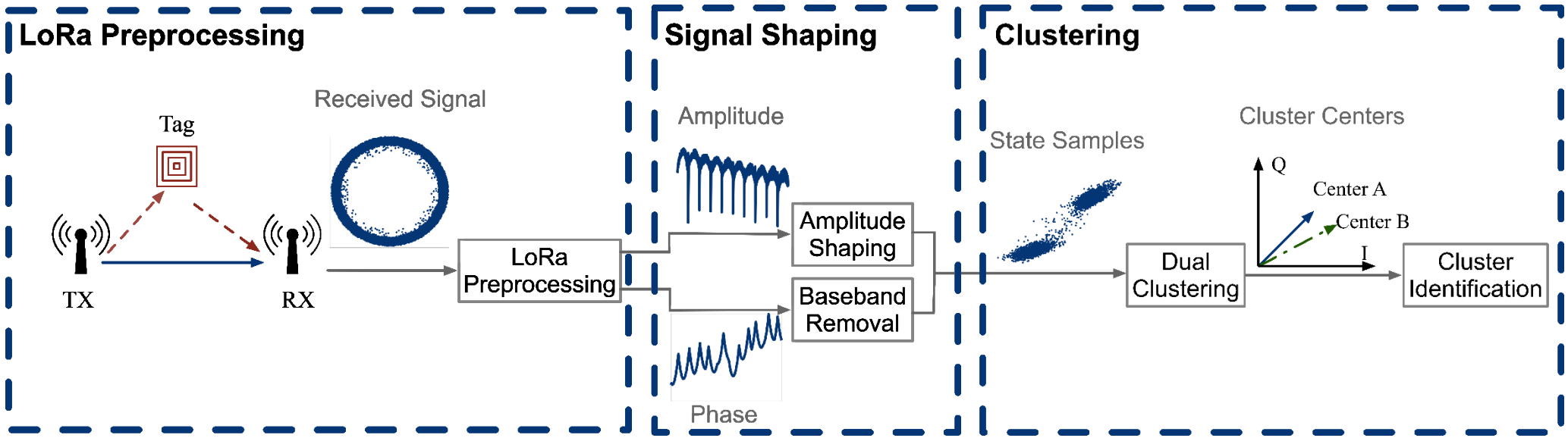


● Impact of Offset and Drift

$$\Delta\varphi_{baseband}(t) = 2\pi(a_0 t^2 + a_1 t + a_2)$$

- a_0, a_1 **and** a_2 **are determined by offsets and drifts.**

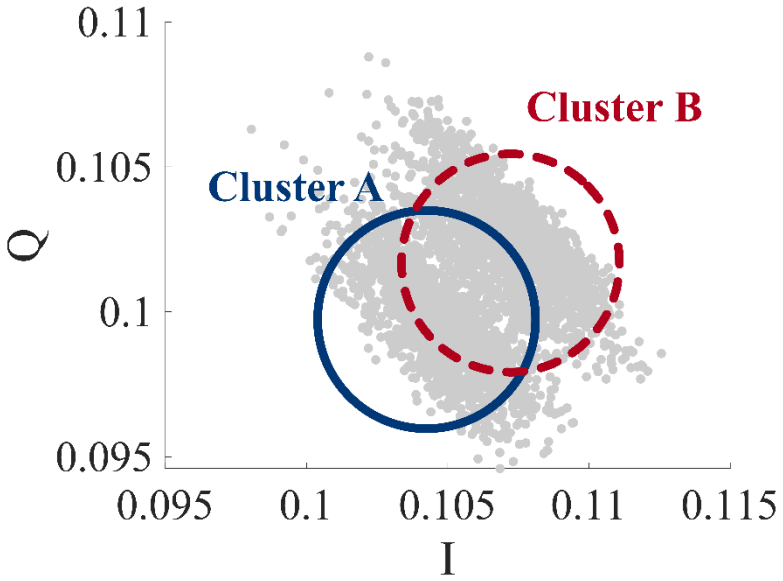
Palantir : System Design



Palantir : System Design

● Multiplicative Noise

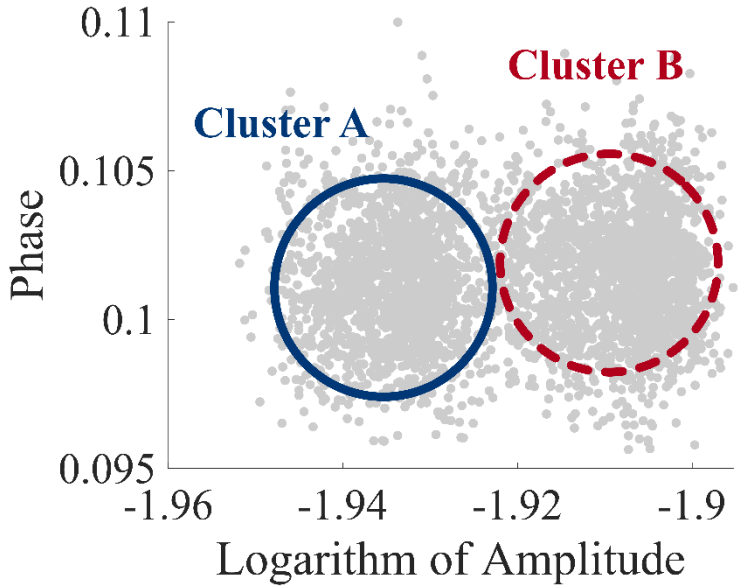
$$S_{sample} = AA_{noise}e^{j2\pi(\theta+\theta_{noise})}$$



I-Q

$$Logarithm\ of\ Amplitude:\ logA + logA_{noise}$$

$$phase:\ \theta + \theta_{noise}$$

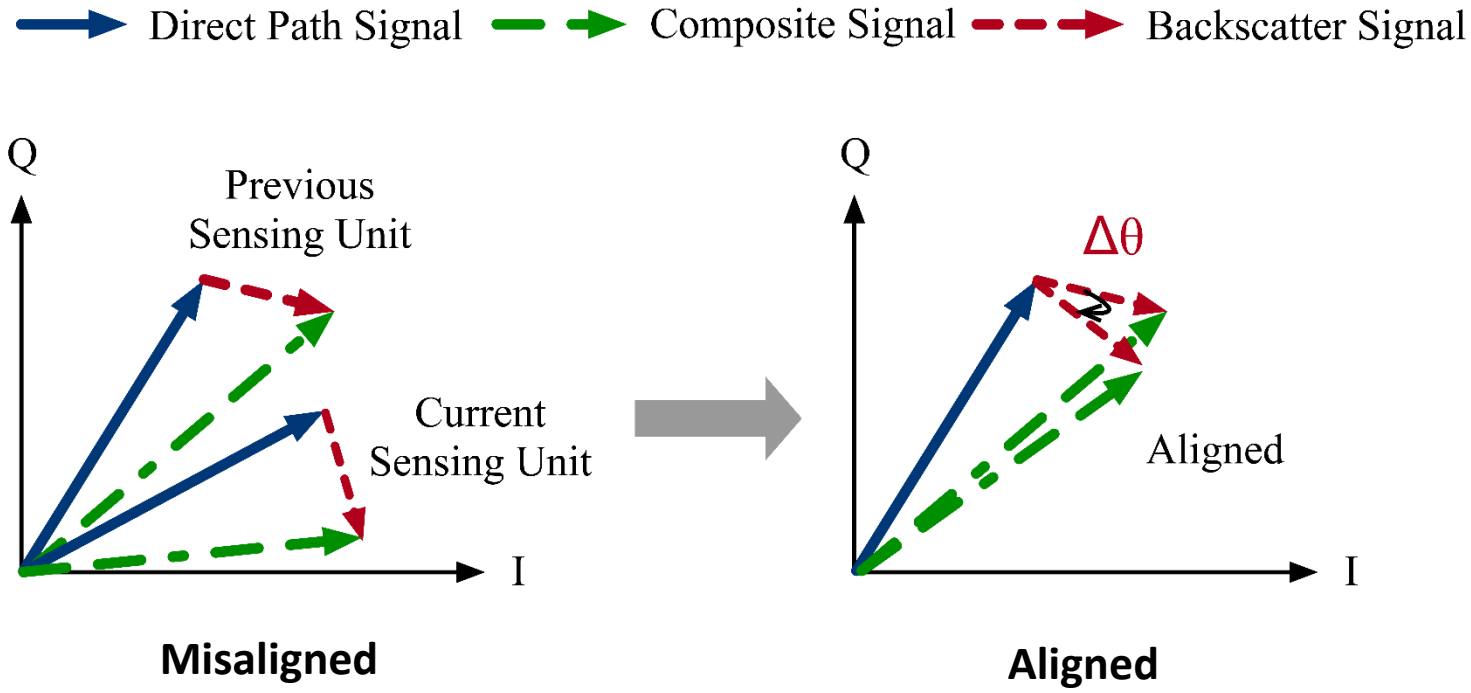


Logarithm of Amplitude-Phase

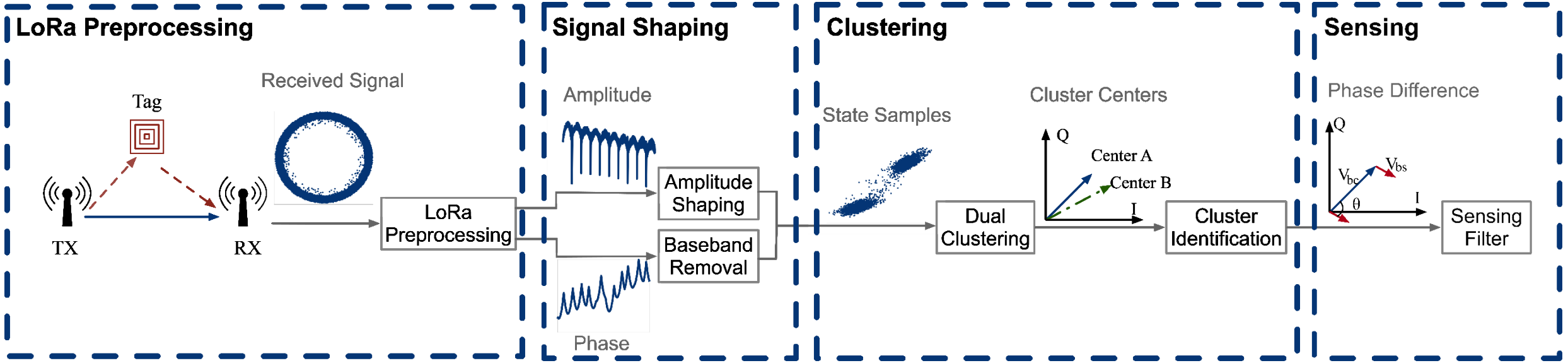
Palantir : System Design

● Cluster Identification

- The movement between the adjacent sensing units is small

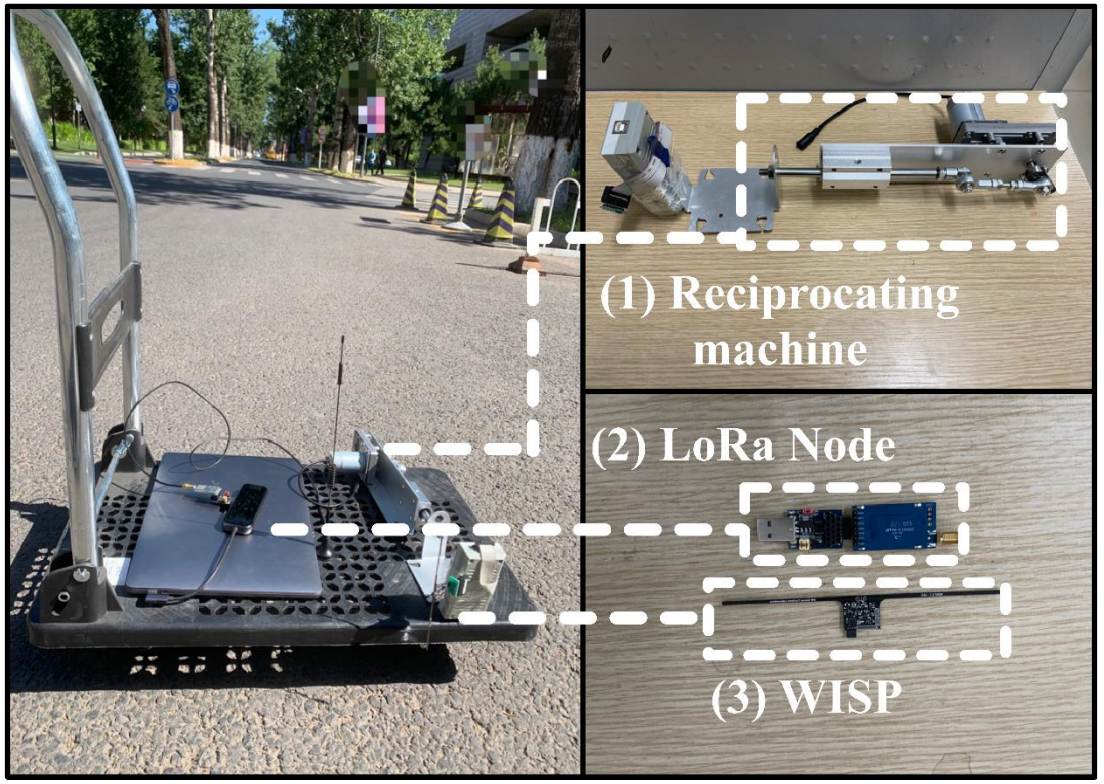


Palantir : System Design



Palantir : Settings

- **Receiver**
  - USRP N210
- **Transmitter**
  - Semtech SX1276 chip
  - Carrier Frequency: 902MHz
  - Bandwidth: 500KHz
- **Backscatter**
  - WISP 5.0



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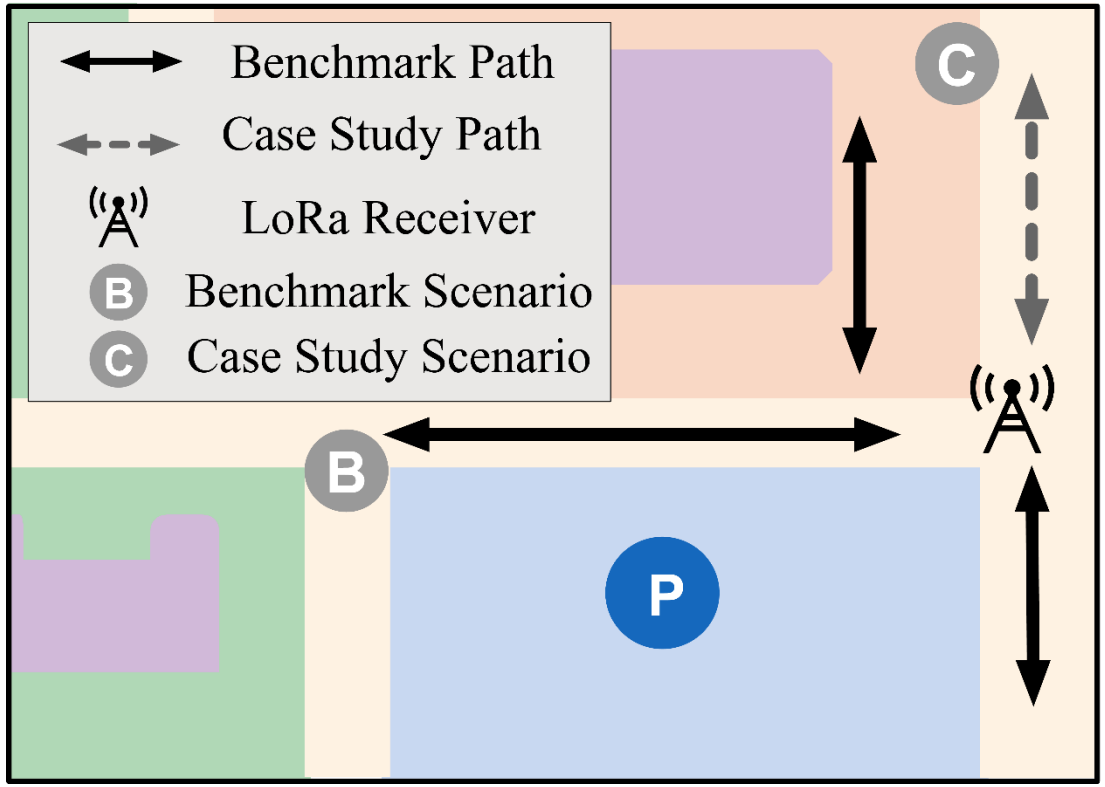
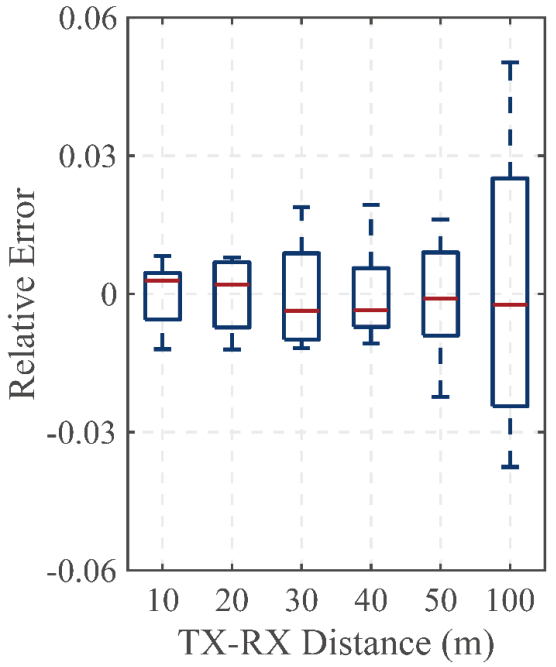
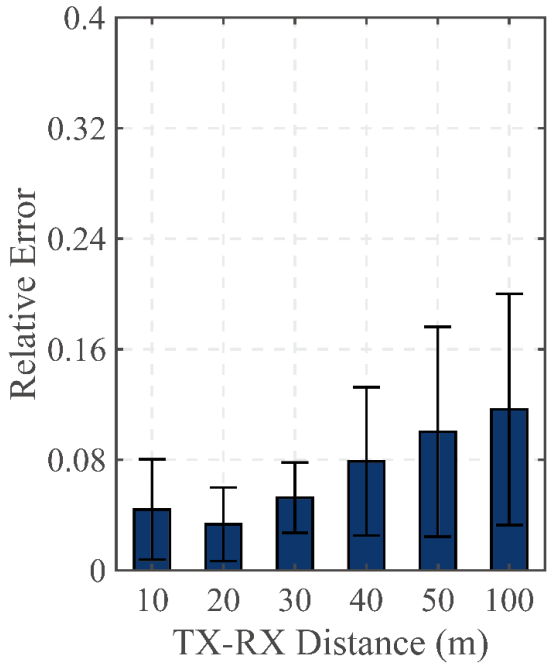


Palantir : Evaluation

- **What we sense?**
  - **Motion period**
    - How fast a cyclist breaths?
  - **Motion amplitude**
    - How deep a cyclist breaths?
- **Metrics**
  - **Motion period deviation**
  - **Motion amplitude deviation**



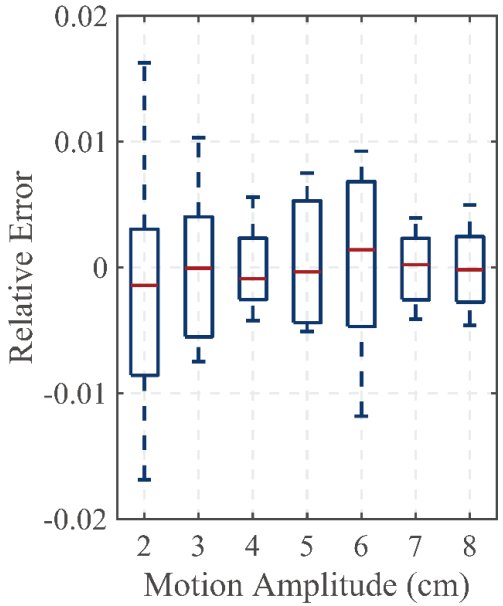
Motion period deviation



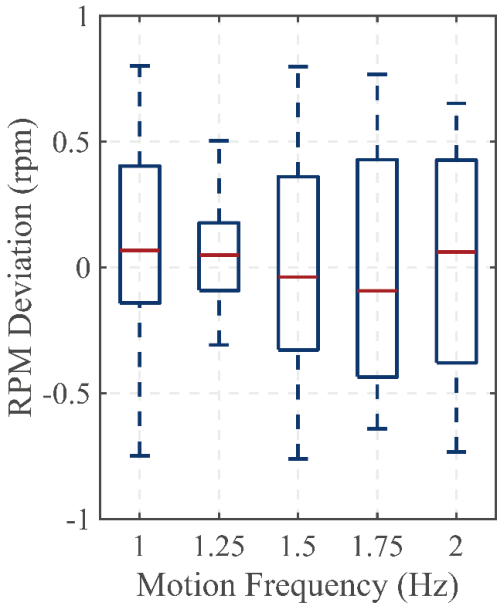
Motion amplitude deviation

Palantir : Evaluation

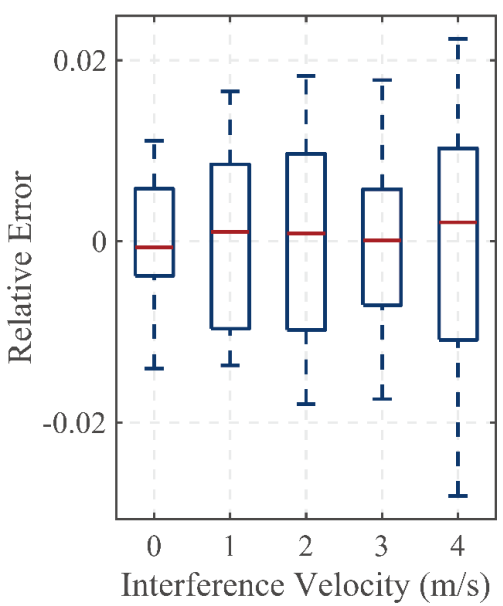
- **Motion period deviation of Palantir in different …**



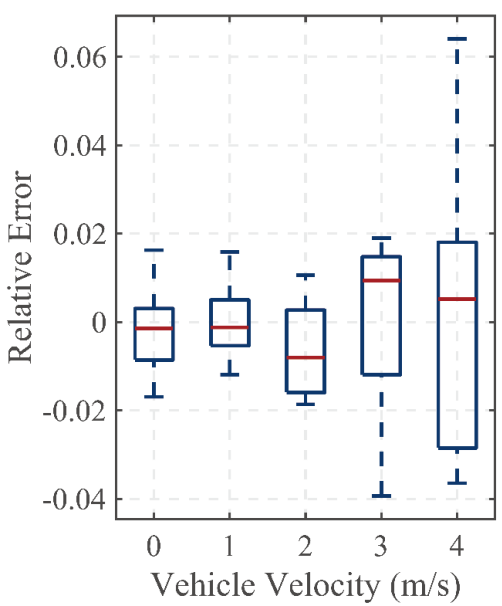
Motion Amplitude



Motion Frequency



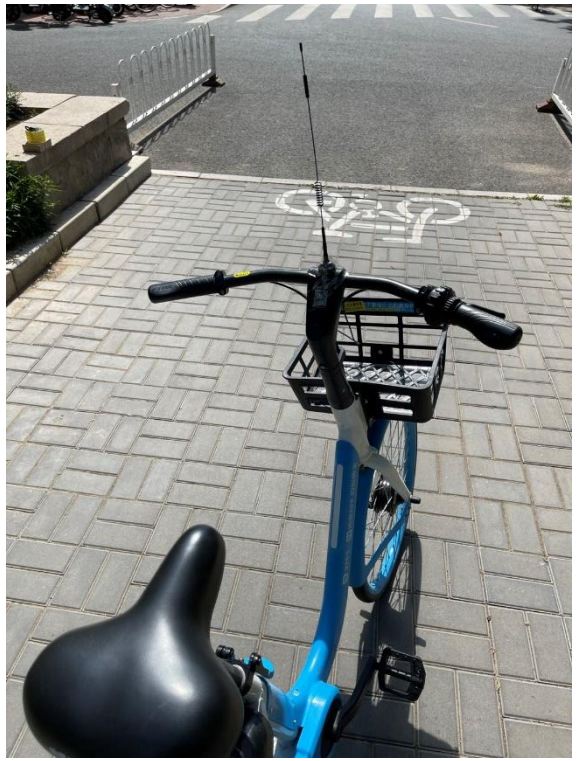
Interference



Mobile Scenario

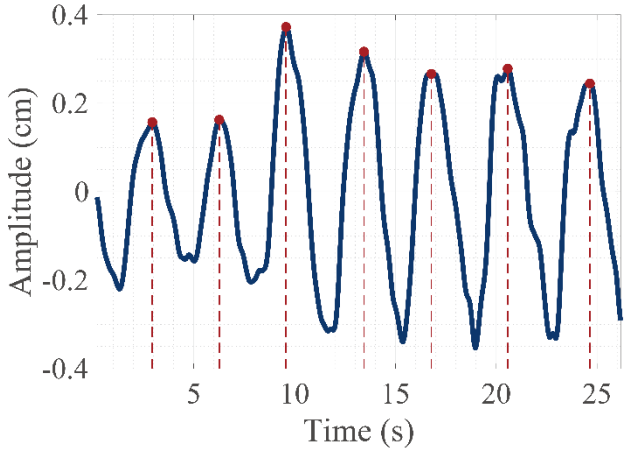
Palantir : Case Study

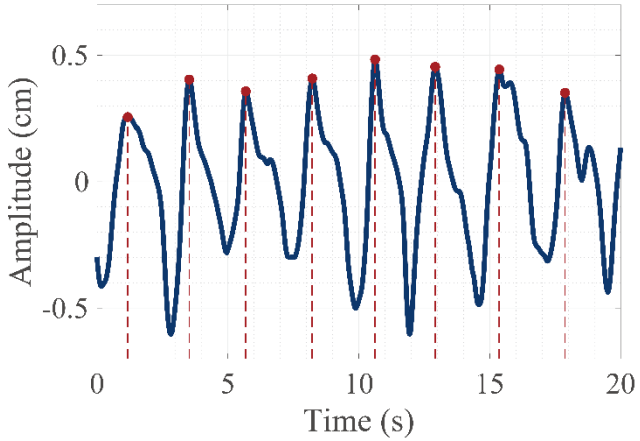
- **Receiver:**
  - **Stationary**
- **Transmitter**
  - **Attached on a sharing bicycle**
- **Backscatter**
  - **Attached to a volunteer**



Palantir : Case Study

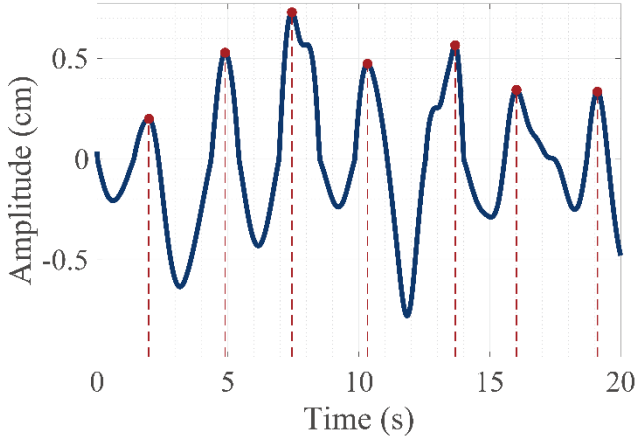
Stationary in 10 m

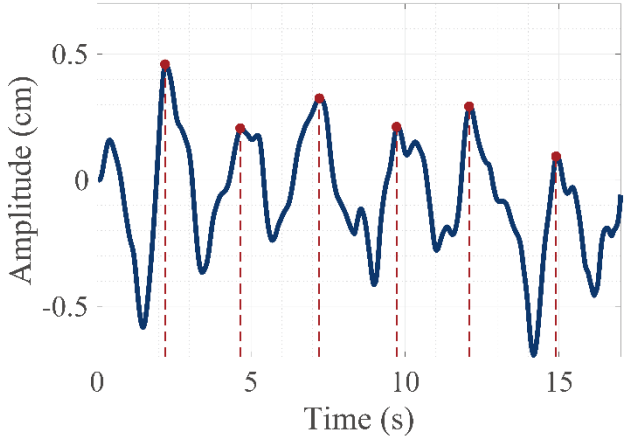




Stationary in 100 m

Riding at low speed





Riding at high speed

Palantir : Conclusion

- **Present a first-of-its-kind long-range sensing system based on the LoRa backscatter.**
  - **Extends the sensing range to 100 m.**
  - **Applied to both stationary and mobile targets.**
- **Separate the coupled challenges and design a complete signal processing scheme.**
  - **Fill the gaps between sensing and communication.**
- **Evaluate the performance of Palantir by performing comprehensive benchmark experiments.**
- **Build a prototype and conduct a case study of respiration monitoring.**

Thanks for Listening

Backup

- **Cluster Identification**
  - **The movement between the adjacent sensing units is small**