

Are RFID Sensing Systems Ready for the Real World?

Ju Wang, Liqiong Chang, Omid Abari and Srinivasan Keshav



ICONLAB.ca

RFIDs



Equipment management



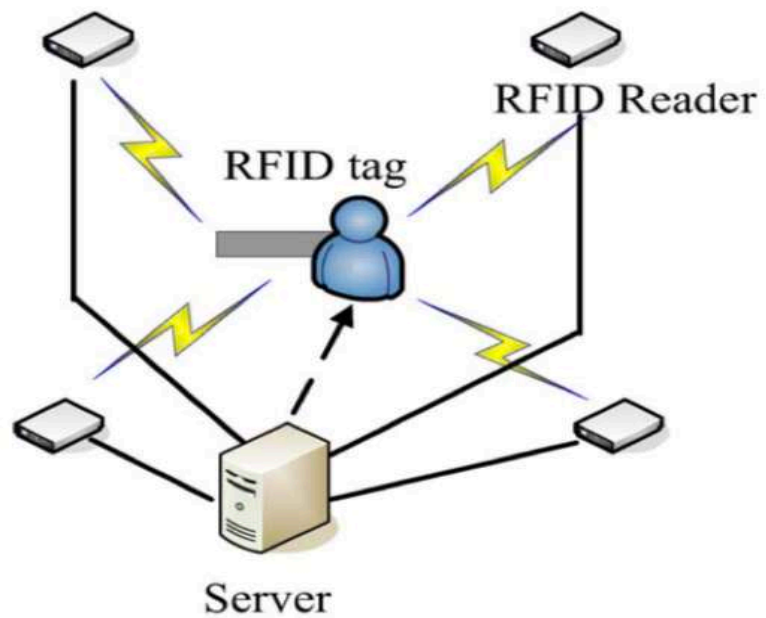
Anti-theft



Document classification

In 2022, the market value of RFIDs is expected to be \$15 billion!

**Beyond identification function in industry,
RFID-sensing systems are proposed in research**



Zhu, et al. IEEE TPDS'14

**Localization
& Tracking**

Chong, et al.
ICAR'03

Ferret
Springer'06

Zhou, et al.
Springer'09

Azzouzi, et al.
RFID'11

Pinit
Sigcomm'13

BackPos
TMC'15

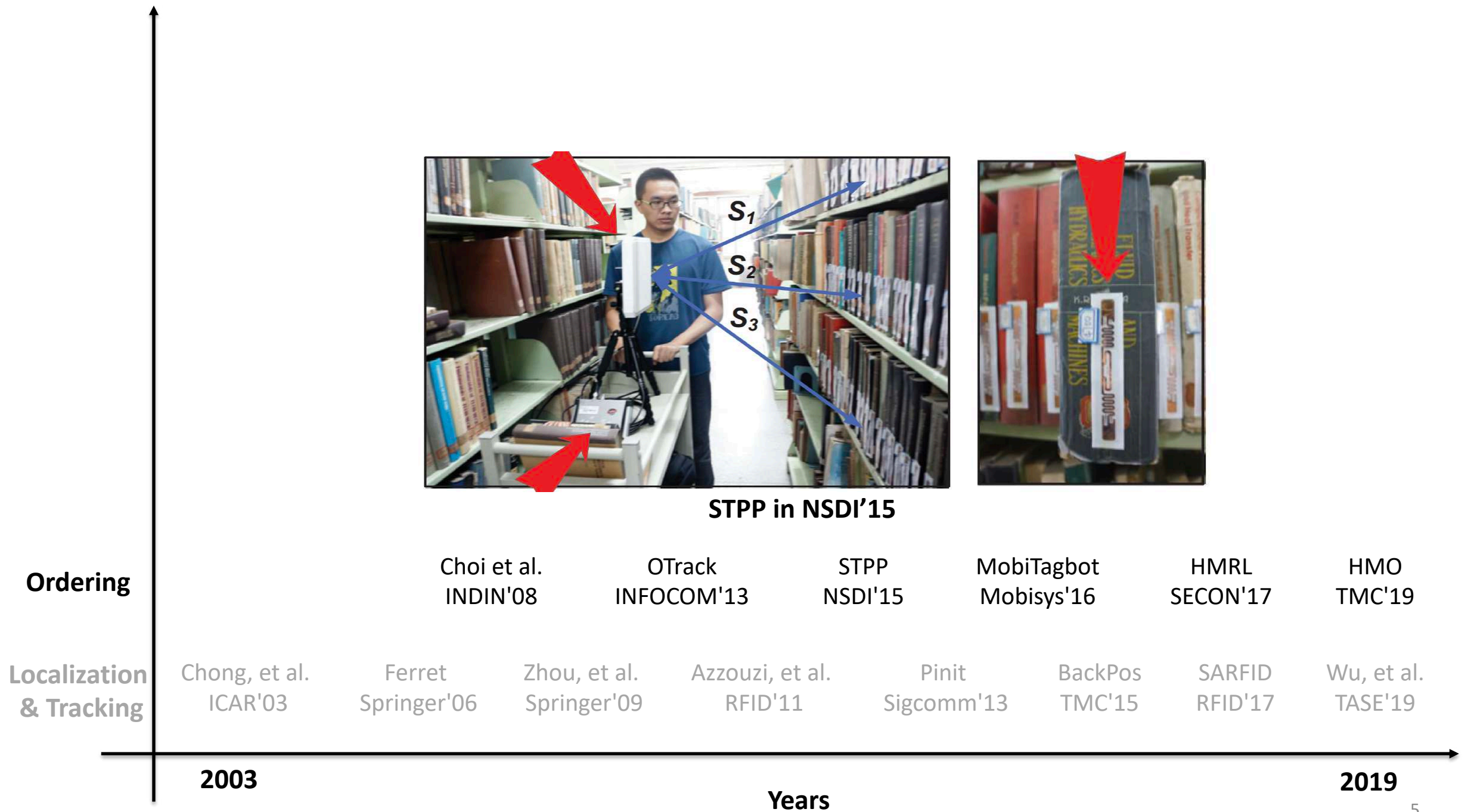
SARFID
RFID'17

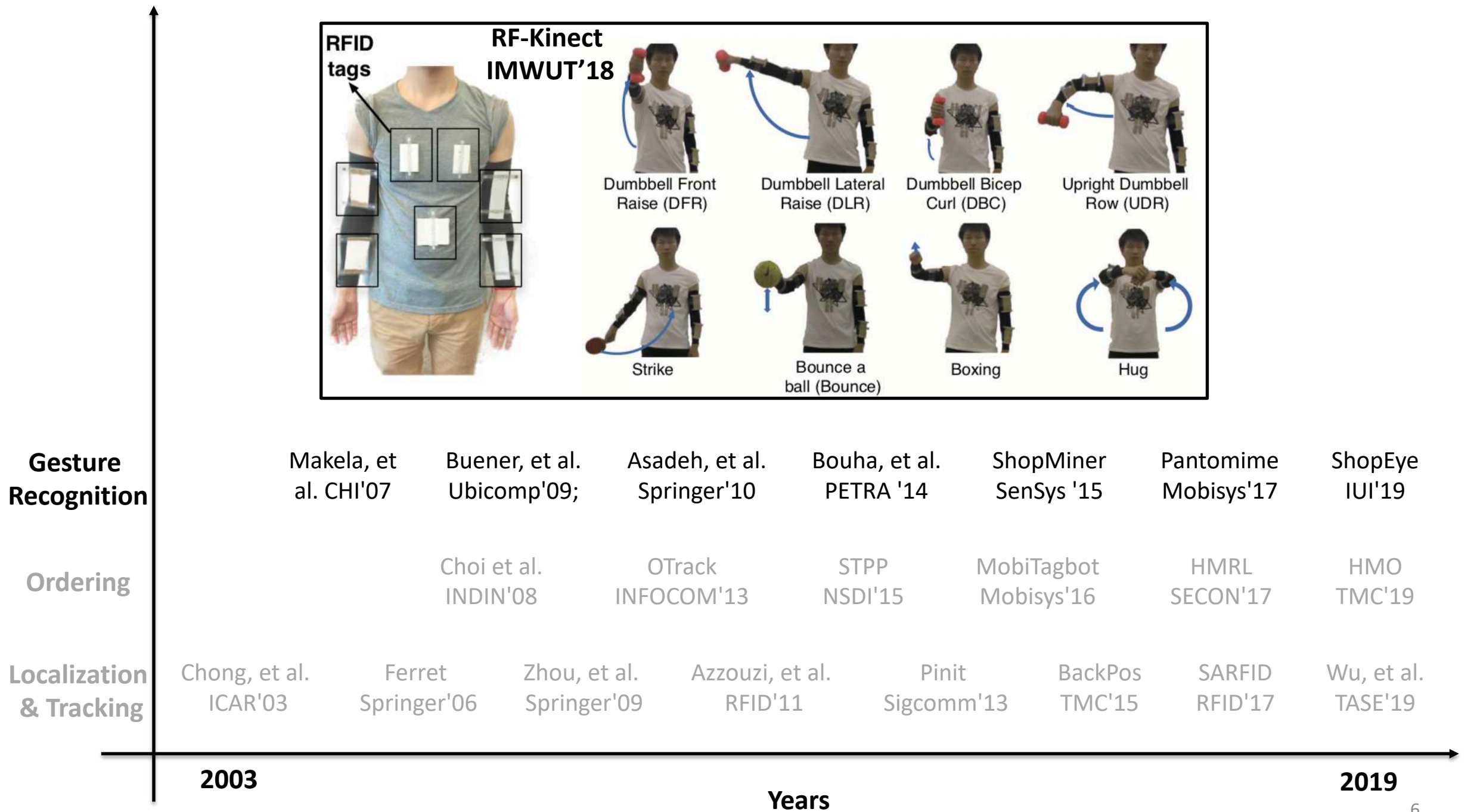
Wu, et al.
TASE'19

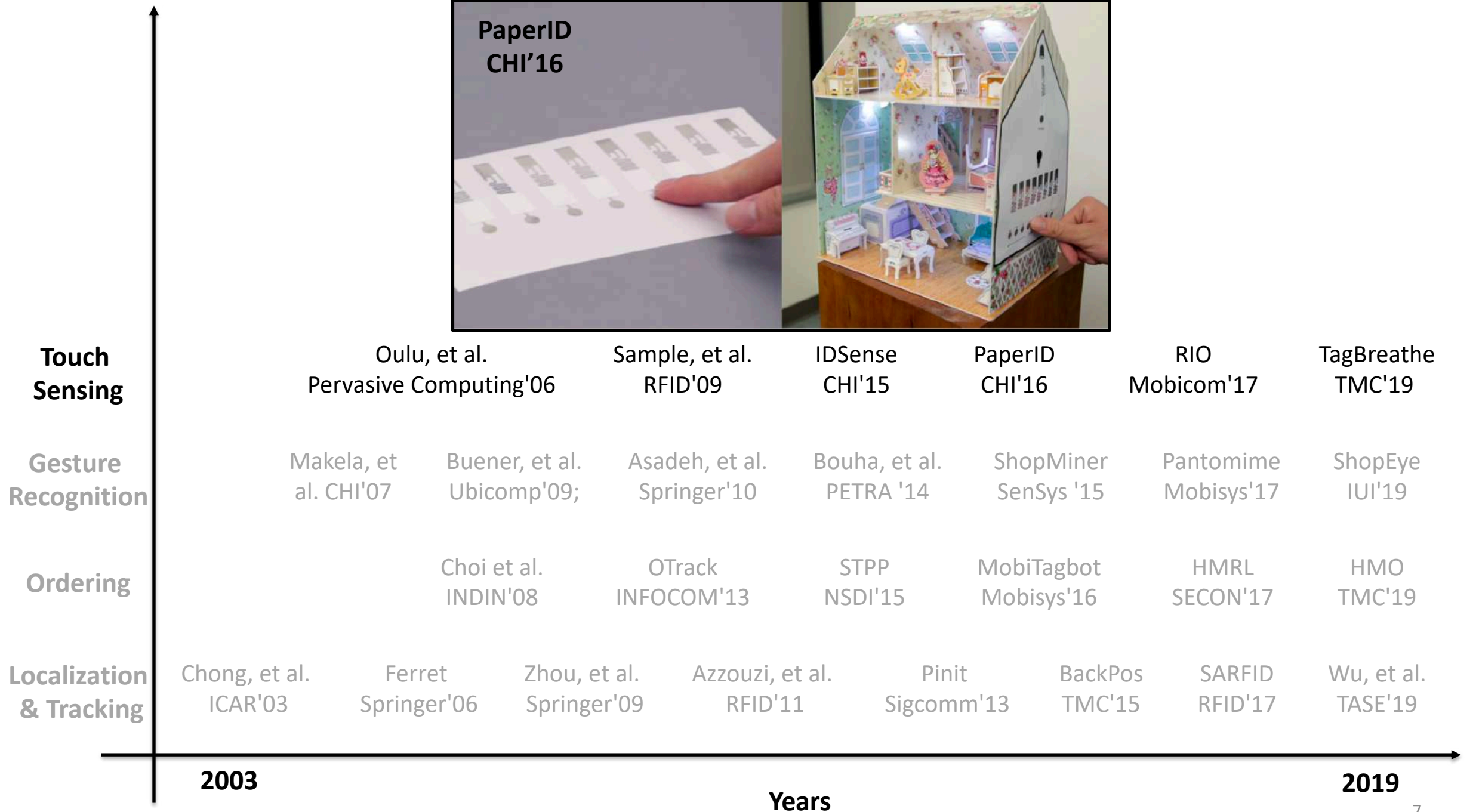
2003

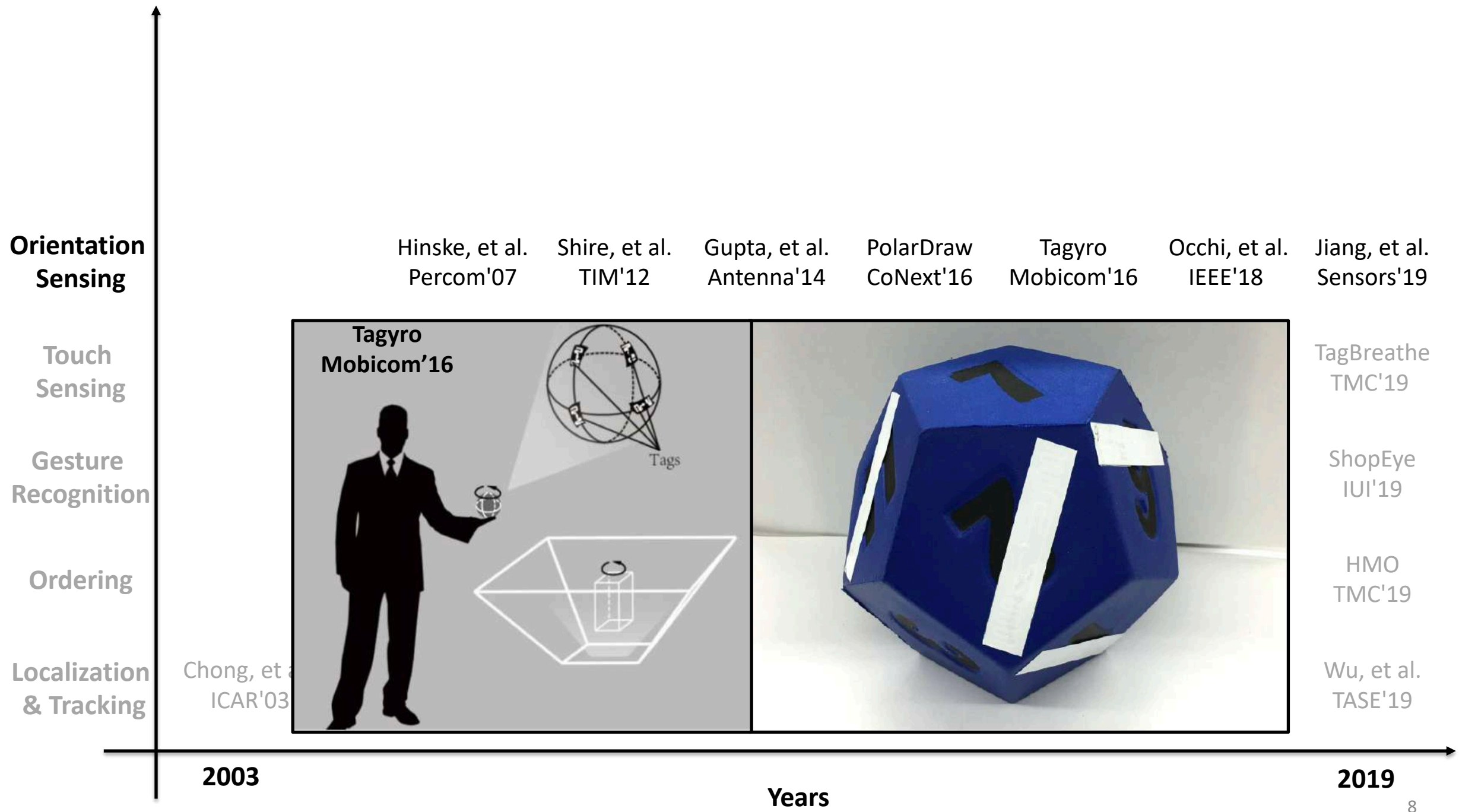
Years

2019









Device-Free
Sensing

Liu, et al. Zhang, et al. Moore, et al. Wagner, et al. Tadar GRFID WallSense Belal, et al.
Percom'07 Percom'09 CiteSeerX'10 WPNC'12 Mobicom'15 TMC'17 Sensors'18 Springer'19

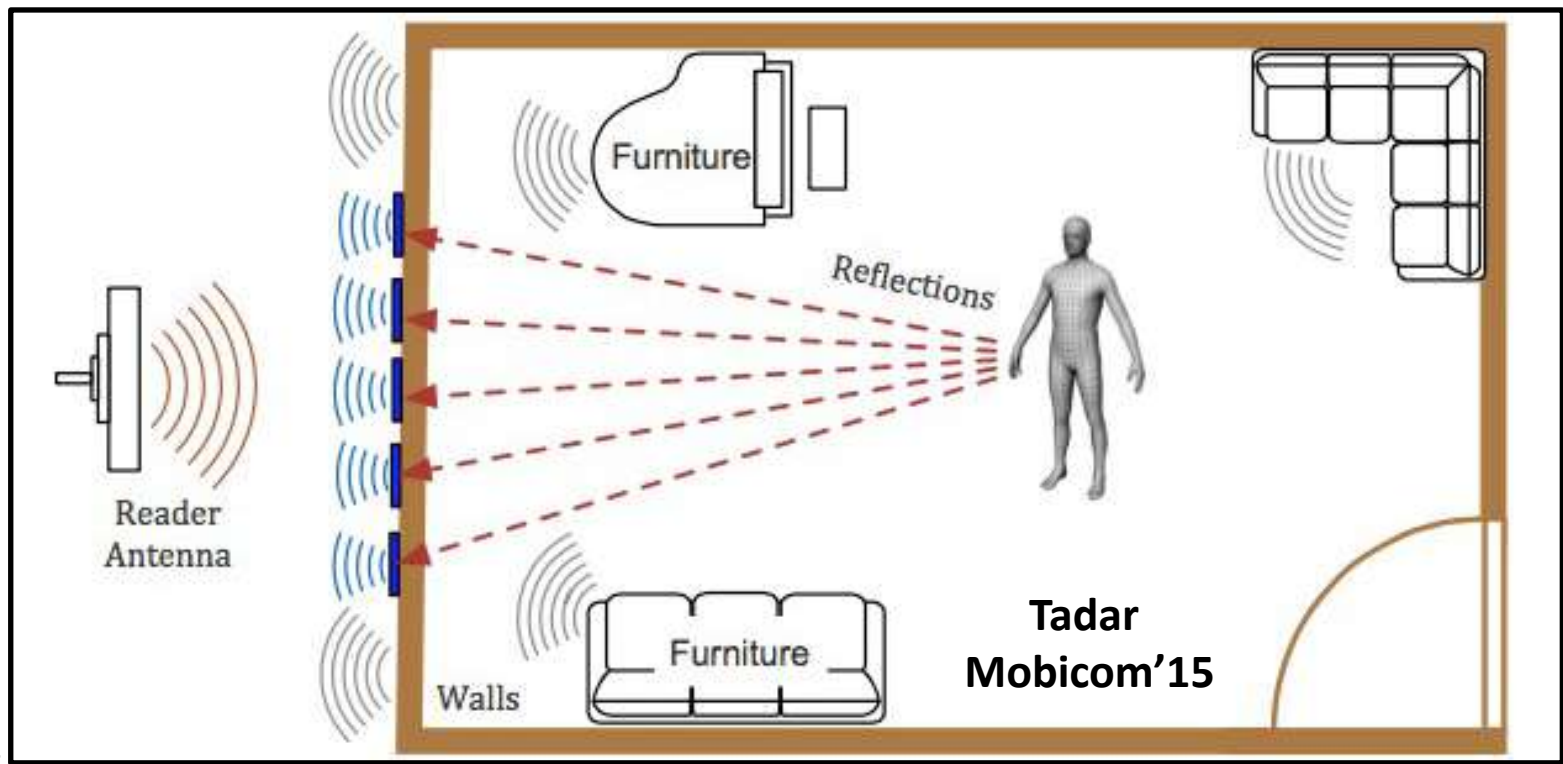
Orientation
Sensing

Touch
Sensing

Gesture
Recognition

Ordering

Localization
& Tracking

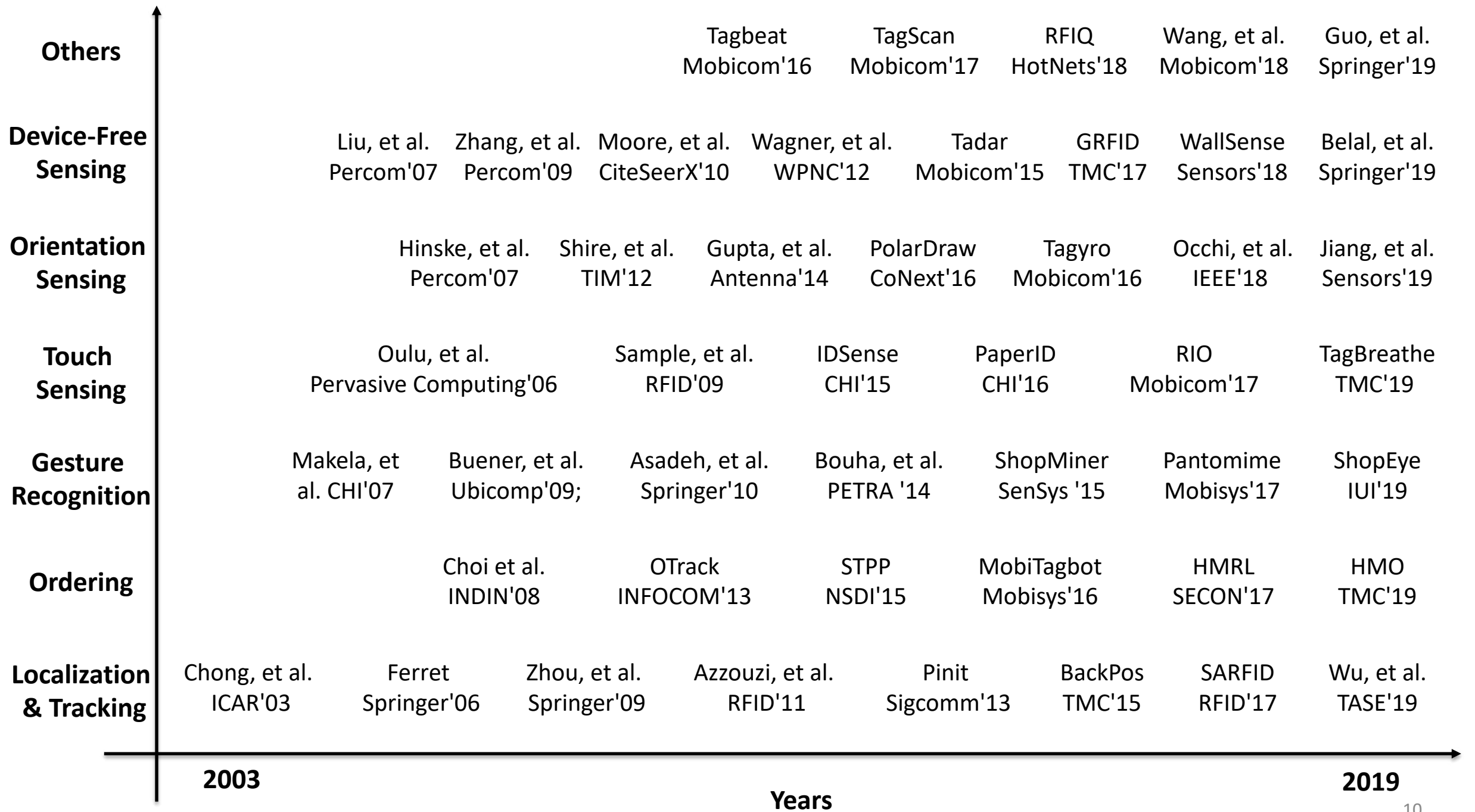


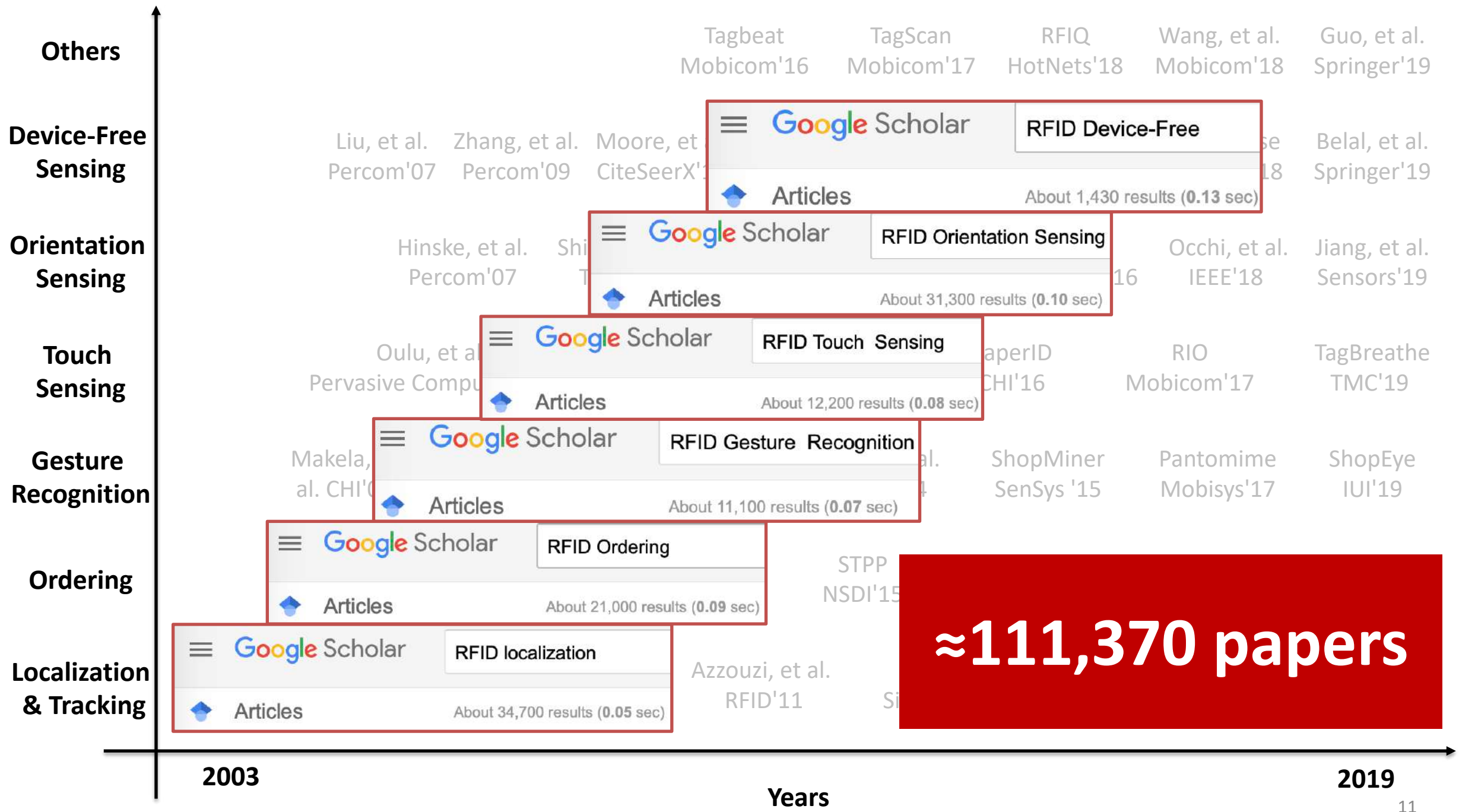
Chong, et al. Percom'06 Zeng, et al. RFID'11 Tadar Mobicom'15 SARFID Wu, et al.
ICAR'03 Springer'06 Springer'09 RFID'11 Sigcomm'13 TMC'15 RFID'17 TASE'19

2003

Years

2019





**Why *none* of these systems are
in widespread use today?**

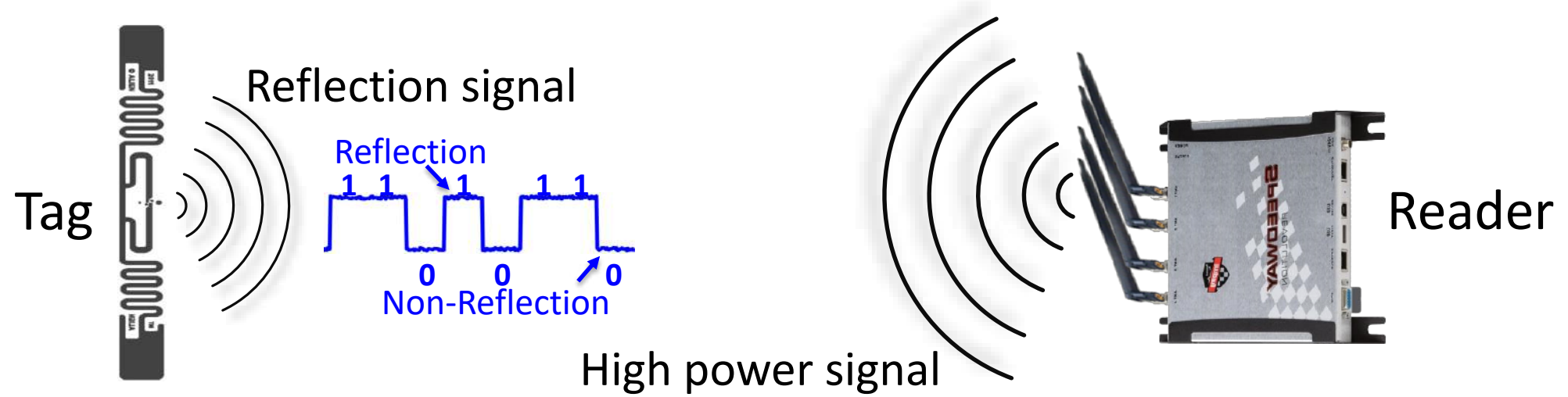
We hypothesize:

RFID-based sensing is *not robust* to variations
in the RF environment or tag geometry

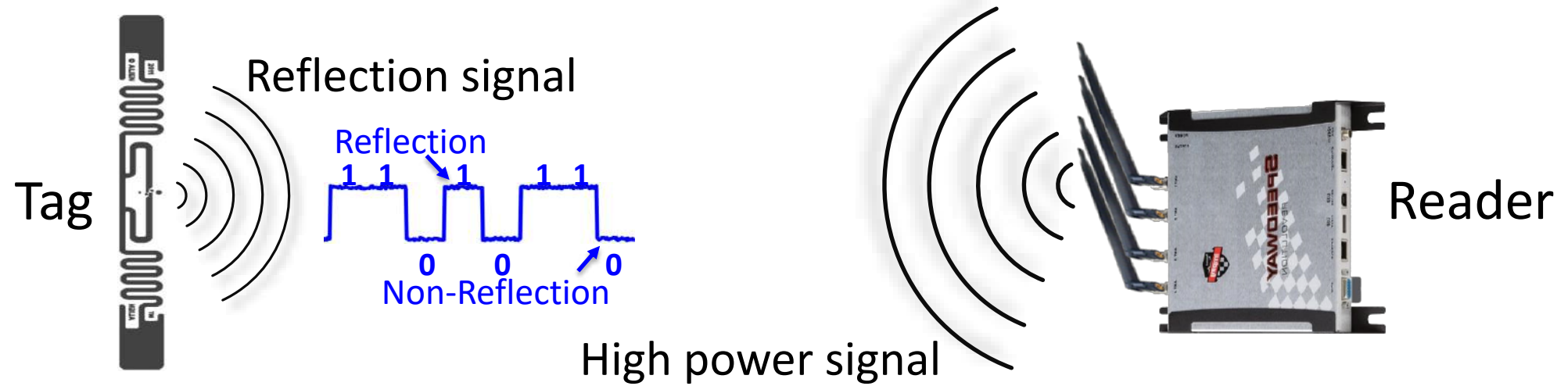
In this talk:

I will *validate* our research *hypothesis*,
provide insights into designing robust RFID systems

How RFID works

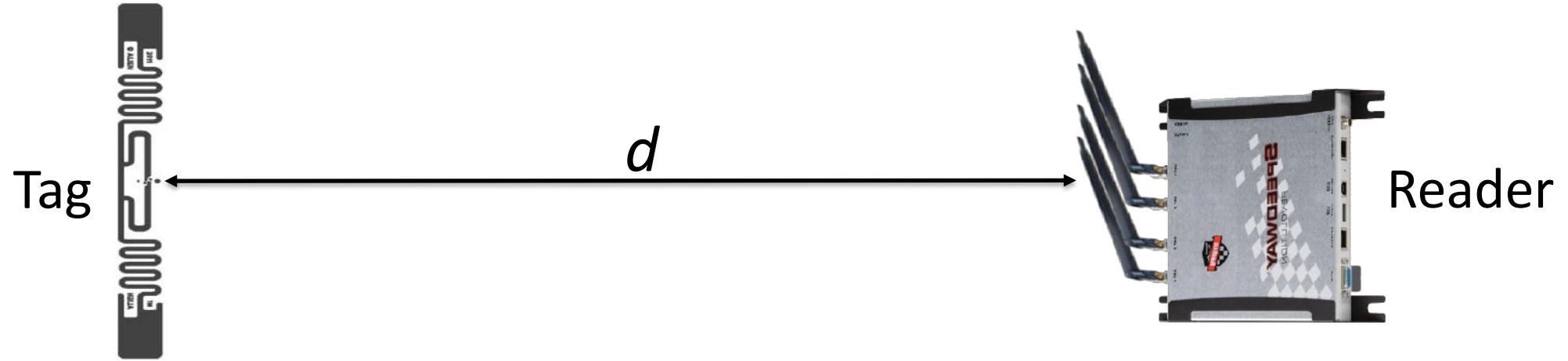


How RFID works



**Received Signal Strength (RSS) & Phase
are important for RFID sensing systems**

What are RSS & Phase



Received Signal Strength (RSS):

$$R(dB) = 10 \log \left[\frac{C}{d^4} P_{tx} \lambda^4 \right]$$

Phase:

$$\phi = \left(\frac{4\pi}{\lambda} d + C \right) \bmod 2\pi$$

d: tag-to-reader distance. *C*: related to RF environment and tag's geometry.

What are RSS & Phase

RSS or Phase is a function of
Distance, RF Environment & Tag's geometry

Received Signal Strength (RSS):

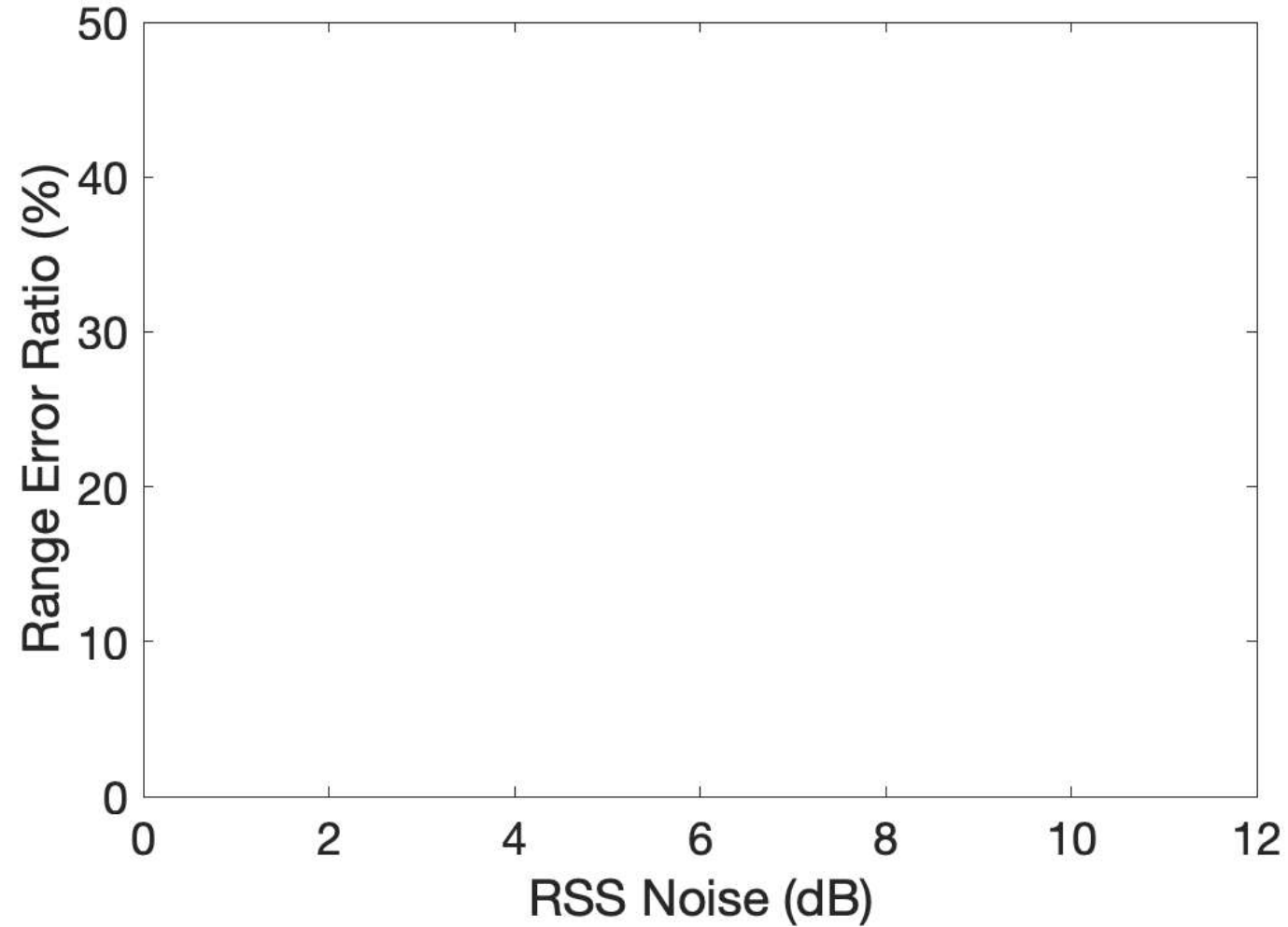
$$R(dB) = 10 \log \left[\frac{C}{d^4} P_{tx} \lambda^4 \right]$$

Phase:

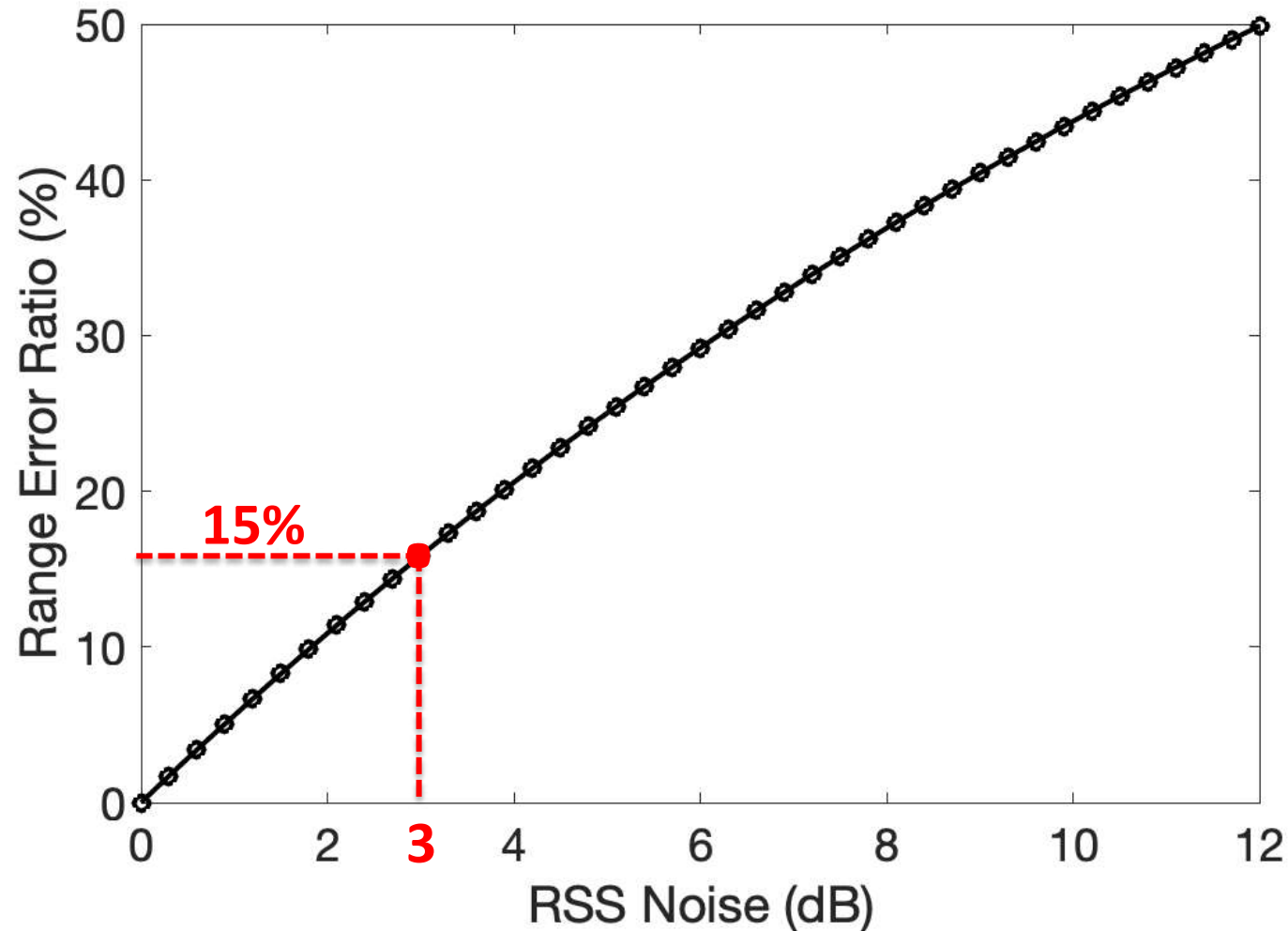
$$\phi = \left(\frac{4\pi}{\lambda} d + C \right) \bmod 2\pi$$

d: tag-to-reader distance. *C*: related to RF environment and tag's geometry.

Impact of RSS Noise on Range Estimation

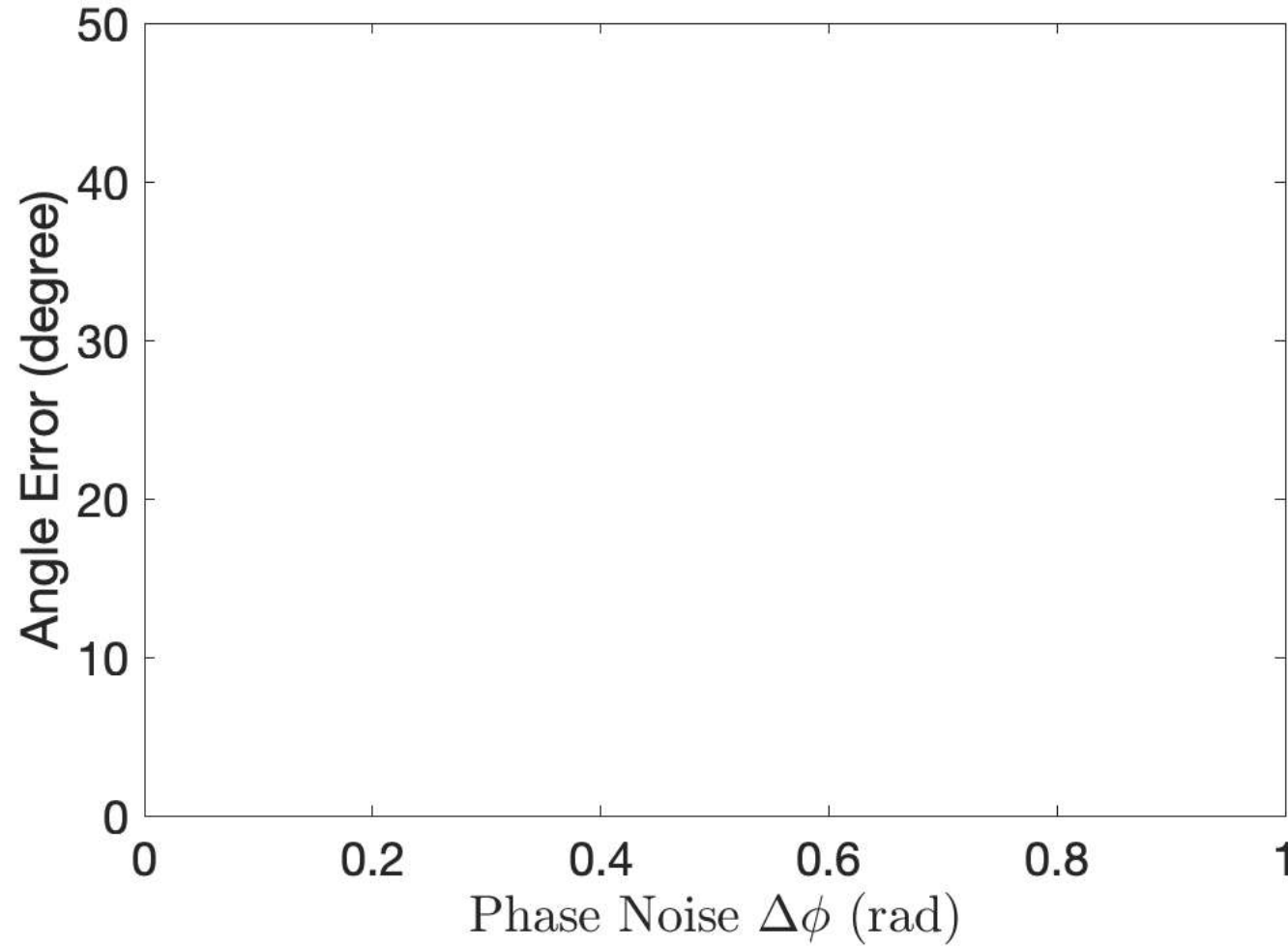


Impact of RSS Noise on Range Estimation

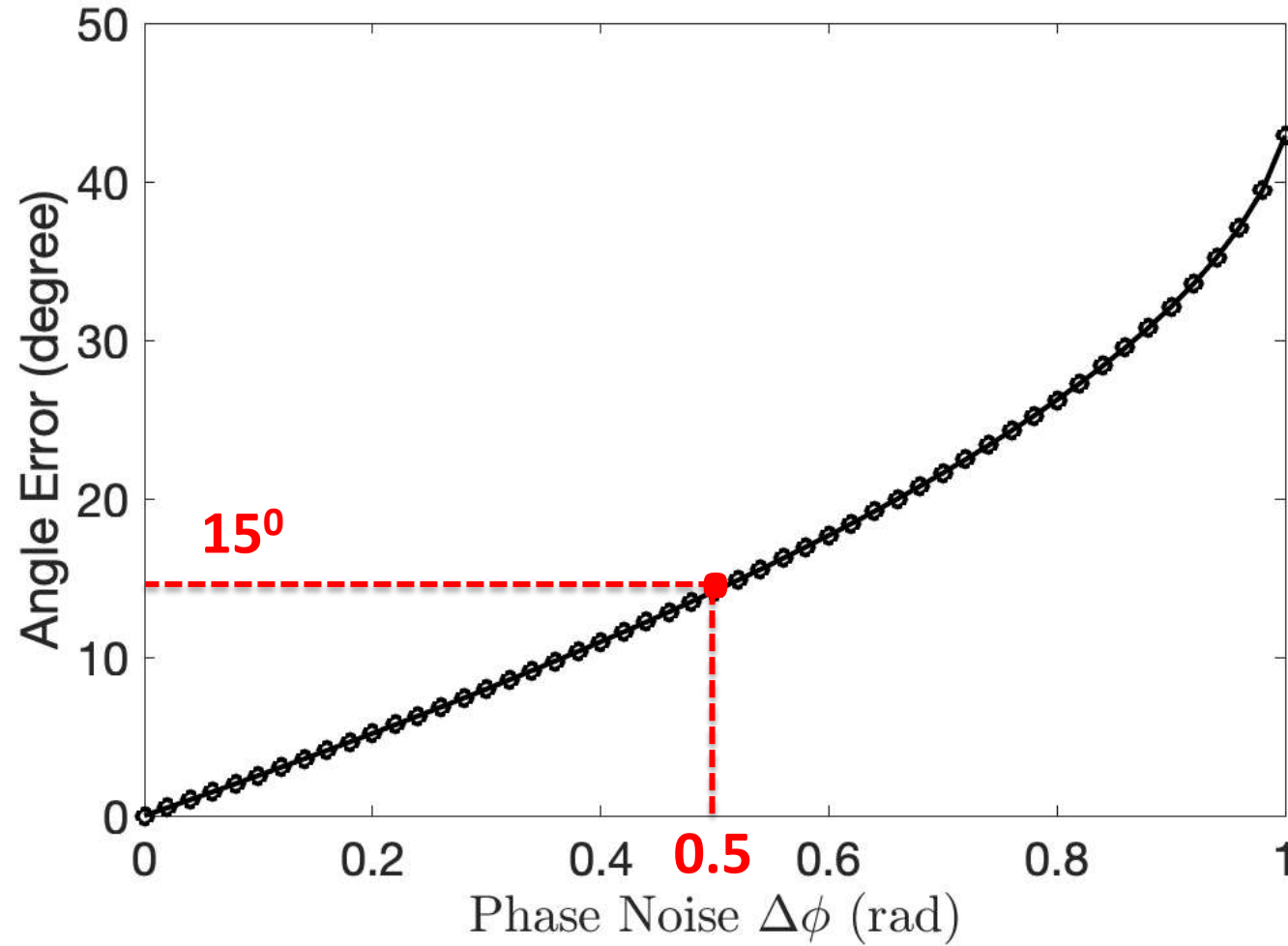


3 dB RSS noise results up to 1.5 m range error

Impact of Phase Noise on Angle Estimation



Impact of Phase Noise on Angle Estimation



0.5 rad phase noise results in 15° angle error

Quality of RSS & Phase is critical for
accuracies of RFID-based applications

How robust are RSS and phase in reality?

Experimental Setup



An Impinj R420 reader

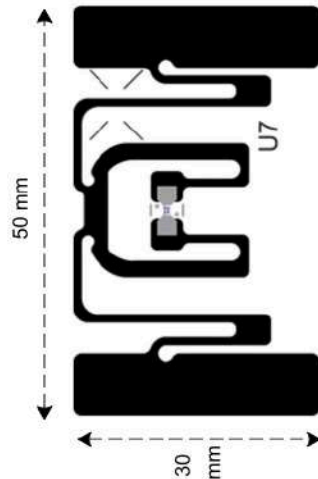


Two reader antennas



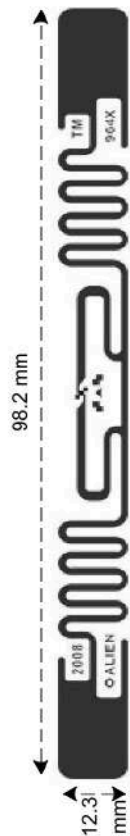
Avery Dennison AD-160u7

Type 1



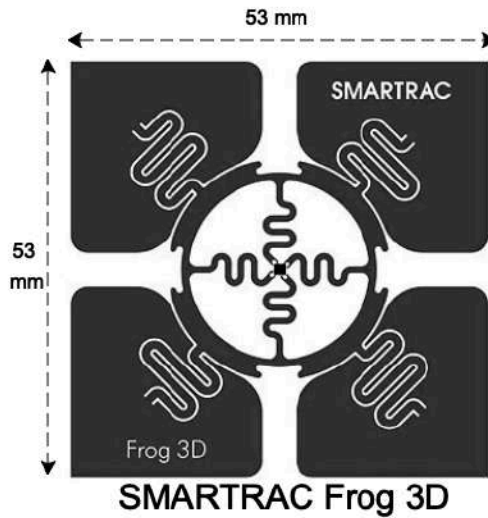
Avery Dennison
AD-383u7

Type 2



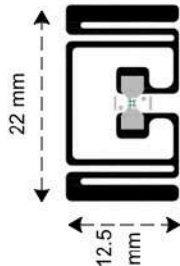
Alien Squiggle ALN-9740

Type 3



SMARTRAC Frog 3D

Type 4



Avery Dennison
AD-172u7

Type 5

Five types of widely used RFID tags

Raw data and test software are openly available:

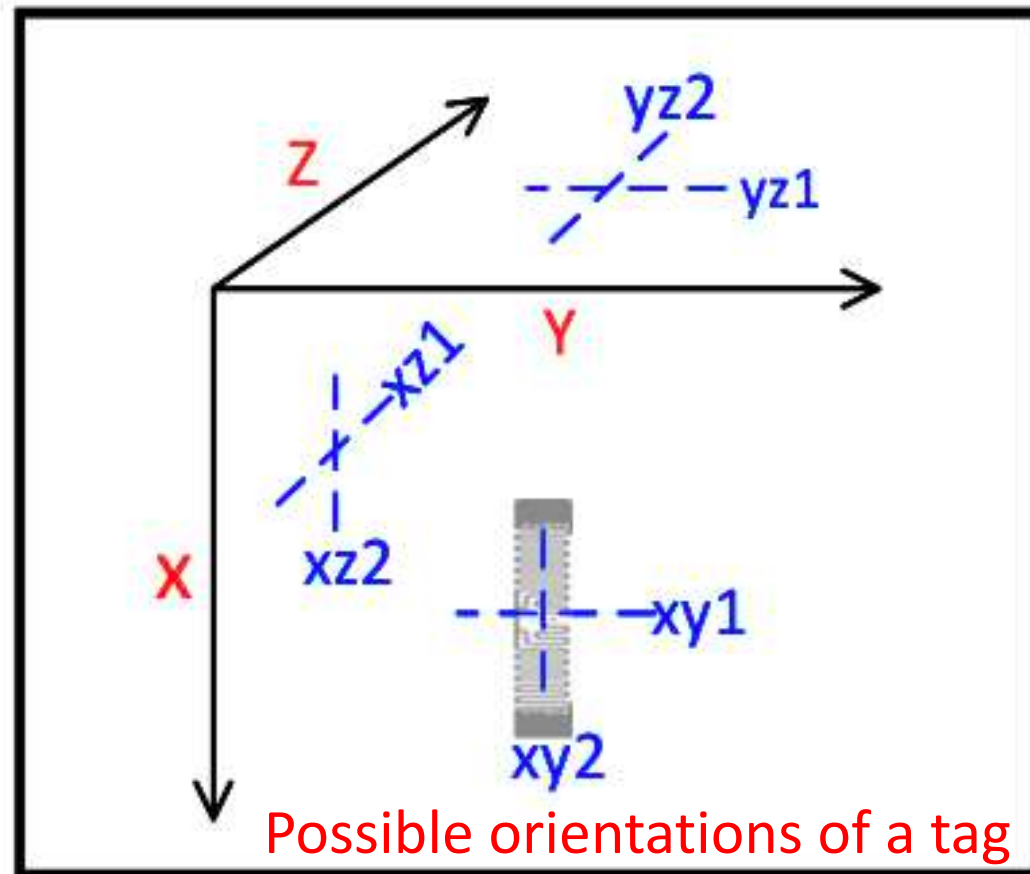
<https://www.dropbox.com/s/z34h0lk7bc8x0p0/Raw-data-and-Software-code.zip?dl=0>

Impact of Setup Parameters on RSS/Phase

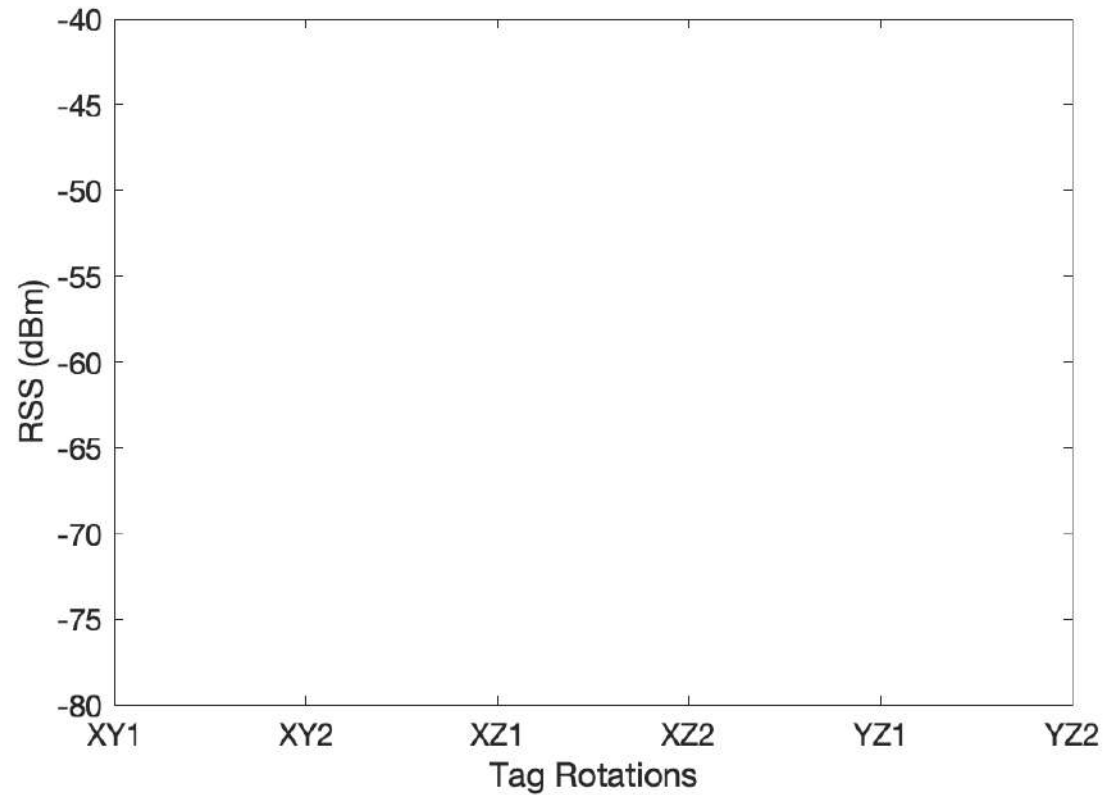
- (1) **Orientation** of a tag
- (2) **Environment**
- (3) **Bending shape** of tag
- (4) **Surface material** that a tag is attached to
- (5) **Deployment angle** of a tag in the antenna's beam
- (6) **Deployment height** of a tag above the floor
- (7) **Small movements** of tag

Impact of Setup Parameters on RSS/Phase

(1) Orientation of a tag

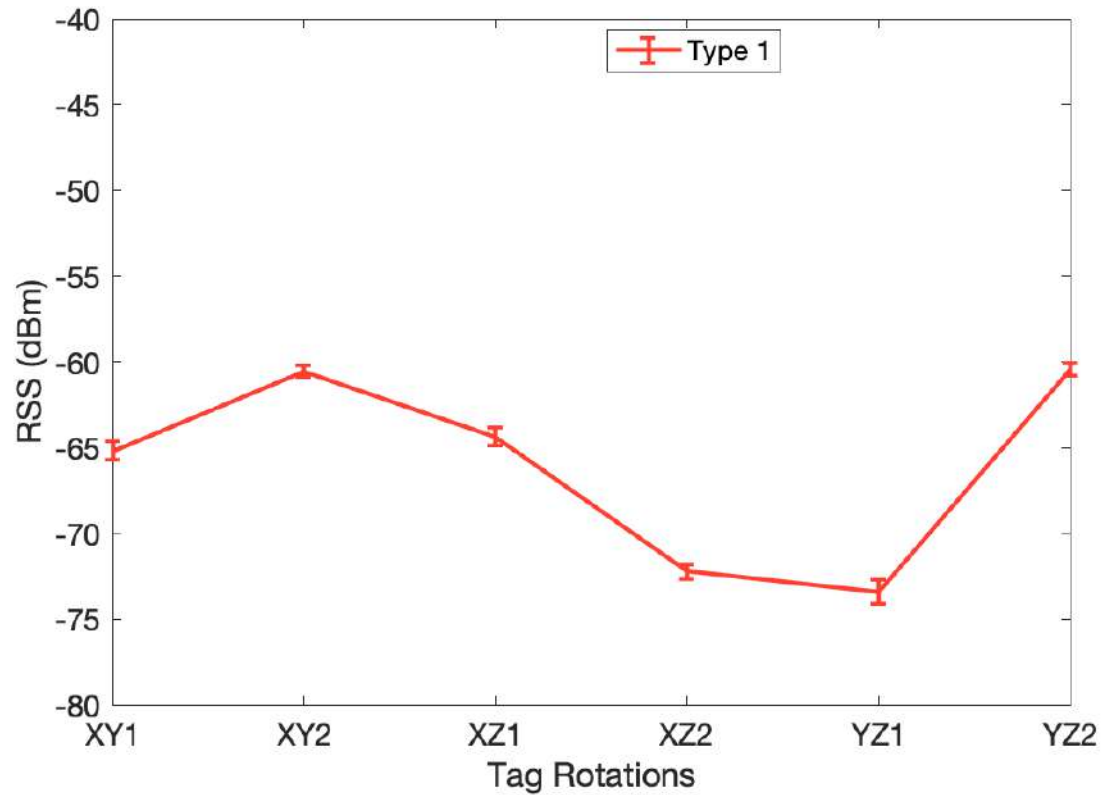


Impact of Tag Orientations



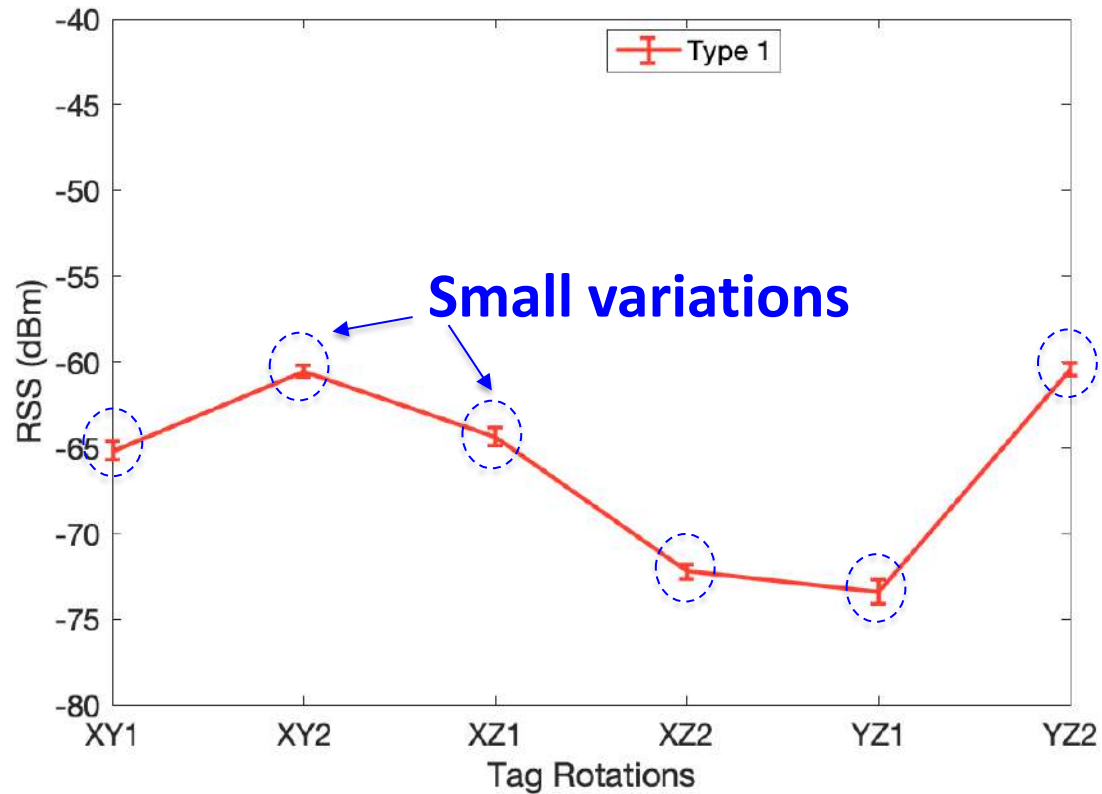
Absolute RSS

Impact of Tag Orientations



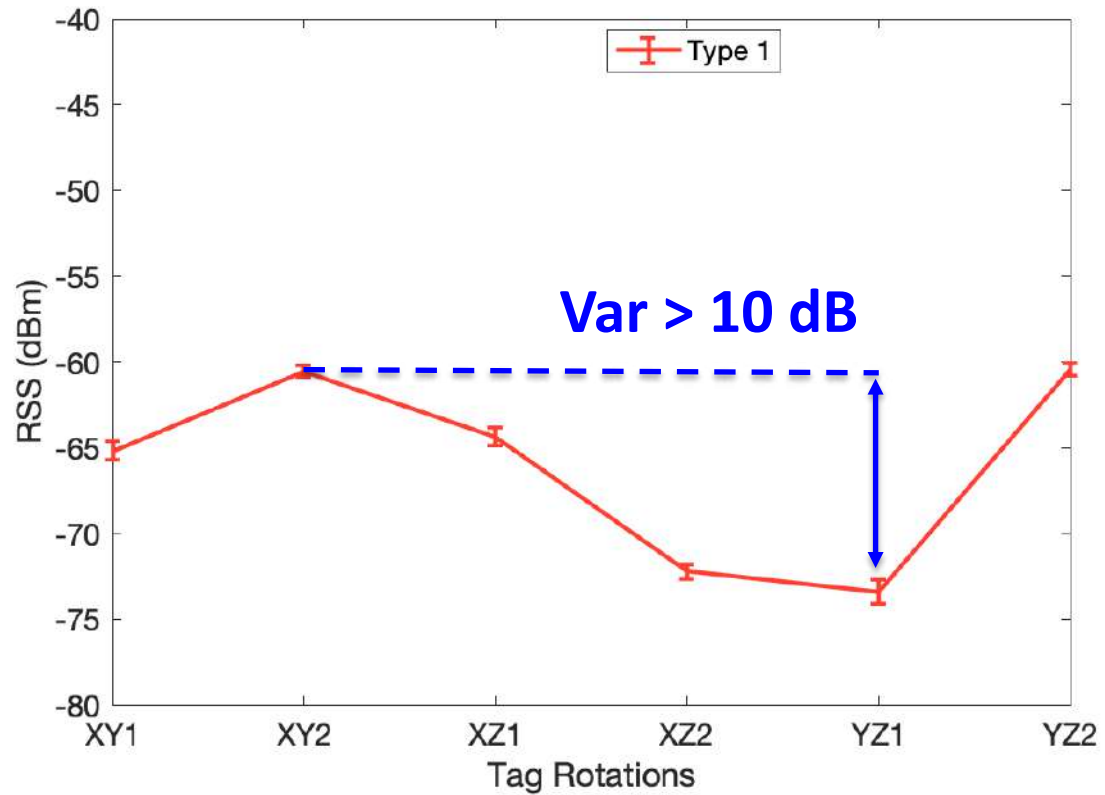
Absolute RSS

Impact of Tag Orientations



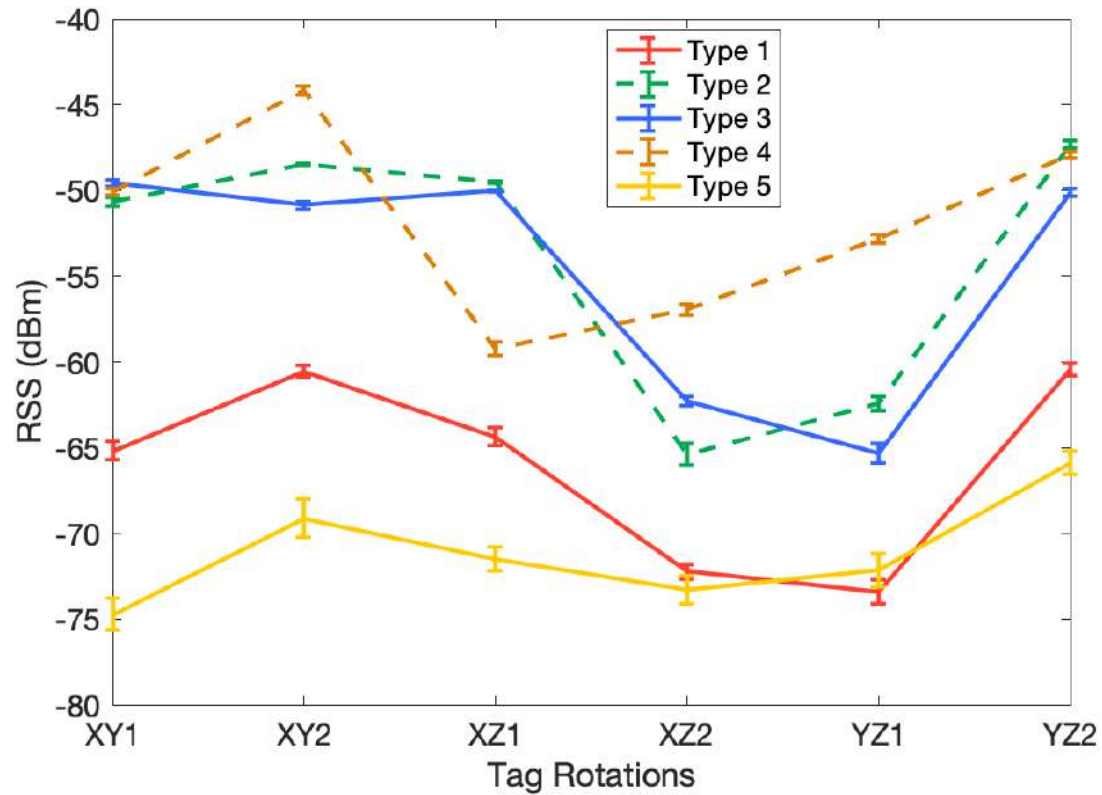
Absolute RSS

Impact of Tag Orientations



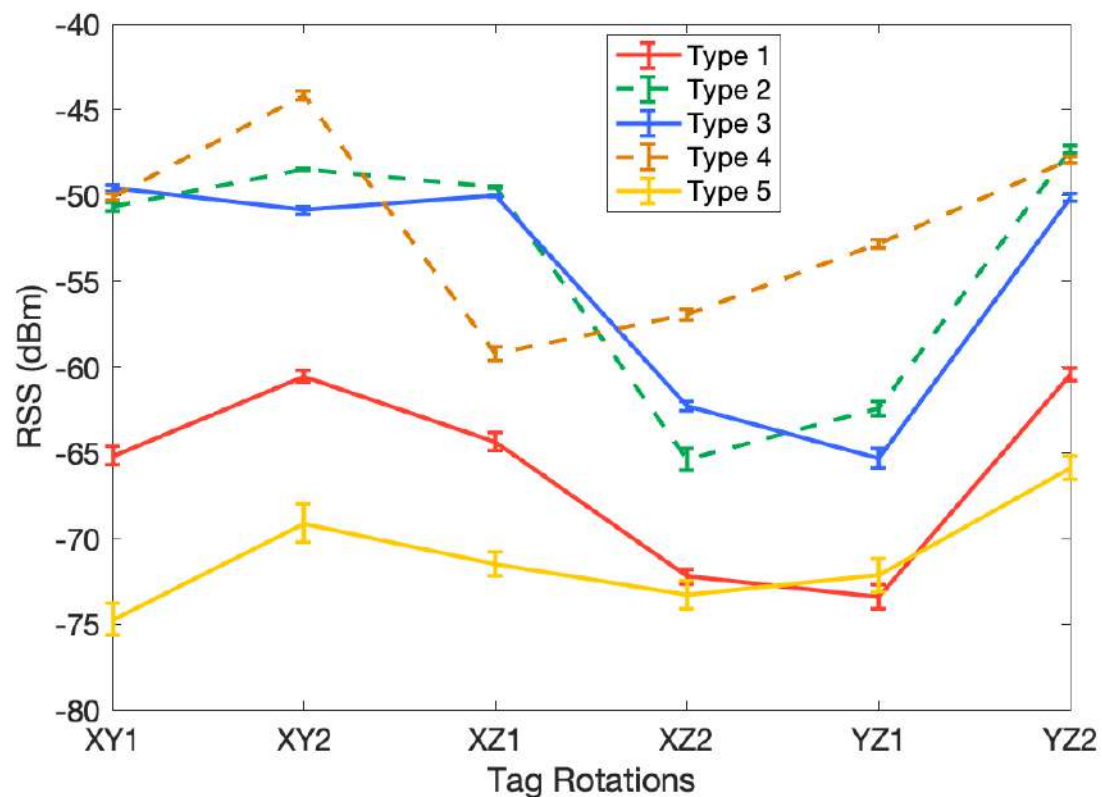
Absolute RSS

Impact of Tag Orientations

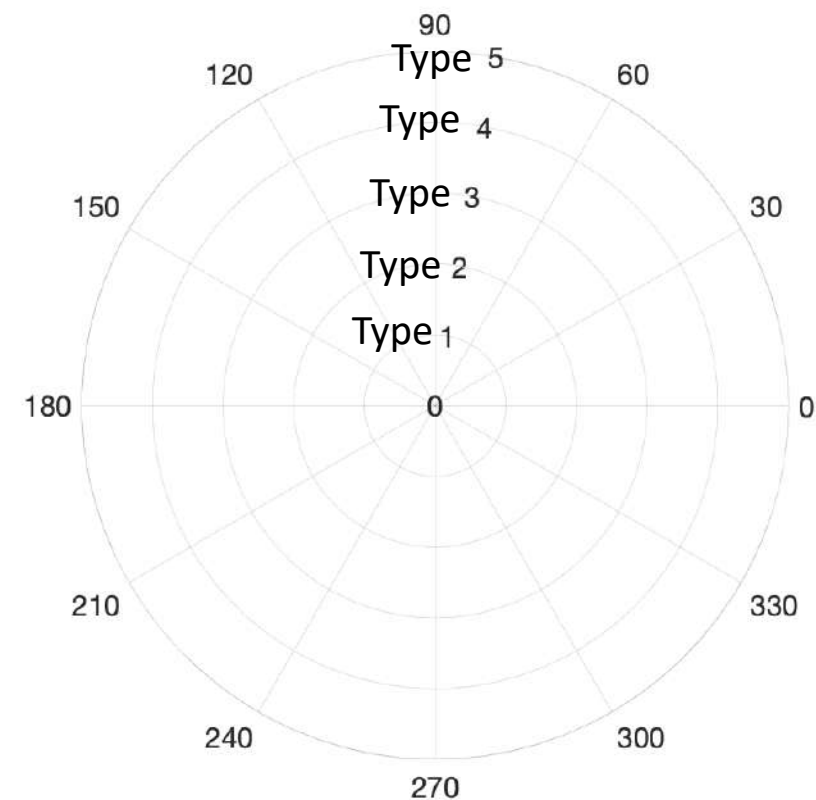


Absolute RSS

Impact of Tag Orientations

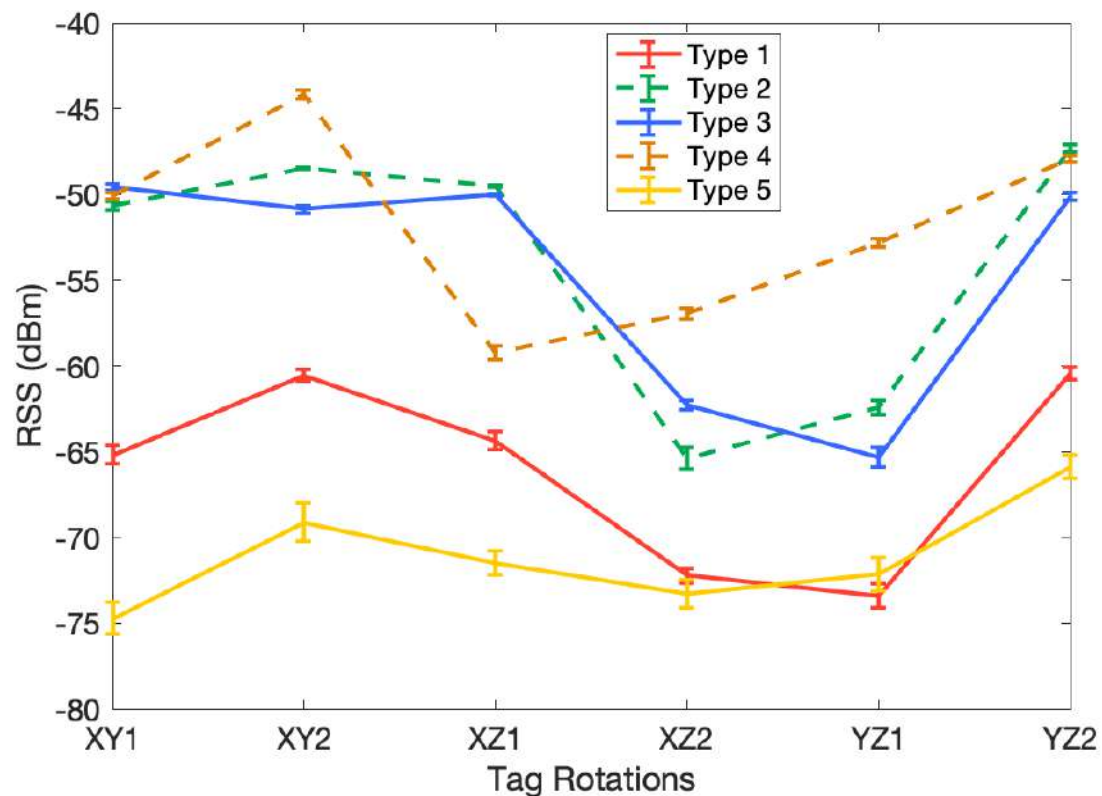


Absolute RSS

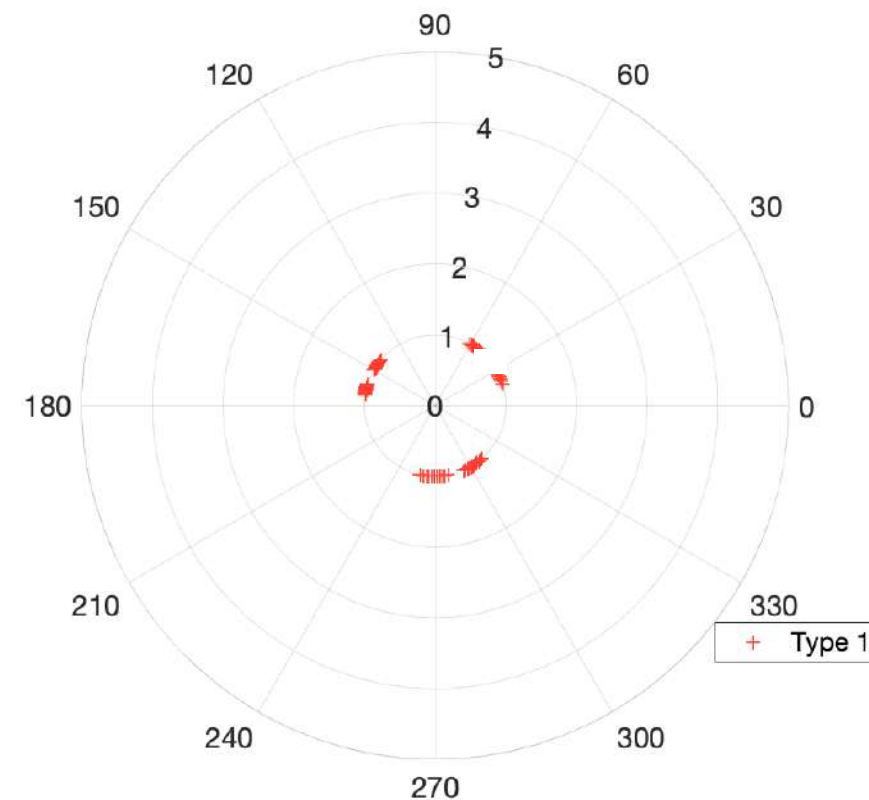


Absolute Phase

Impact of Tag Orientations

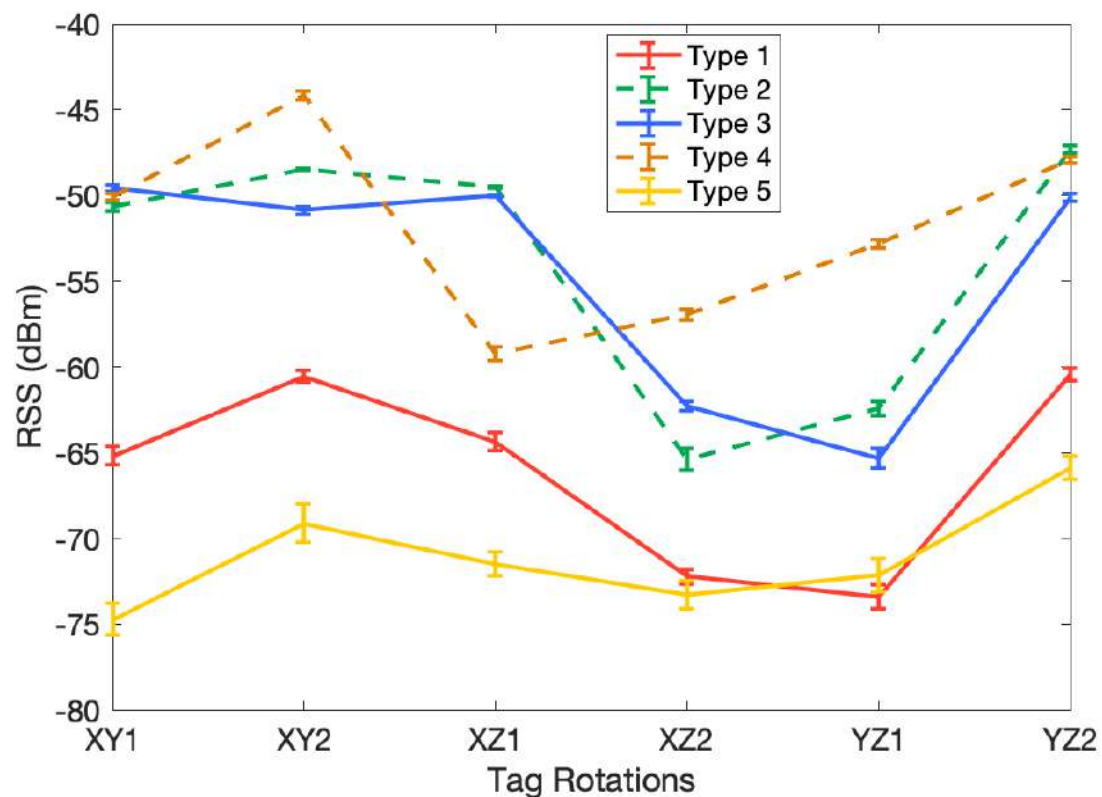


Absolute RSS

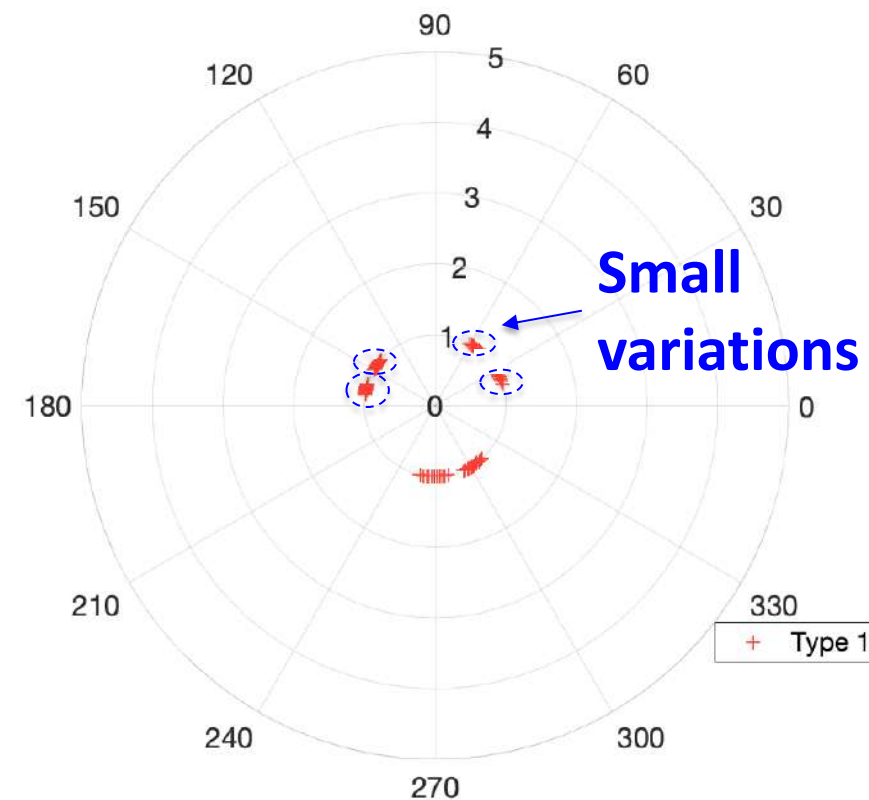


Absolute Phase

Impact of Tag Orientations

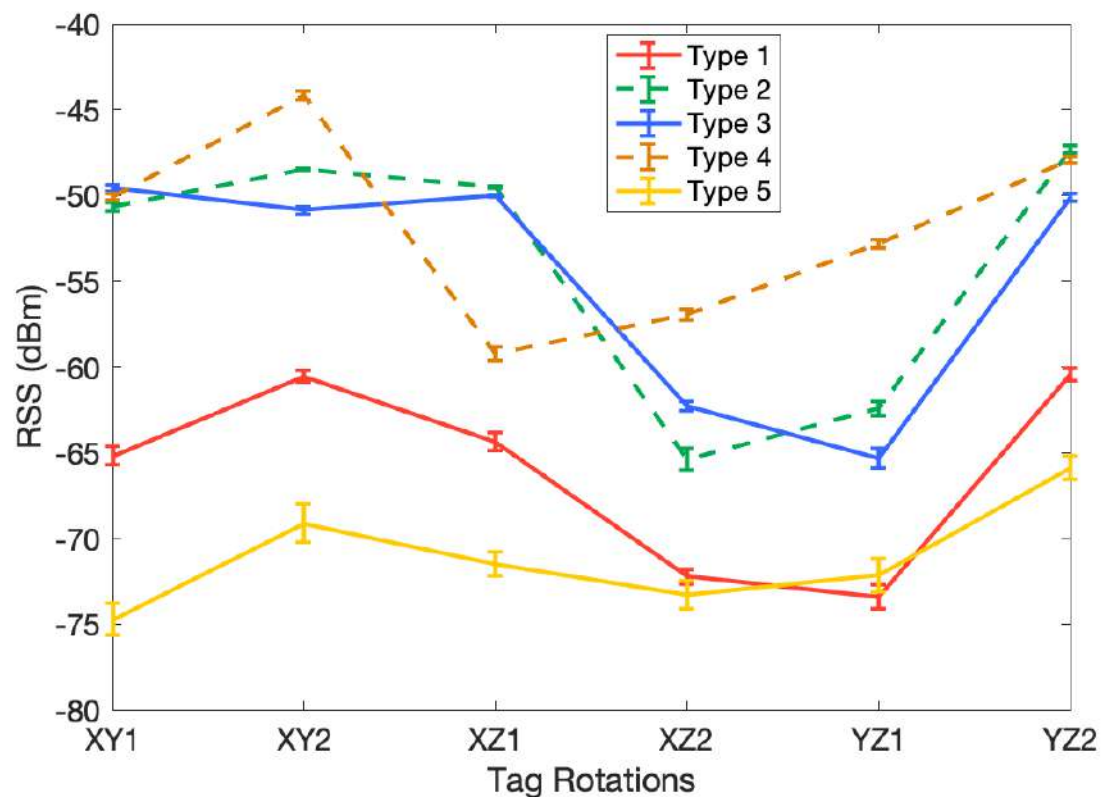


Absolute RSS

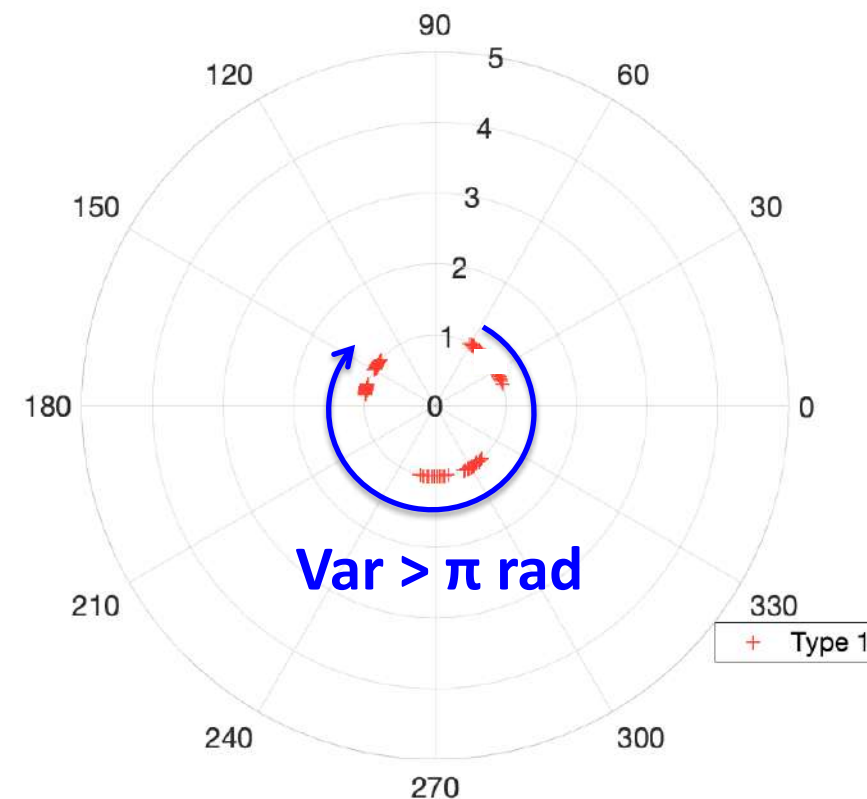


Absolute Phase

Impact of Tag Orientations

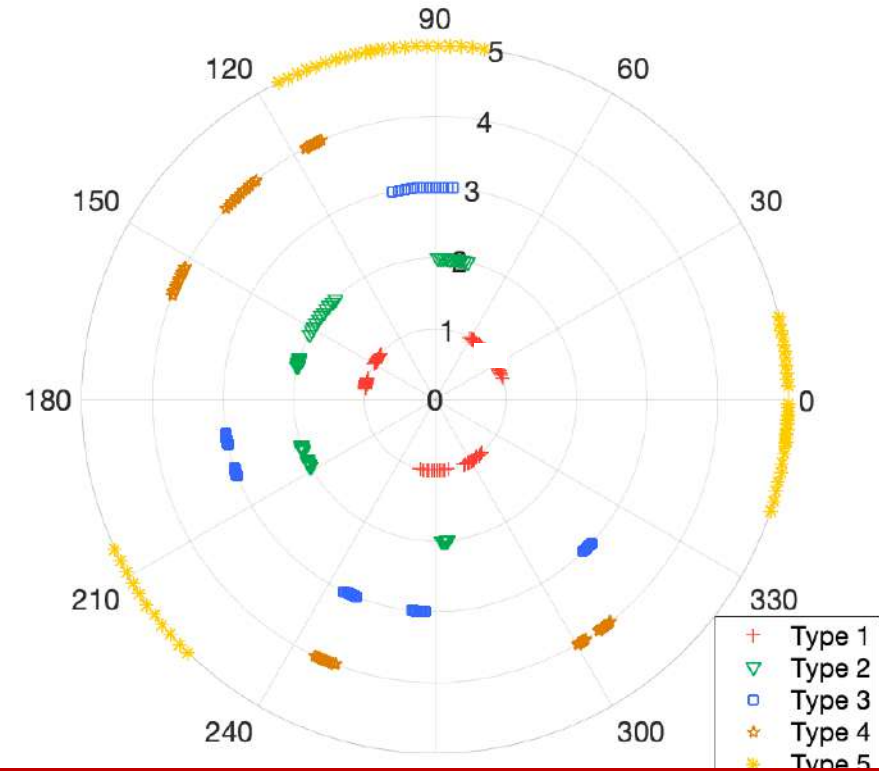
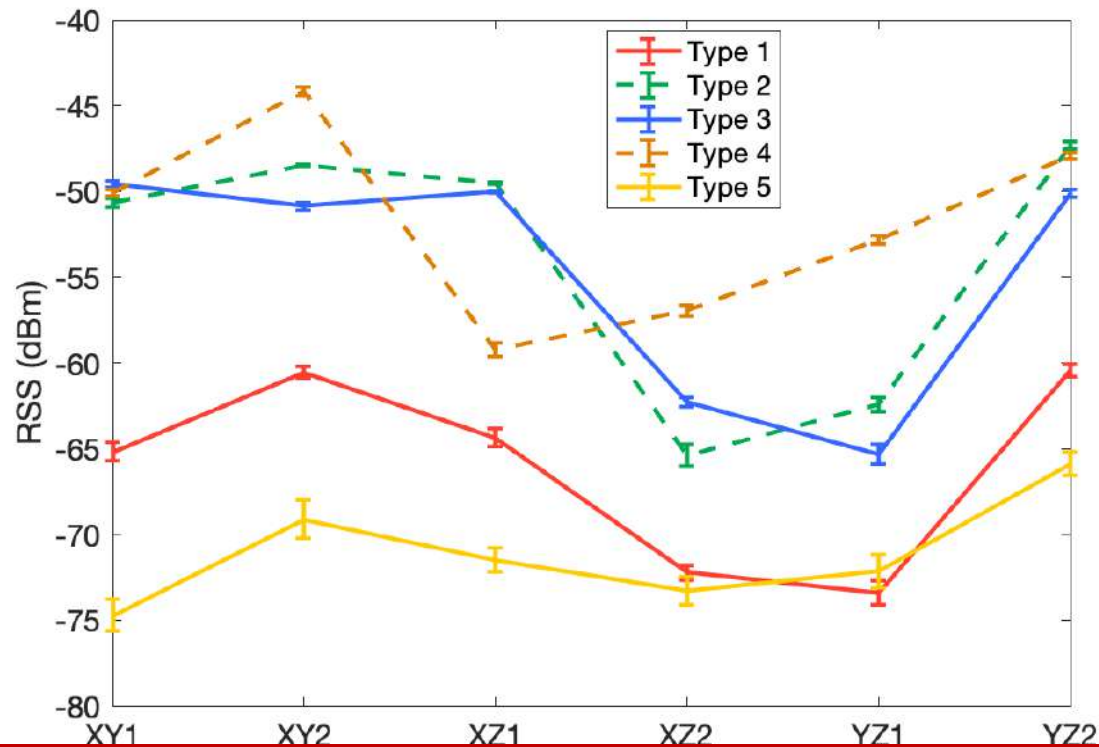


Absolute RSS



Absolute Phase

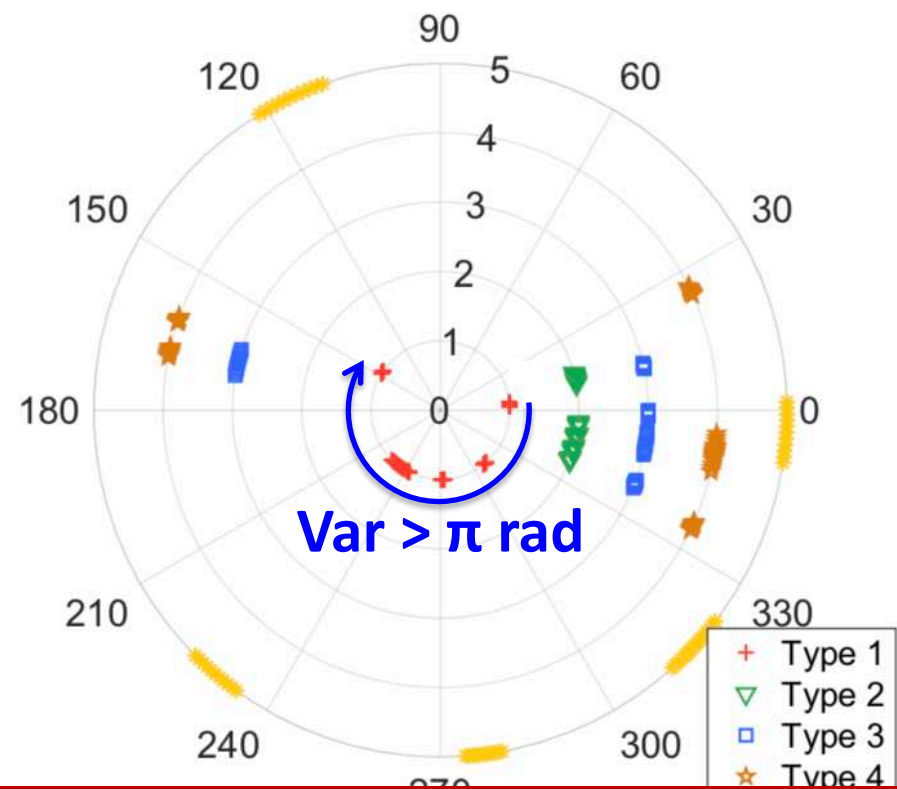
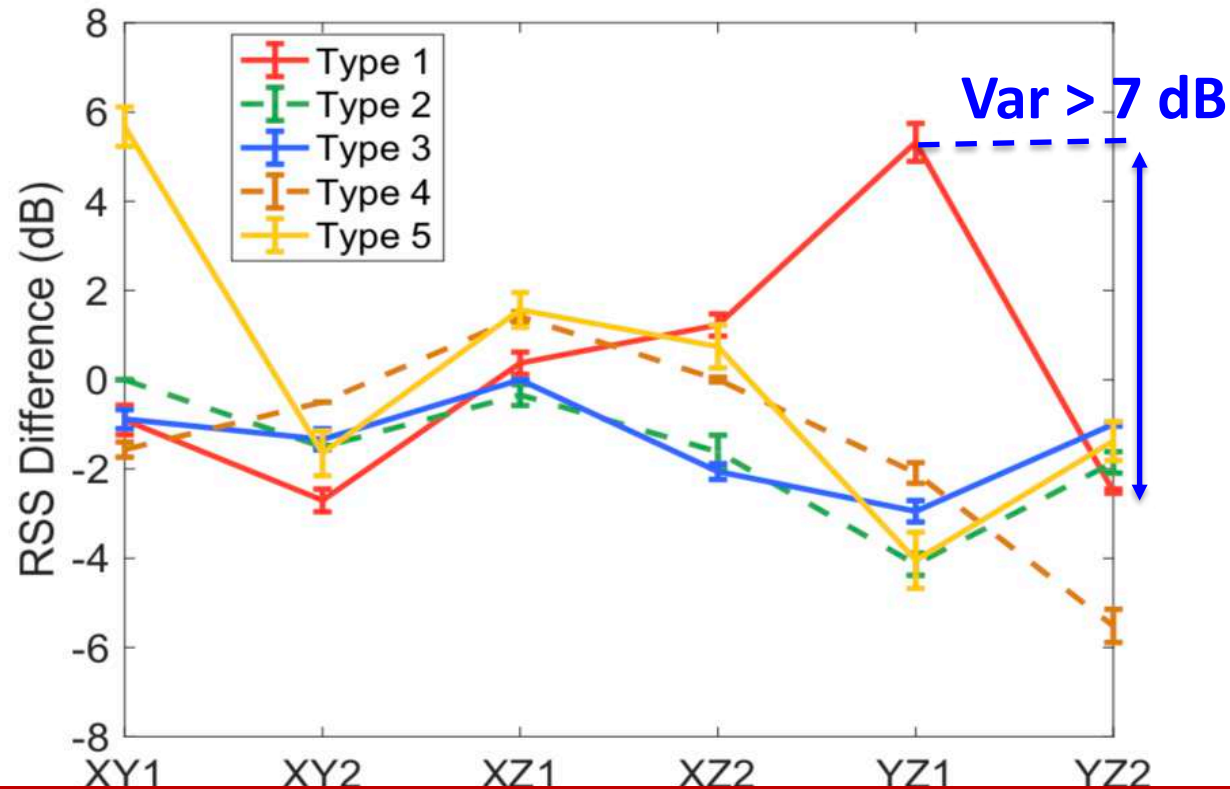
Impact of Tag Orientations



Tag orientation causes significant changes in absolute RSS and phase

Impact of Orientations on Differential RSS/Phase

Impact of Orientations on Differential RSS/Phase



Tag orientation causes significant changes in differential RSS and phase

Impact of Setup Parameters on RSS/Phase



(1) **Orientation** of a tag

(2) **Environment**

(3) **Bending shape** of tag

(4) **Surface material** that a tag is attached to

(5) **Deployment angle** of a tag in the antenna's beam

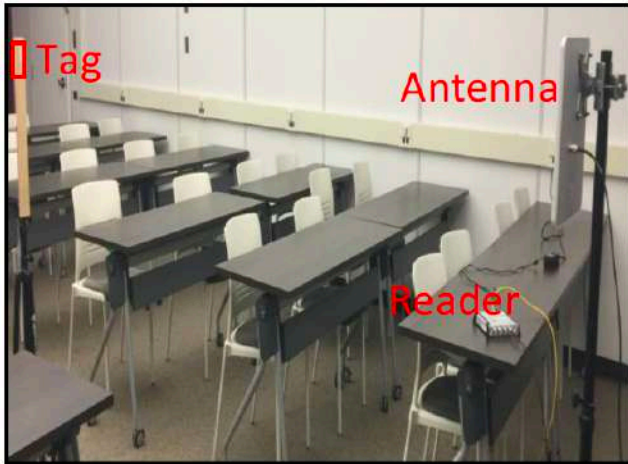
(6) **Deployment height** of a tag above the floor

(7) **Small movements** of tag

Impact of Setup Parameters on RSS/Phase

✗ (1) Orientation of a tag

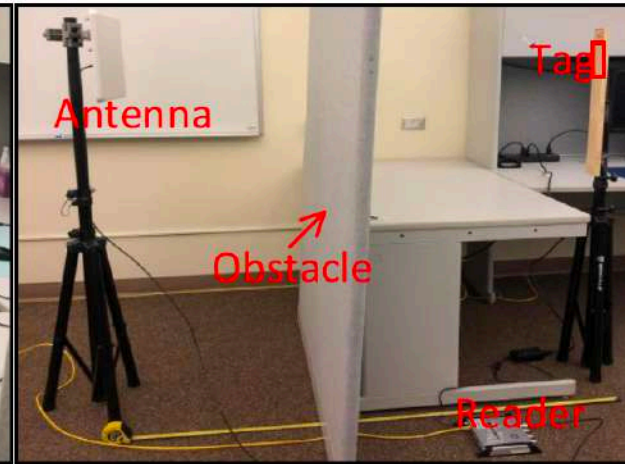
(2) Environment



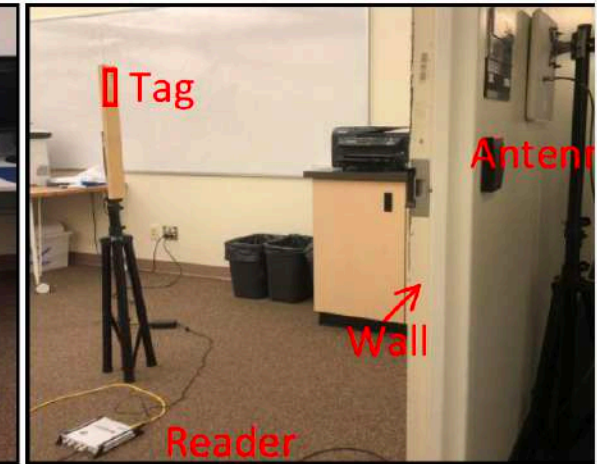
1. Classroom scene



2. Office scene



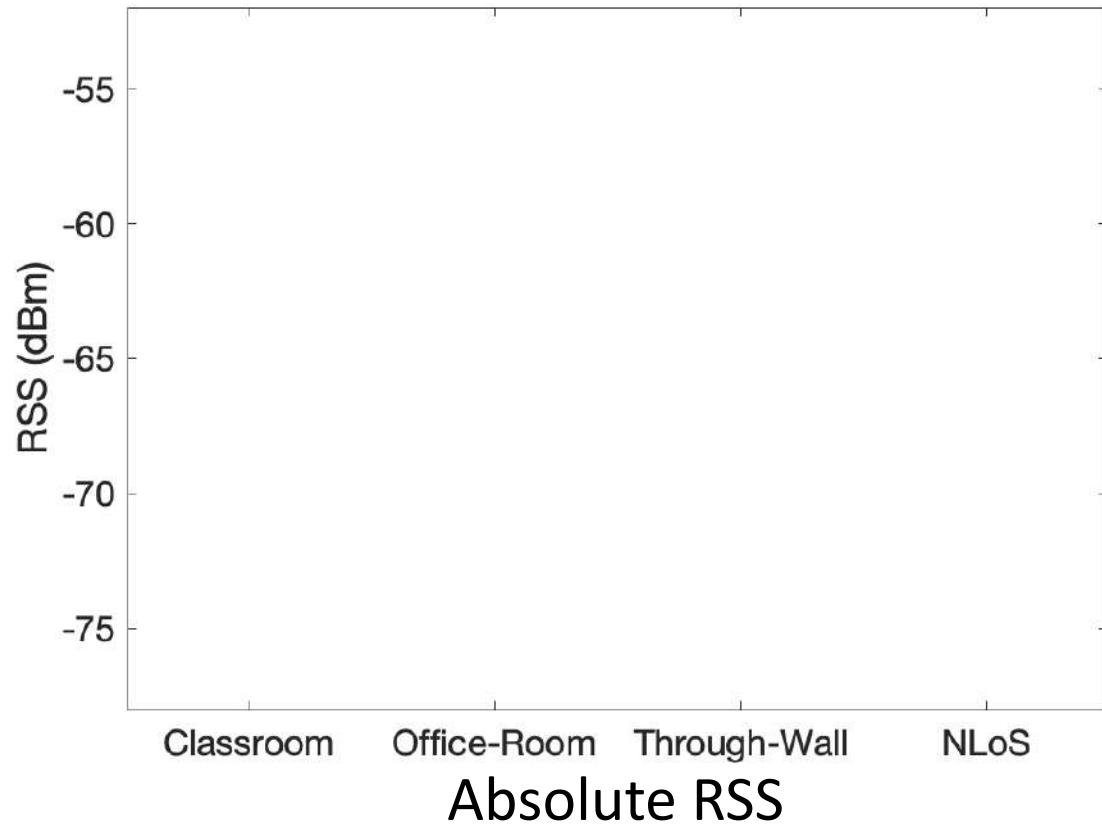
3. Non-line-of-sight
(NLoS) scene



4. Through-wall scene

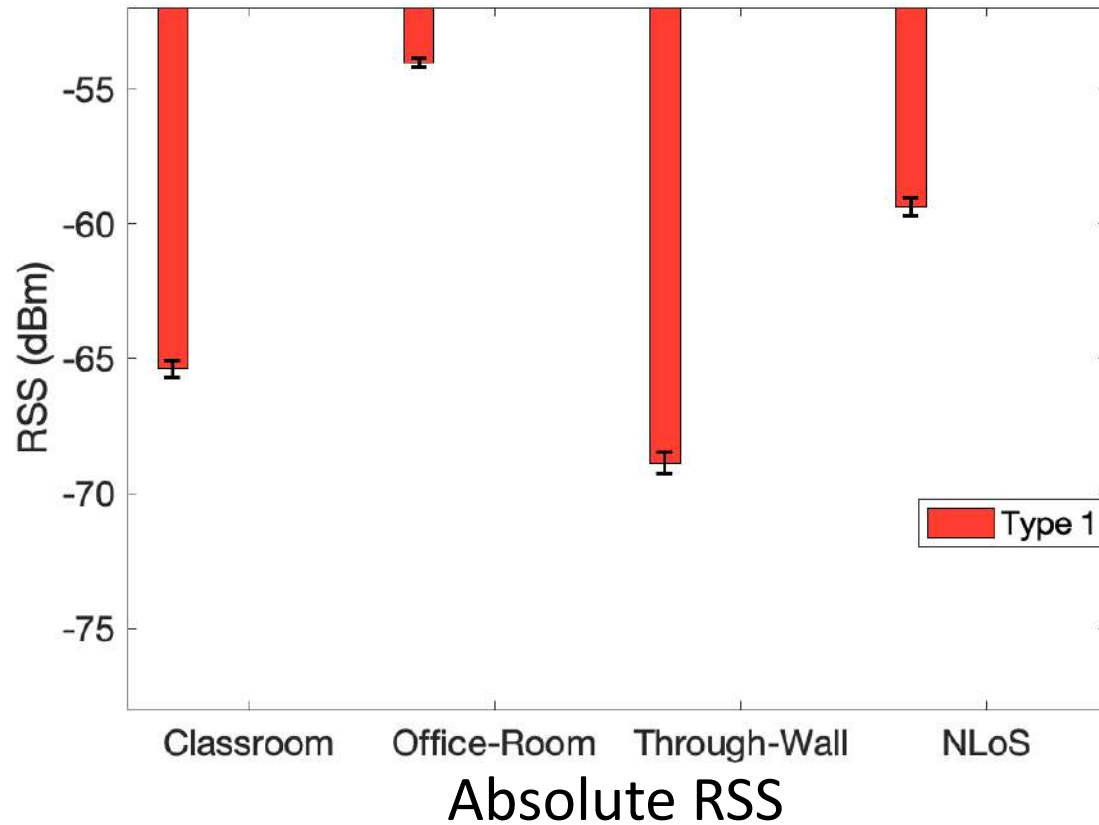
Impact of Environment

Variations of phase/RSS of a SAME setup in four environments:



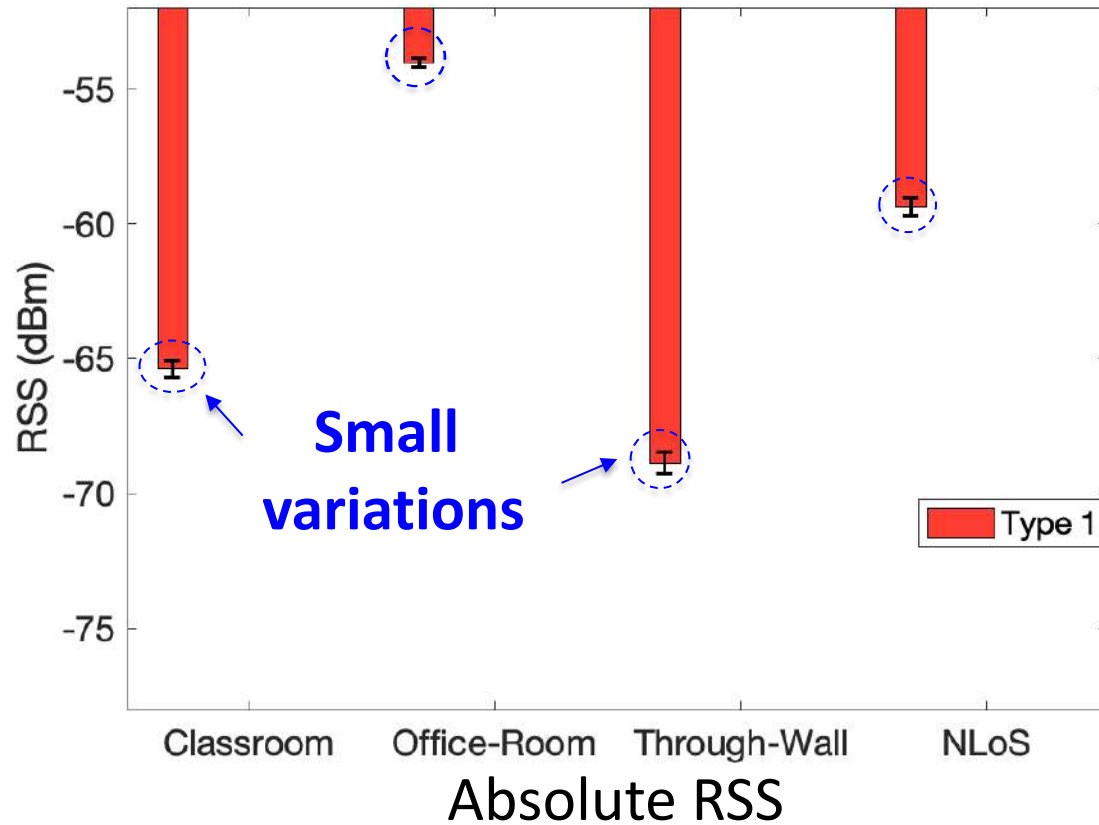
Impact of Environment

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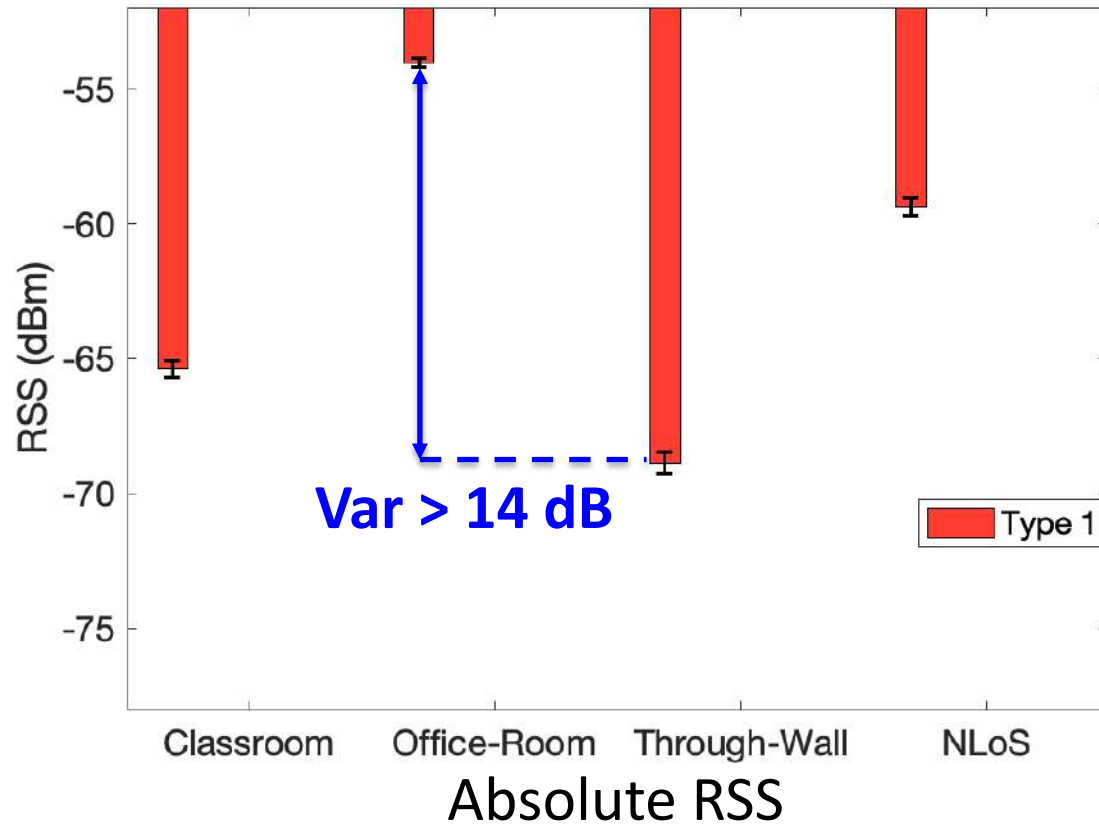
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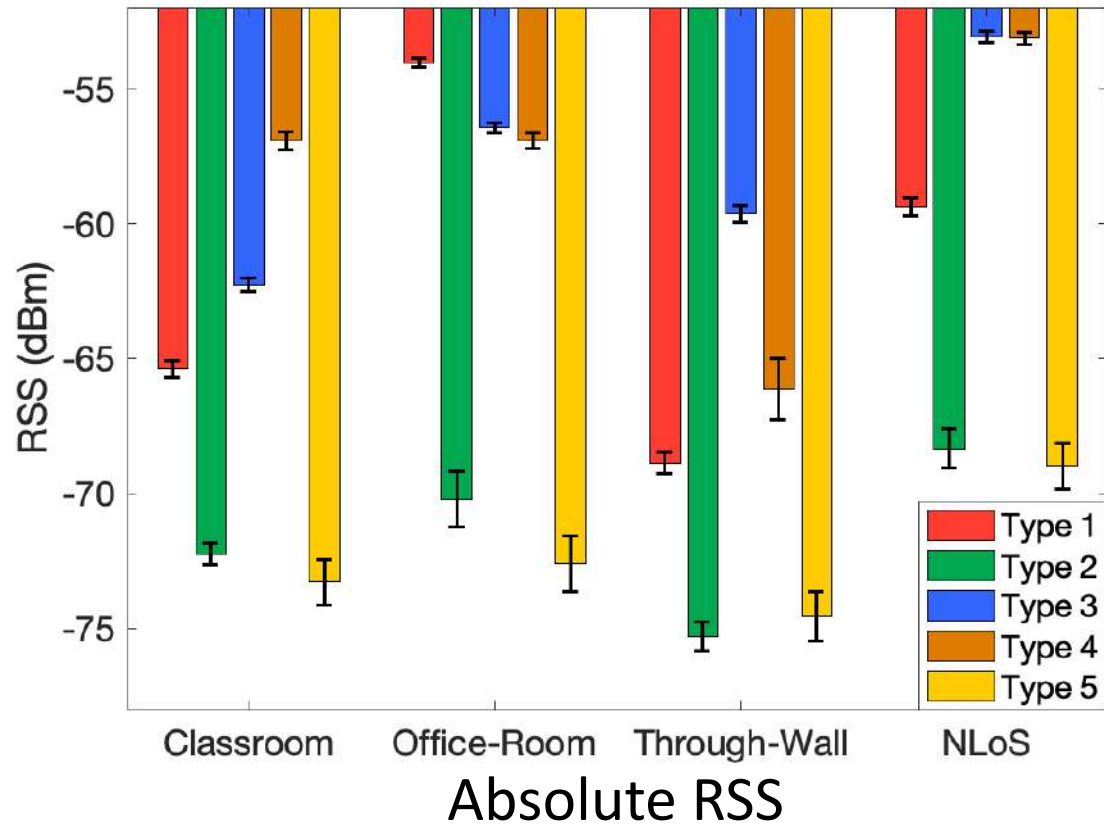
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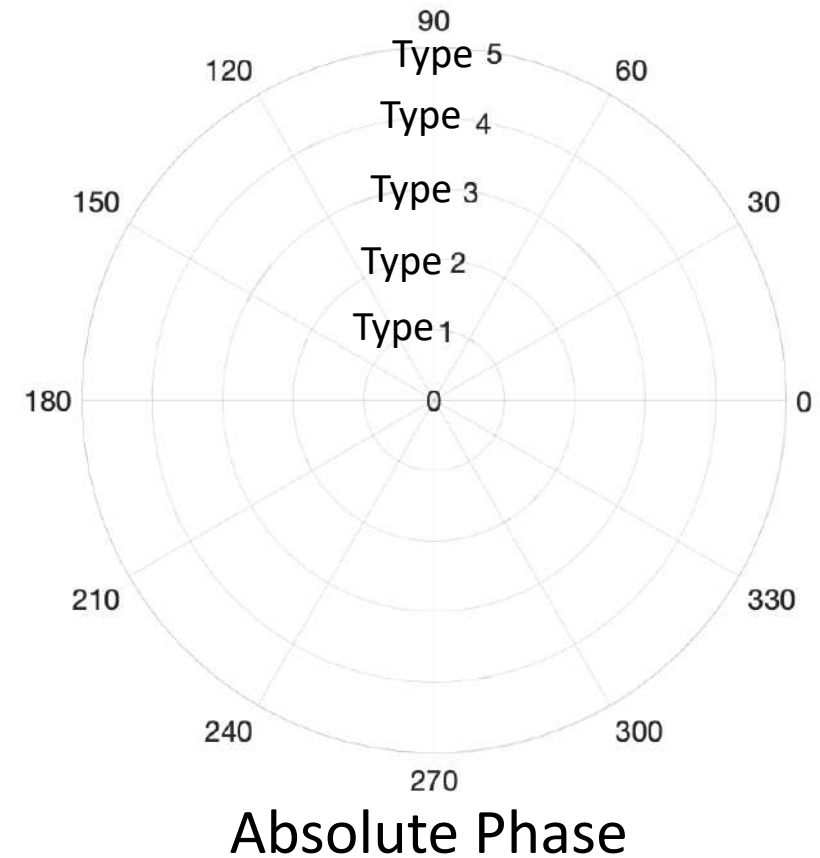
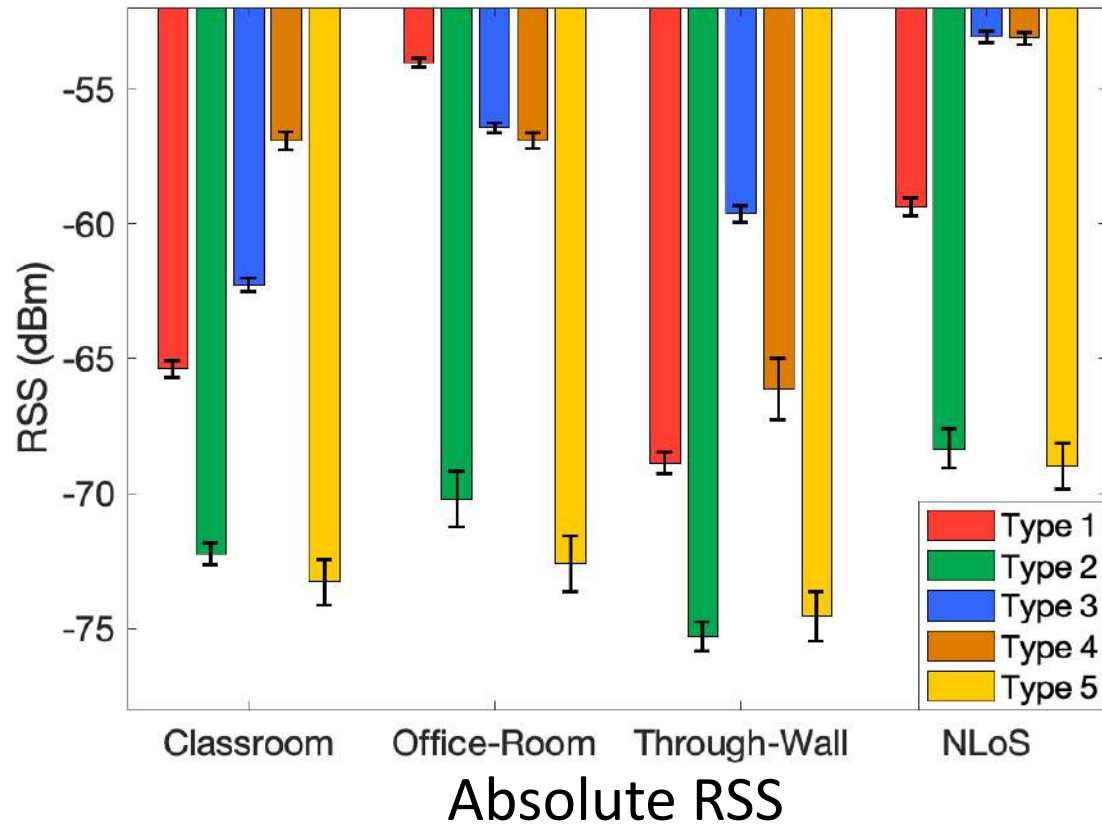
Impact of Environment

Variations of phase/RSS of a SAME setup in four environments:



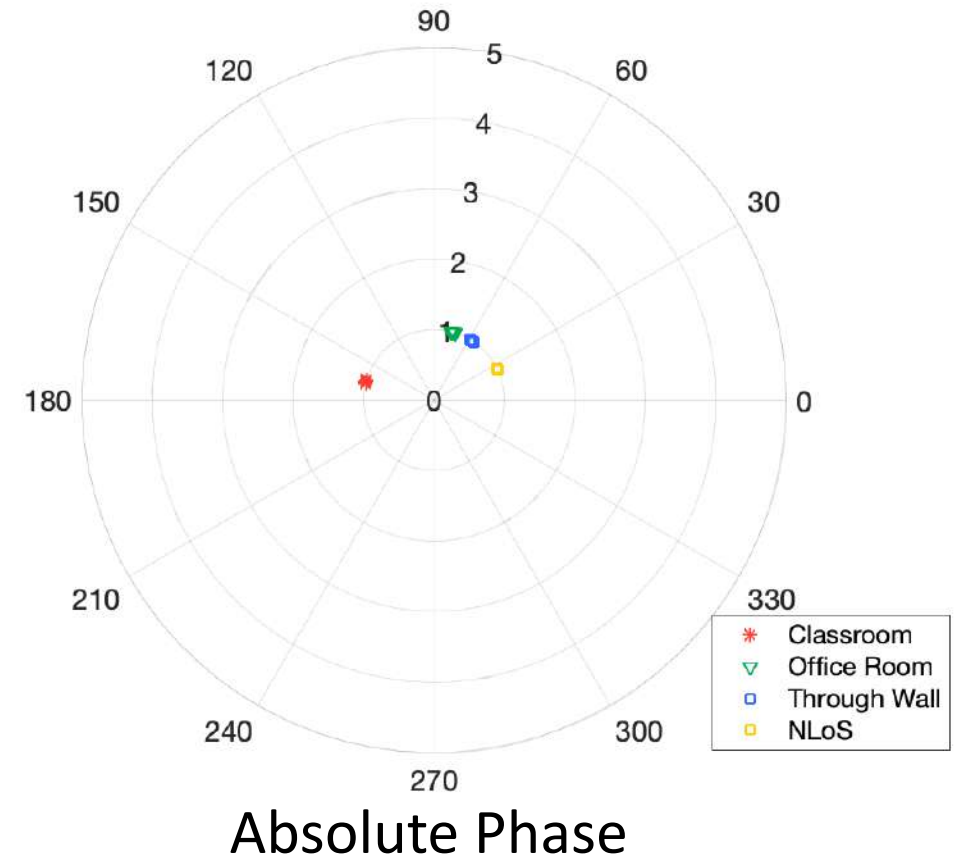
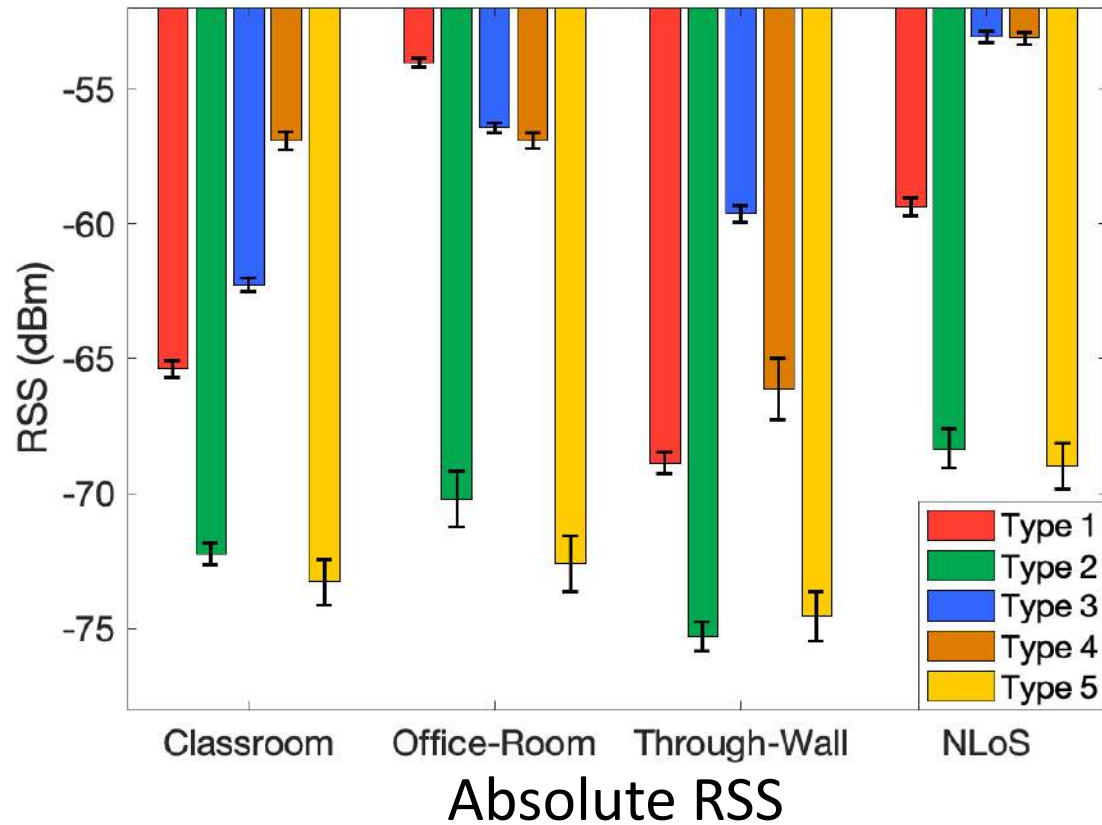
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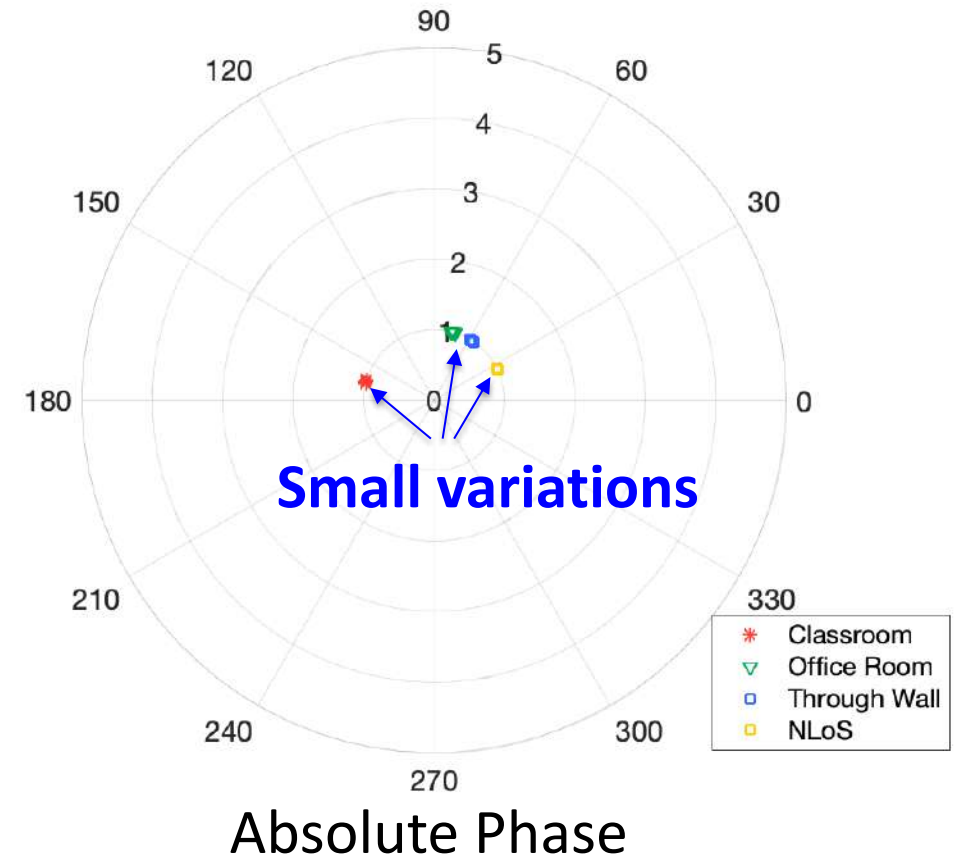
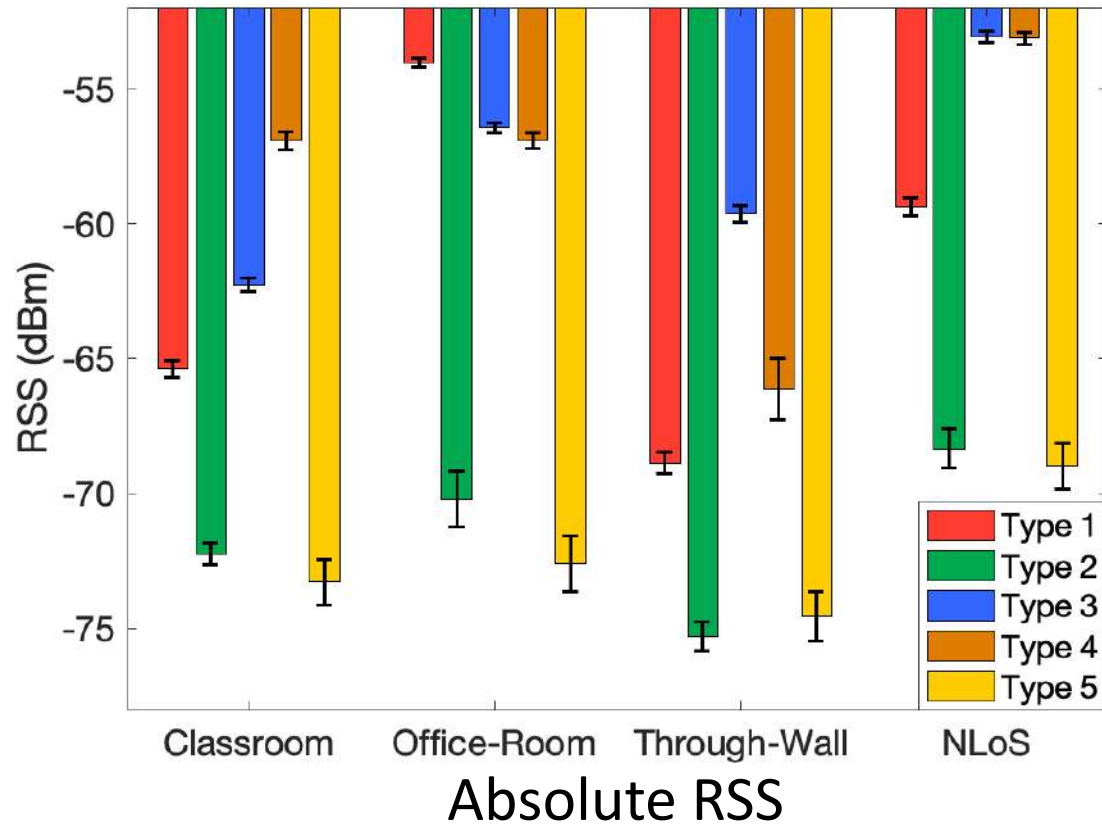
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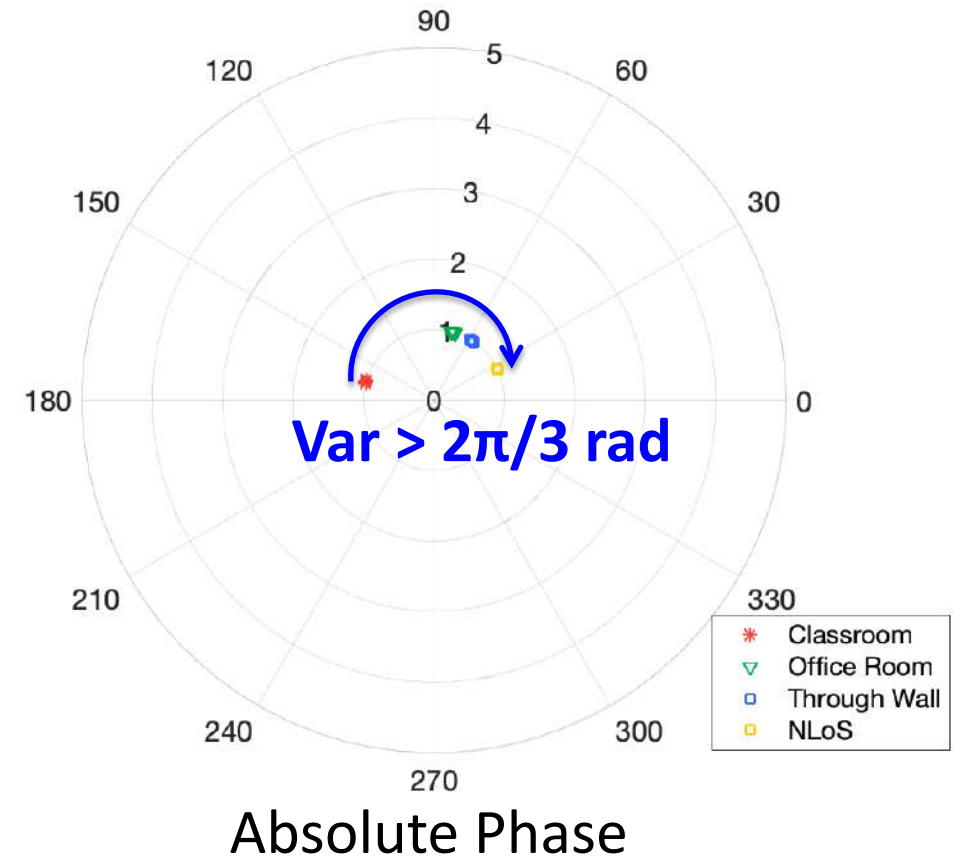
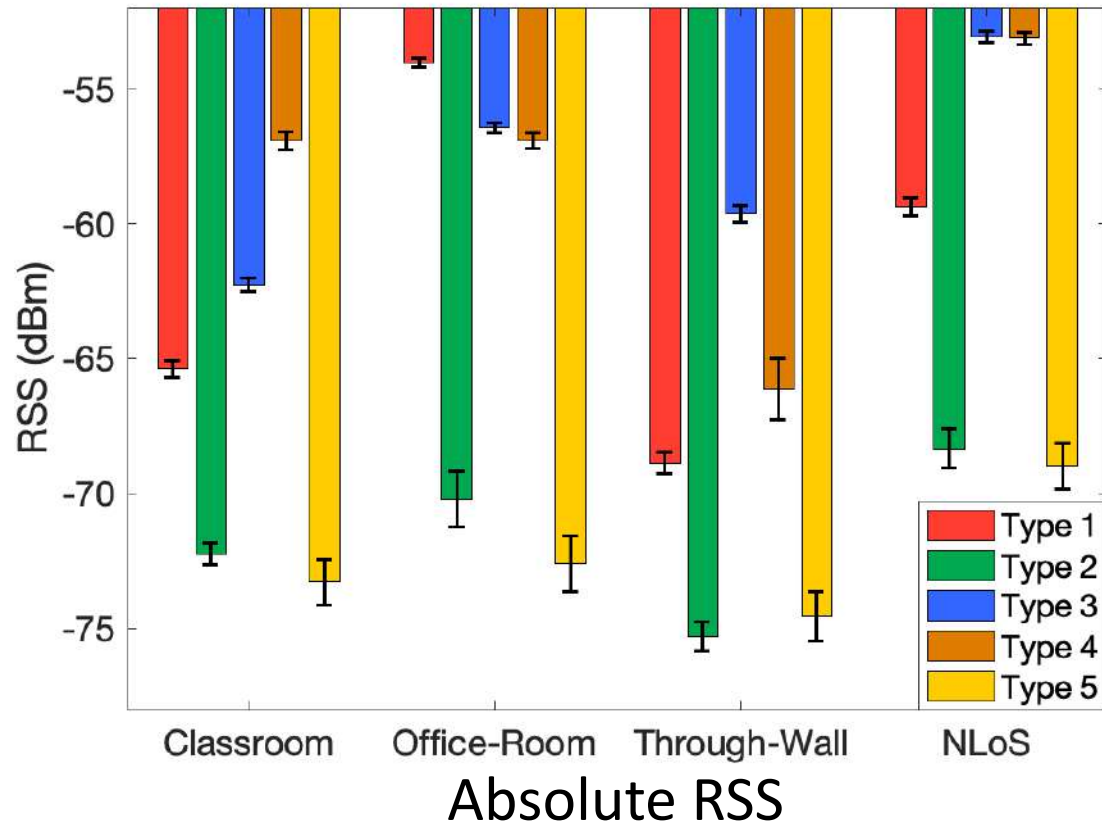
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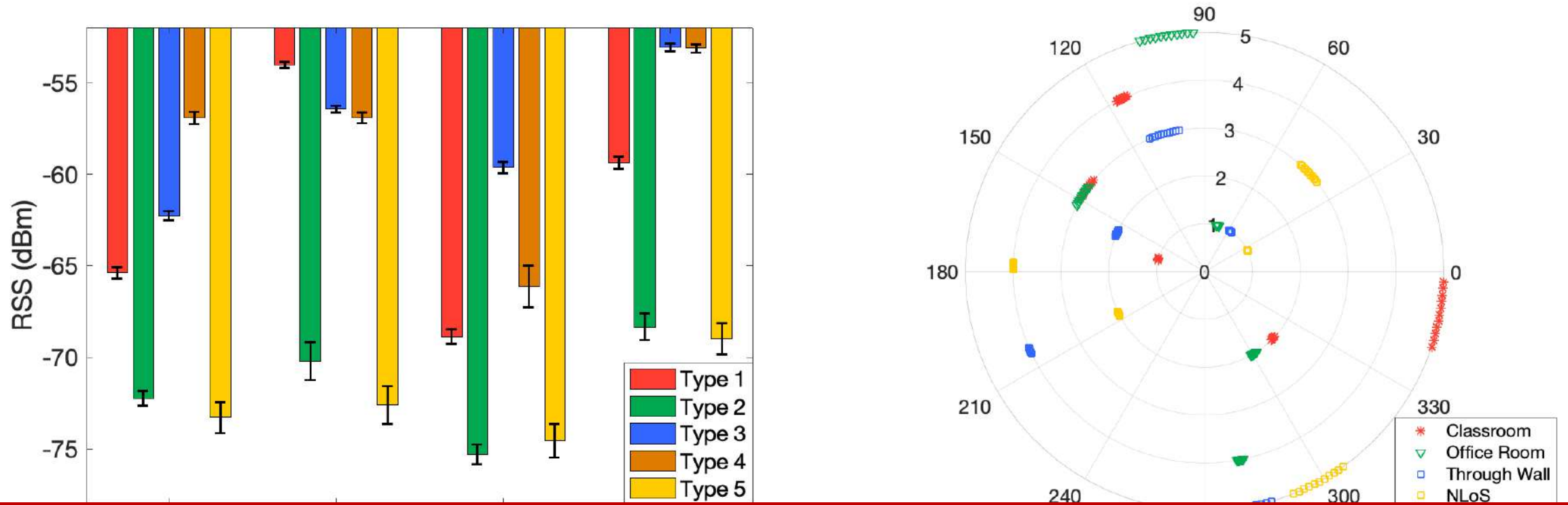
Impact of Environment

Variations of phase/RSS of a SAME setup in four environments:



Impact of Environment

Variations of phase/RSS of a SAME setup in four environments:



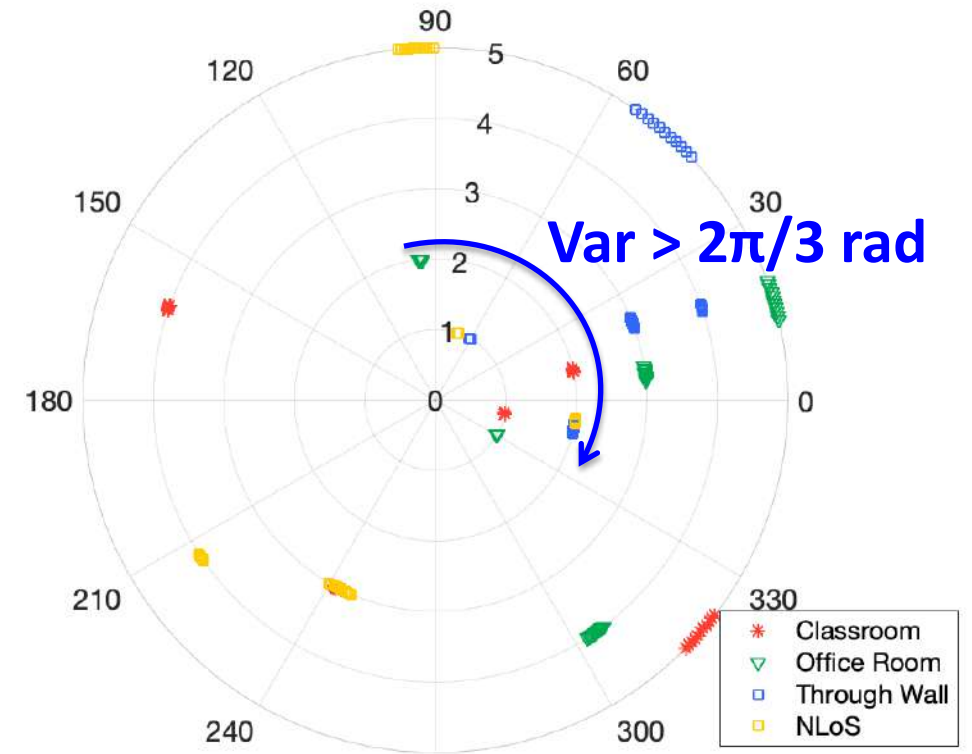
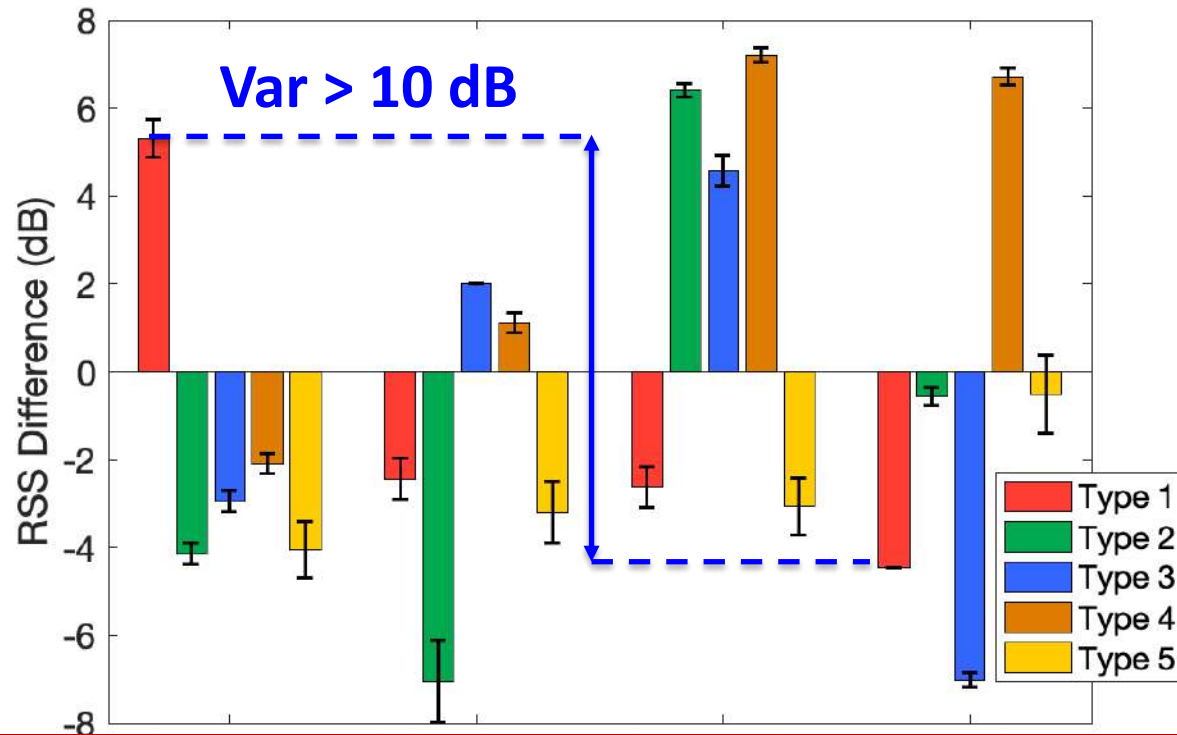
Environment changes cause significant variations in absolute RSS and phase

Impact of Environment

Variations of *differential* phase/RSS of a SAME setup in four environments:

Impact of Environment

Variations of *differential* phase/RSS of a SAME setup in four environments:



Environment changes cause significant variations in differential RSS and phase

Impact of Setup Parameters on RSS/Phase



(1) **Orientation** of a tag



(2) **Environment**

(3) **Bending shape** of tag

(4) **Surface material** that a tag is attached to

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Impact of Setup Parameters on RSS/Phase

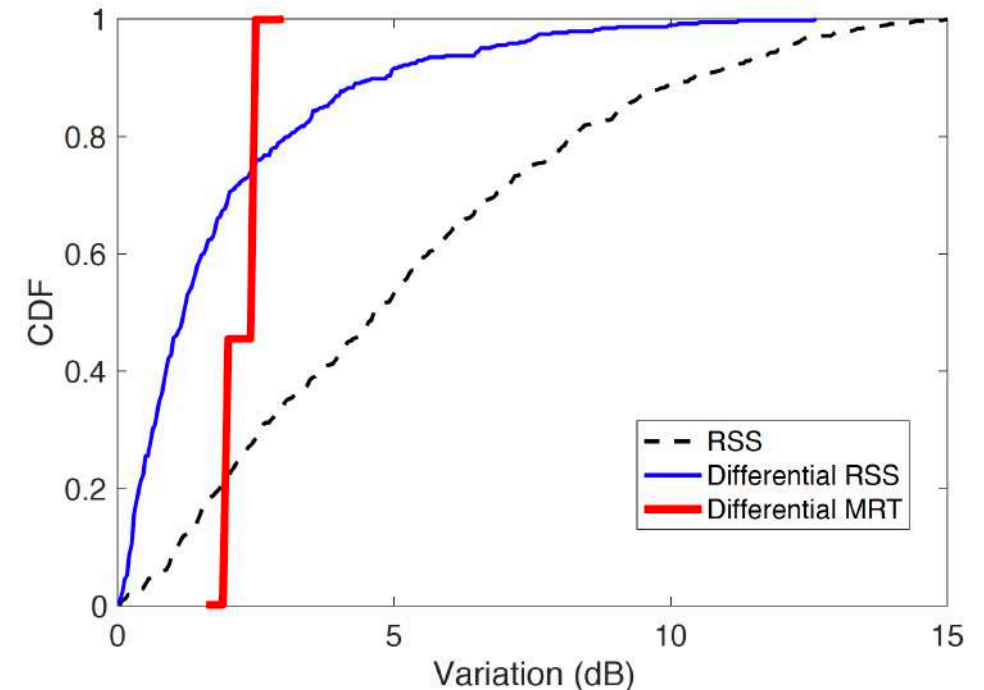
- ✗ (1) **Orientation** of a tag
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Insights into designing robust RFID systems

Insight 1: Choosing Appropriate Signal Parameters

For example,

- A new feature “Differential Minimum Response Threshold (MRT)” [1], which is more robust than RSS and Differential RSS, for temperature sensing, light sensing, etc.



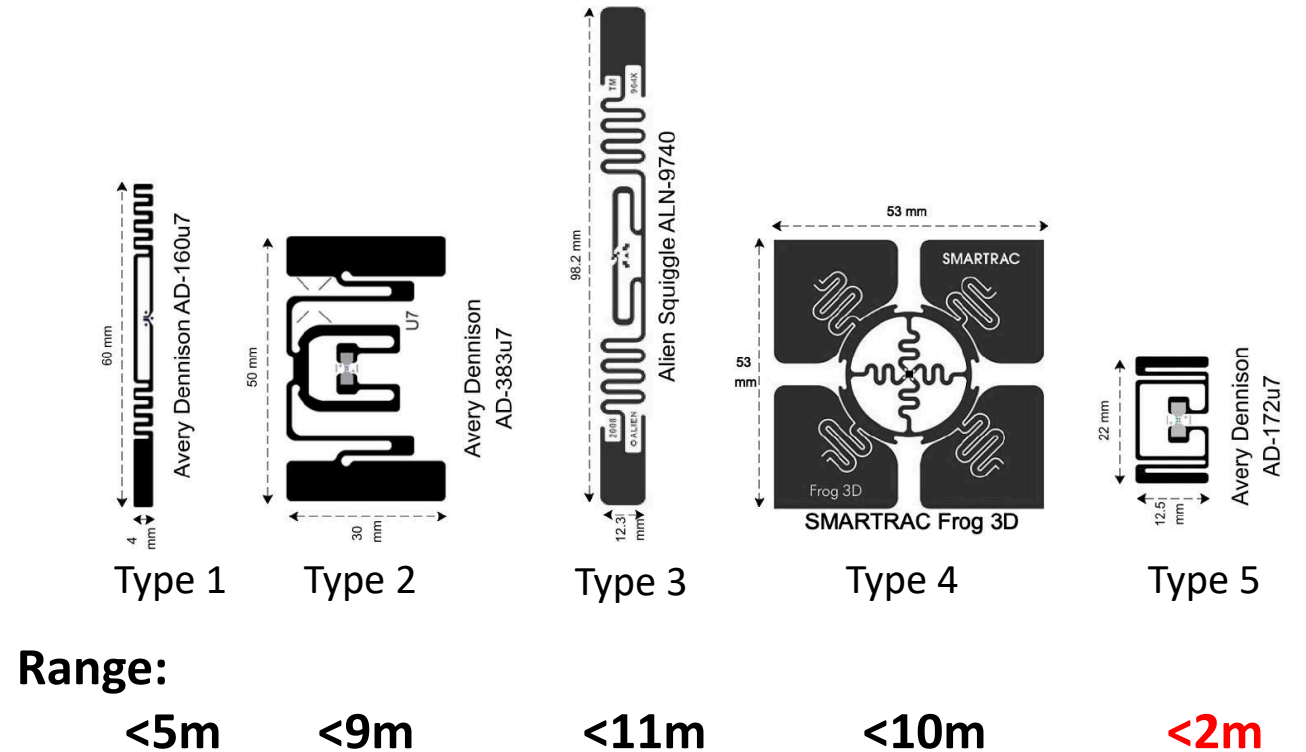
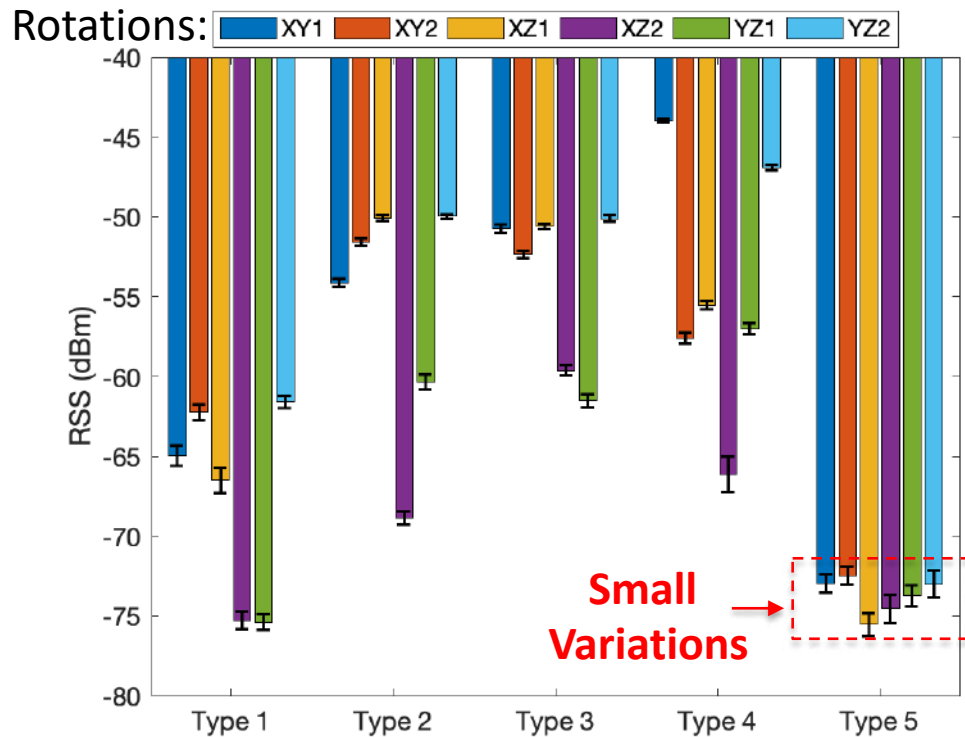
Comparison of RSS, Differential RSS and Differential MRT *in a dynamic environment*.

[1] Ju Wang, Omid Abari, and Srinivasan Keshav. Challenge: RFID Hacking for Fun and Profit. In Proc. ACM MobiCom. 2018.

Insight 2: Choosing Appropriate Tag Types

For example:

- Trade-off between the robustness and working distance



Conclusion

1. High accuracy reported by past studies is repeatable, but *only* when the tag geometry and RF environment are tightly controlled.
2. We should start thinking about how to develop **Robust** RFID-based sensing systems, instead of improving their accuracy.