Are RFID Sensing Systems Ready for the Real World?

Ju Wang, Liqiong Chang, Omid Abari and Srinivasan Keshav





RFIDs



Equipment management



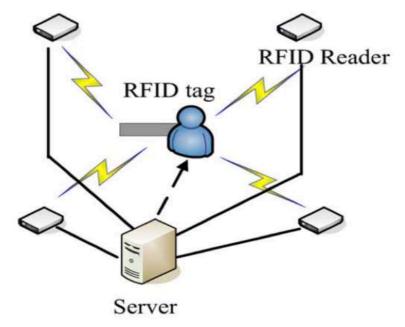
Anti-theft



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

Chong, et al. Localization BackPos Ferret Zhou, et al. Azzouzi, et al. Pinit **SARFID** Wu, et al. Sigcomm'13 TMC'15 TASE'19 ICAR'03 Springer'06 Springer'09 RFID'11 RFID'17 & Tracking 2003 2019 **Years**

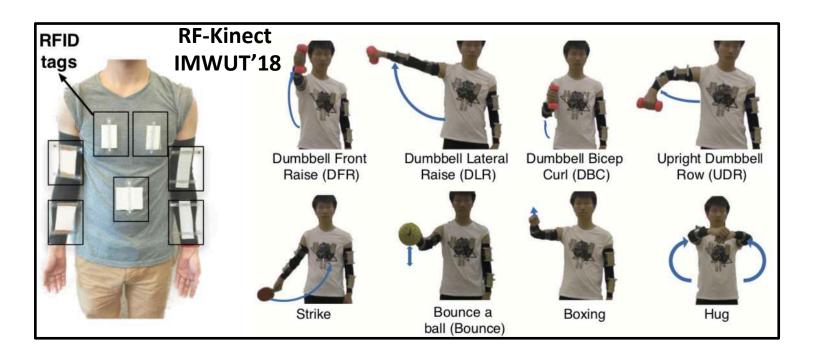




STPP in NSDI'15

Ordering	Choi e INDIN		rack COM'13	ST NSD		Mobit Mobis	O	HMRL SECON'17	HMO TMC'19
Localization & Tracking	Ferret Springer'06	Zhou, e Springe	Azzouzi, et RFID'11		Pini Sigcom		BackPos TMC'15	SARFID RFID'17	Wu, et al. TASE'19

2003



Gesture
Recognition

Ordering

Localization & Tracking

Ma	kela,	et
al.	CHI')7

Buener, et al. Ubicomp'09;

Asadeh, et al. Springer'10

Bouha, et al. PETRA '14

ShopMiner SenSys '15

Pantomime ShopEye Mobisys'17

IUI'19

Choi et al. INDIN'08

OTrack INFOCOM'13

STPP NSDI'15 MobiTagbot Mobisys'16

HMRL HMO SECON'17 TMC'19

Chong, et al. Azzouzi, et al. Pinit BackPos Ferret Zhou, et al. SARFID Wu, et al. ICAR'03 Springer'06 Springer'09 RFID'11 Sigcomm'13 TMC'15 RFID'17 TASE'19

2003



Touch Sensing	Oulu, et Pervasive Com			•	Sample, et al. RFID'09		IDSense CHI'15		ľ	RIO Mobicom'17	TagBreathe TMC'19
Gesture Recognition		lakela, et l. CHI'07	Buener, et al. Ubicomp'09;		deh, et al. ringer'10		a, et al. RA '14	Shop! SenSy	Miner /s '15	Pantomime Mobisys'17	ShopEye IUI'19
Ordering			Choi et al. INDIN'08		Track COM'13	STP NSDI		MobiTa Mobisy	0	HMRL SECON'17	HMO TMC'19
Localization & Tracking	Chong, et al. ICAR'03	. Ferr Springe	,	et al. ger'09	Azzouzi, e RFID'1		Pini Sigcom		BackPos TMC'15		Wu, et al. TASE'19

Years

Orientation Sensing

Touch Sensing

Gesture Recognition

Ordering

Localization & Tracking

Hinske, et al. Percom'07

Shire, et al. TIM'12 Gupta, et al. Antenna'14

Years

PolarDraw CoNext'16 Tagyro Mobicom'16 Occhi, et al. Jia IEEE'18 Se

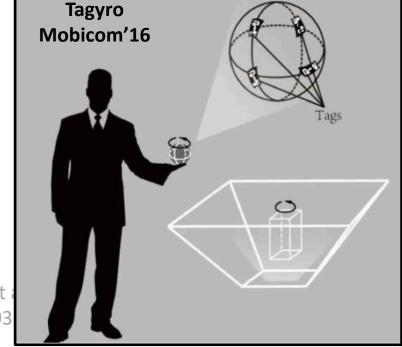
Jiang, et al. Sensors'19

TagBreathe TMC'19

ShopEye IUI'19

HMO TMC'19

Wu, et al. TASE'19



Chong, et a ICAR'03

2003

2019



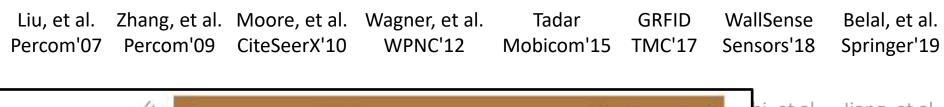
Orientation Sensing

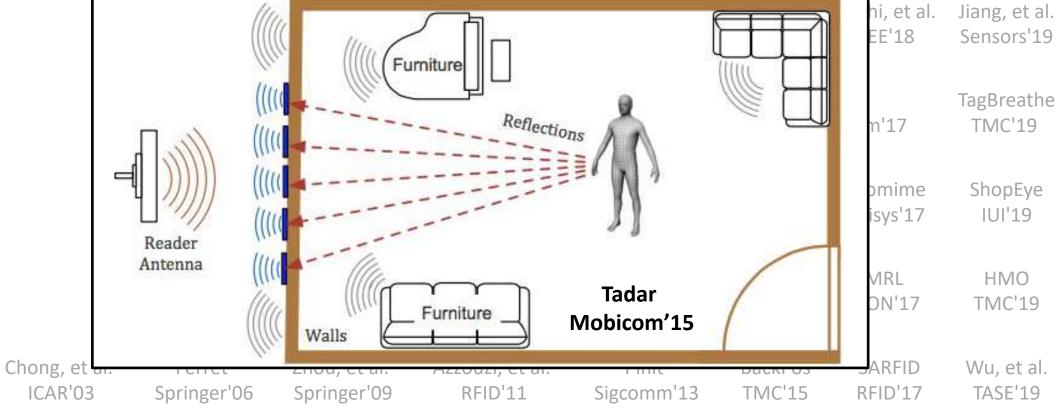
Touch Sensing

Gesture Recognition

Ordering

Localization & Tracking

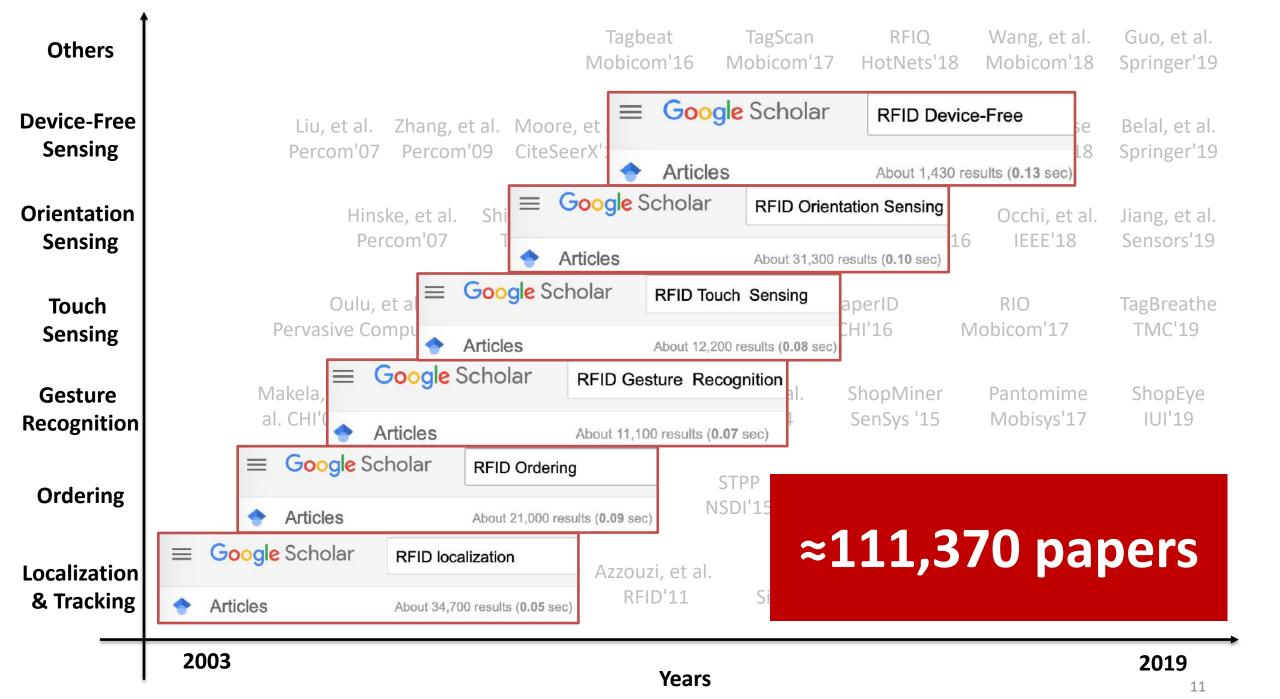




2003

Others			Tagbeat Mobicom'	•	RFIQ 7 HotNets'18	Wang, et al. Mobicom'18	Guo, et al. Springer'19		
Device-Free Sensing	Liu, et Percom	O,	· · · · · · · · · · · · · · · · · · ·	6 - /	adar GRFID icom'15 TMC'17		Belal, et al. Springer'19		
Orientation Sensing	I	· ·	ire, et al. Gupta, 6 「IM'12 Antenn		- 07	Occhi, et al. IEEE'18	Jiang, et al. Sensors'19		
Touch Sensing		llu, et al. Computing'06	Sample, et al. RFID'09	IDSense CHI'15	PaperID CHI'16 M	RIO 1obicom'17	TagBreathe TMC'19		
Gesture Recognition	Makela, et al. CHI'07	Buener, et al. Ubicomp'09;	Asadeh, et al. Springer'10	Bouha, et al. PETRA '14	ShopMiner SenSys '15	Pantomime Mobisys'17	ShopEye IUI'19		
Ordering		Choi et al. INDIN'08	OTrack INFOCOM'13	STPP NSDI'15	MobiTagbot Mobisys'16	HMRL SECON'17	HMO TMC'19		
Localization & Tracking	O,	erret Zhou, nger'06 Spring	· · · · · · · · · · · · · · · · · · ·				Wu, et al. TASE'19		
	2003	2003 Veers							

Years



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

We hypothesize:

RFID-based sensing is *not robust* to variations

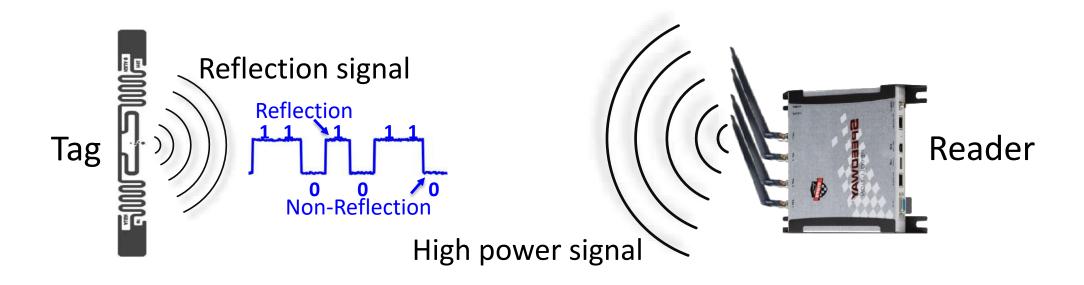
in the RF environment or tag geometry

In this talk:

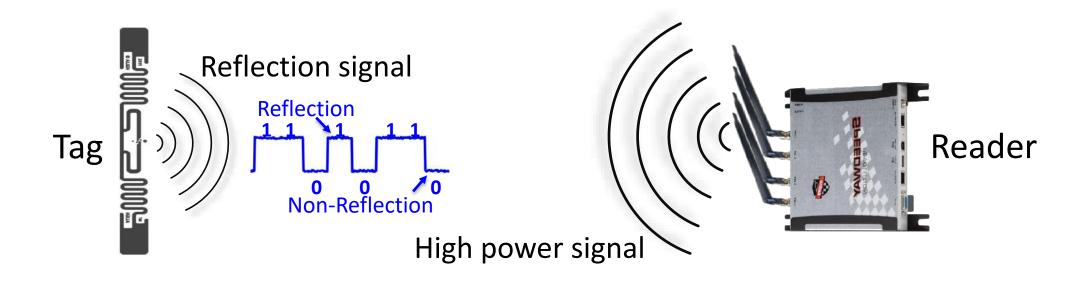
I will validate our research hypothesis,

provide insights into designing robust RFID systems

How RFID works

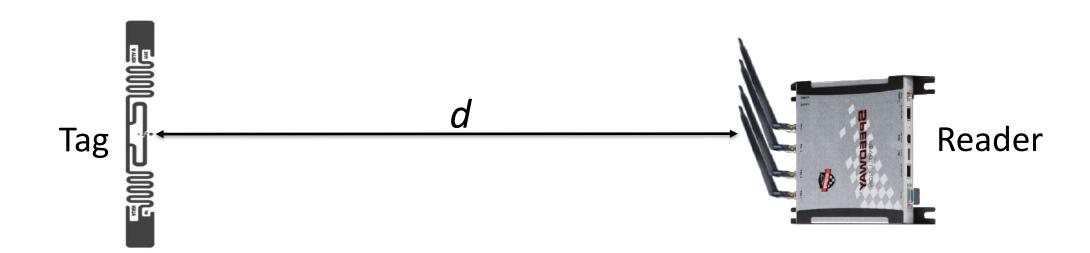


How RFID works



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:

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

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):

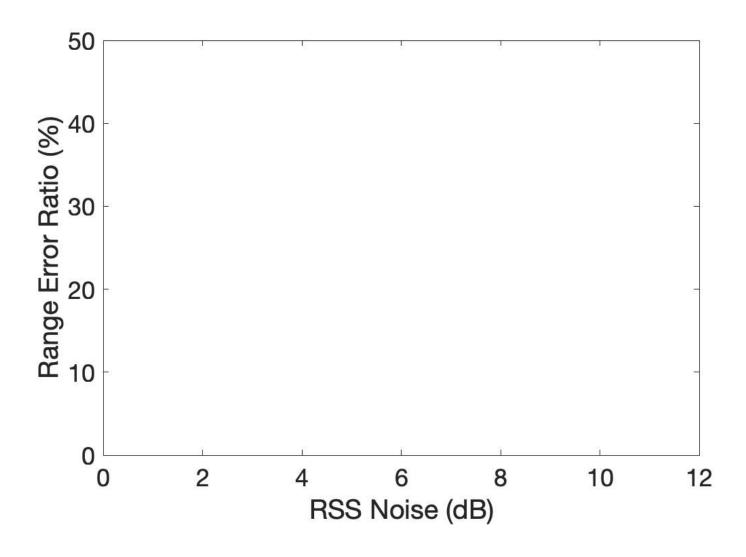
$$R(dB) = 10 \log \left[\frac{C}{d^4} P_{tx} \lambda^4 \right]$$

Phase:

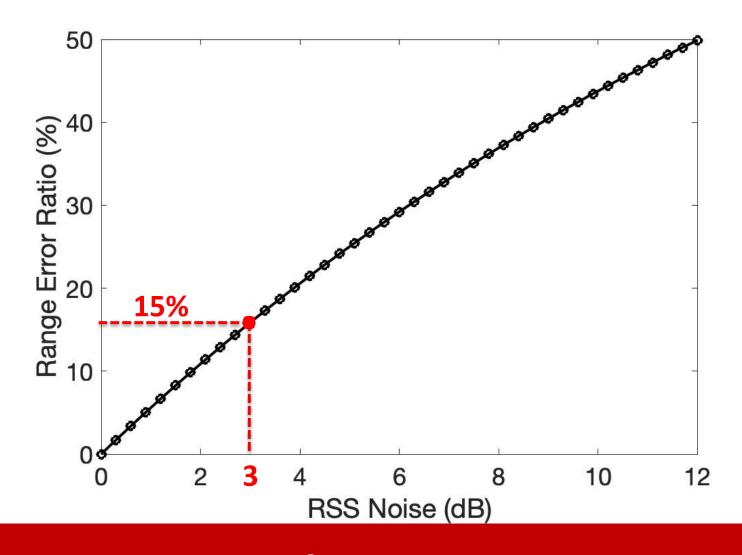
$$\emptyset = \left(\frac{4\pi}{\lambda} \frac{d}{d} + C\right) \bmod 2\pi$$

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

Impact of RSS Noise on Range Estimation

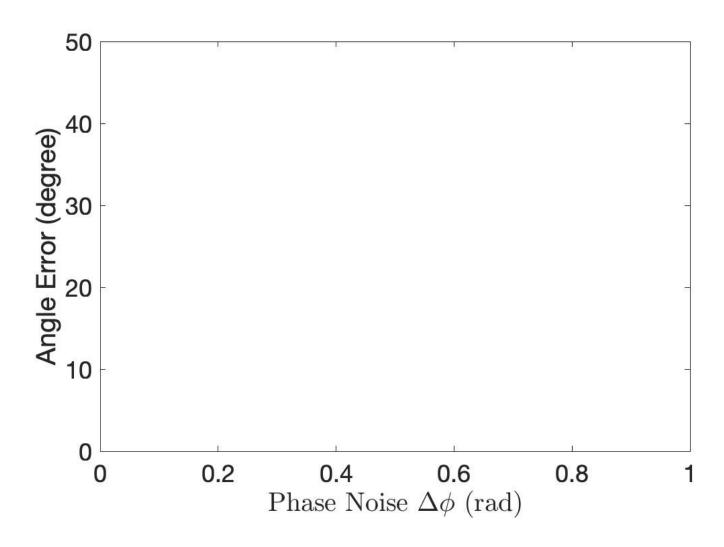


Impact of RSS Noise on Range Estimation

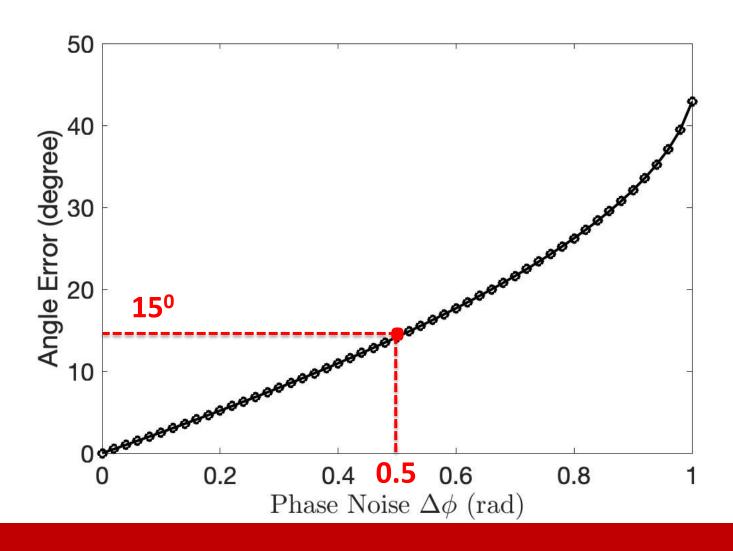


3 dB RSS noise results up to 1.5 m range error₂₀

Impact of Phase Noise on Angle Estimation



Impact of Phase Noise on Angle Estimation



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

How robust are RSS and phase in reality?

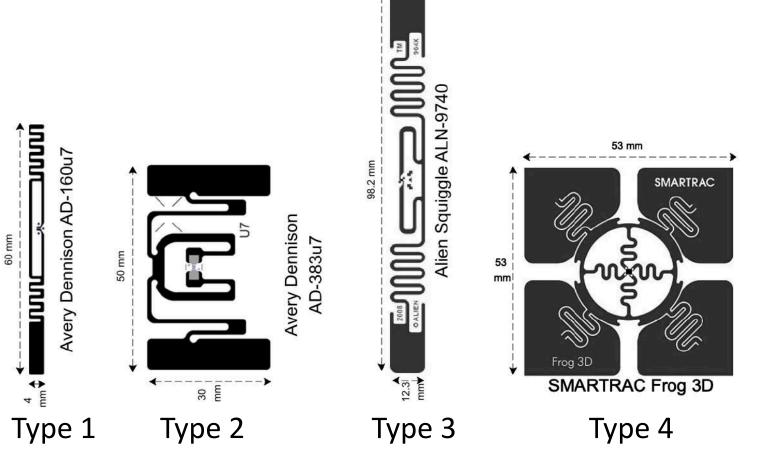
Experimental Setup



An Impinj R420 reader



Two reader antennas



Five types of widely used RFID tags

Type 5

Avery Dennison

AD-172u7

Raw data and test software are openly available:

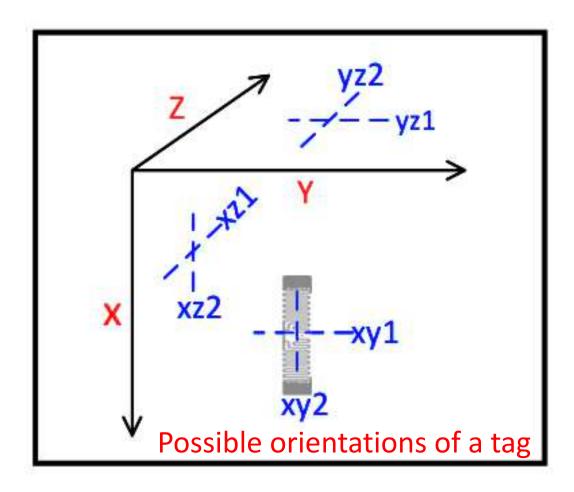
https://www.dropbox.com/s/z34h0lk7bc8x0p0/Raw-data-and-Software-code.zip?dl=0

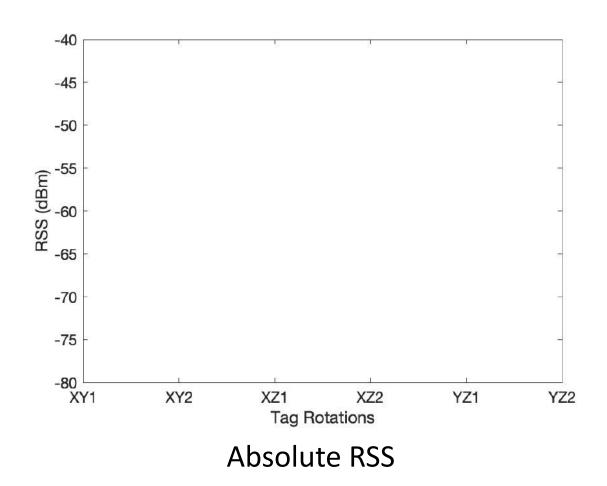
Impact of Setup Parameters on RSS/Phase

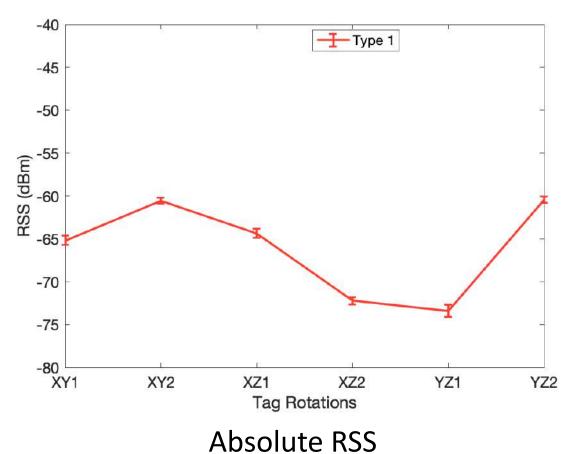
- (1) **Orientation** of a tag
- (2) Environment
- (3) **Bending shape** of tag
- (4) Surface material that a tag is attached to
- (5) **Deployment angle** of a tag in the antenna's beam
- (6) **Deployment height** of a tag above the floor
- (7) Small movements of tag

Impact of Setup Parameters on RSS/Phase

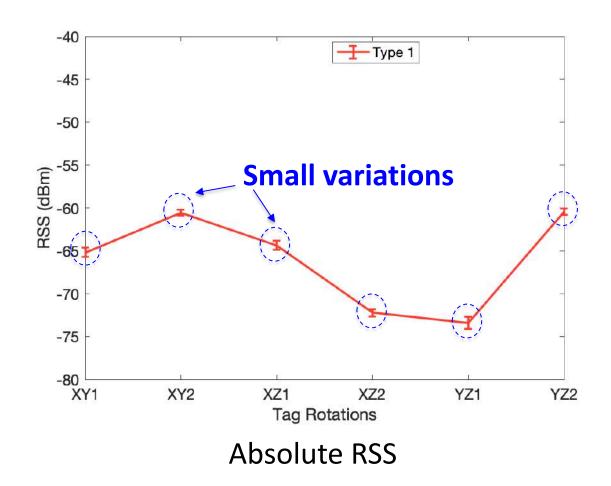
(1) **Orientation** of a tag

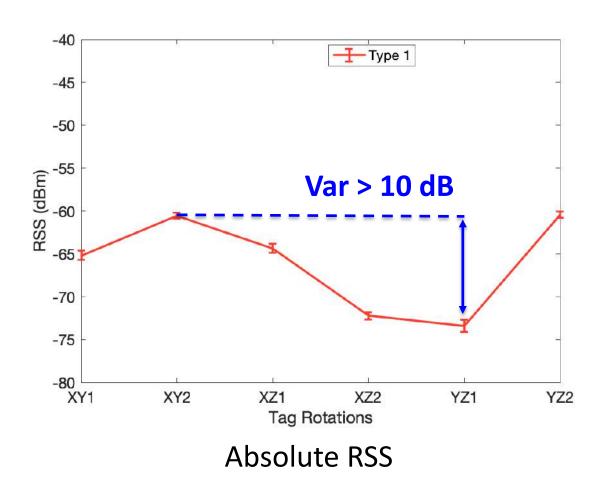


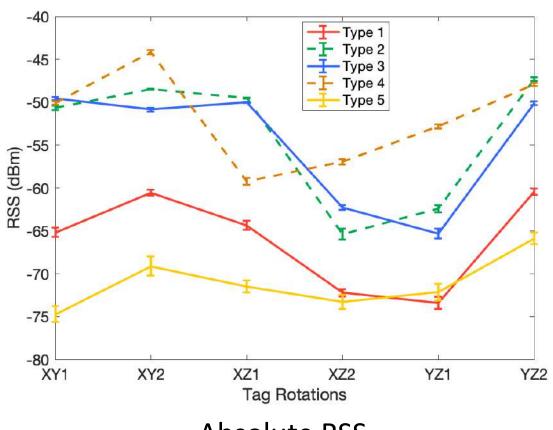




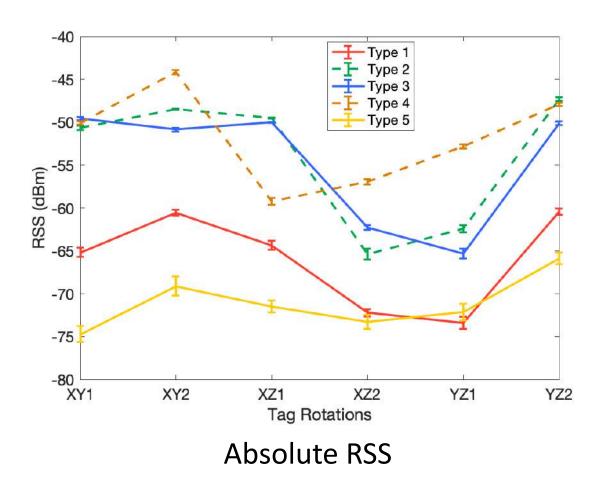
Absolute NS

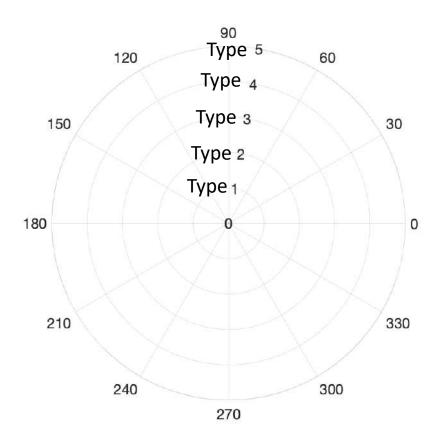




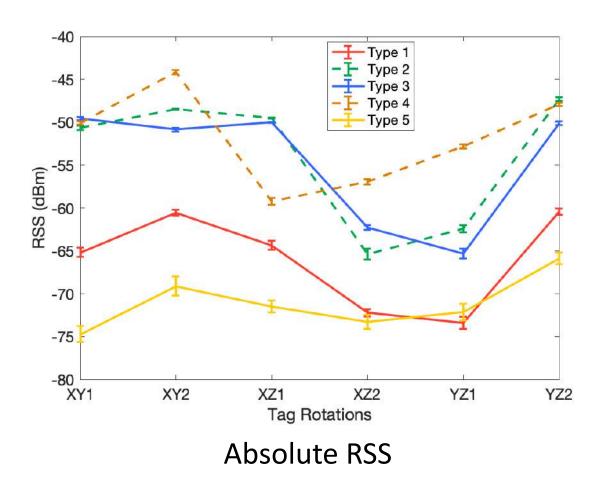


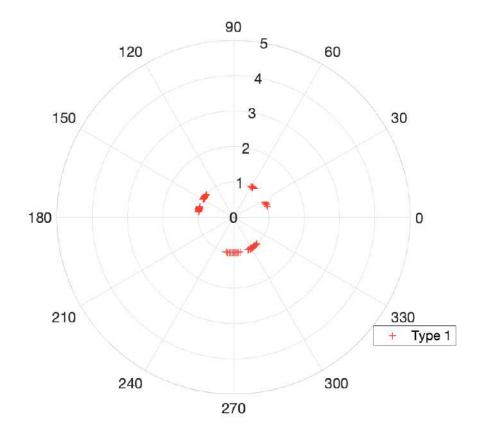
Absolute RSS



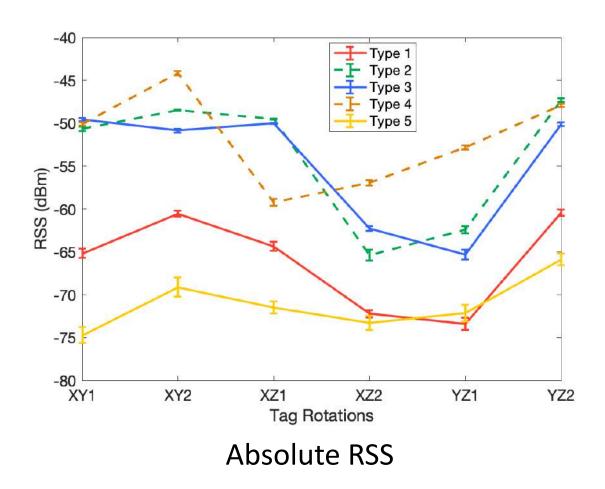


Absolute Phase





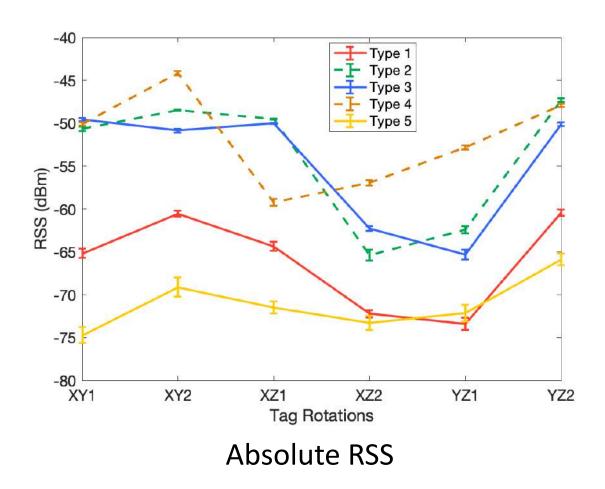
Absolute Phase



Small variations Type 1

Absolute Phase

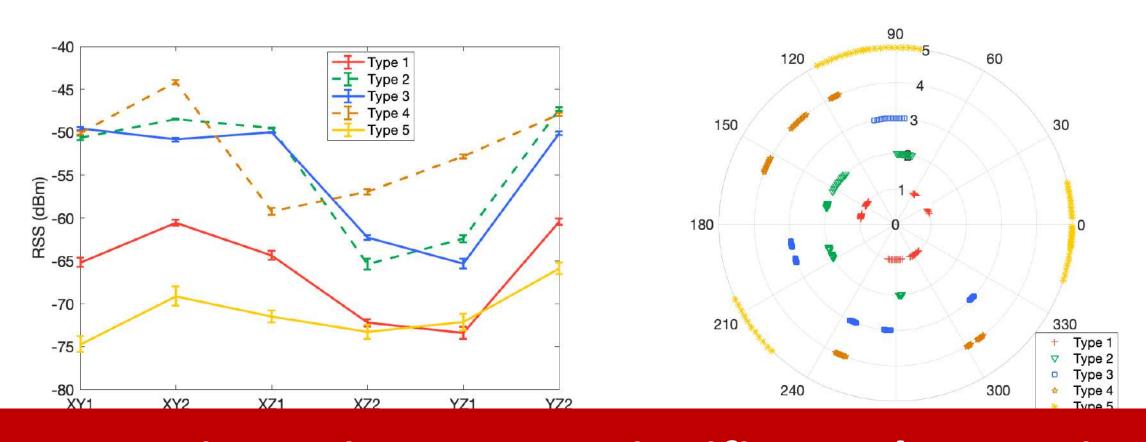
Impact of Tag Orientations



 $Var > \pi rad$ Type 1

Absolute Phase

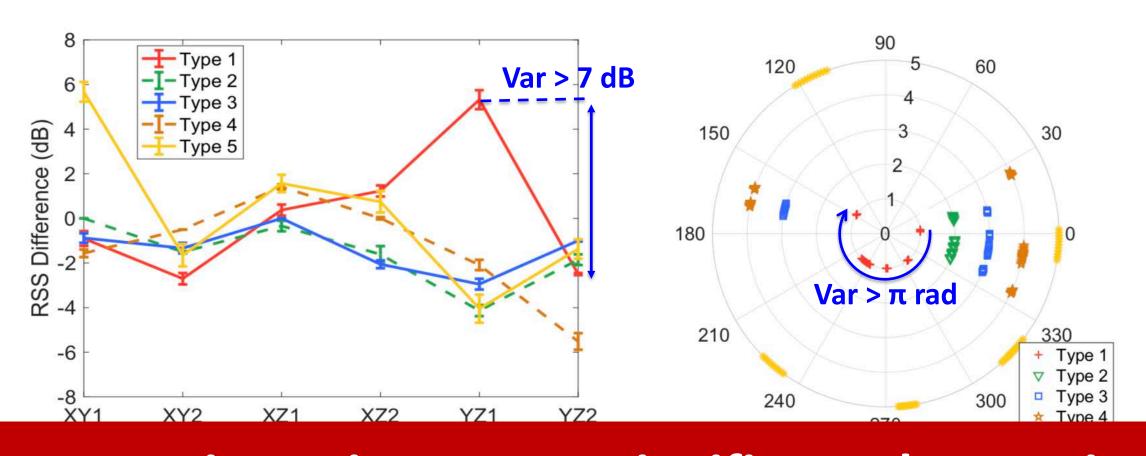
Impact of Tag Orientations



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



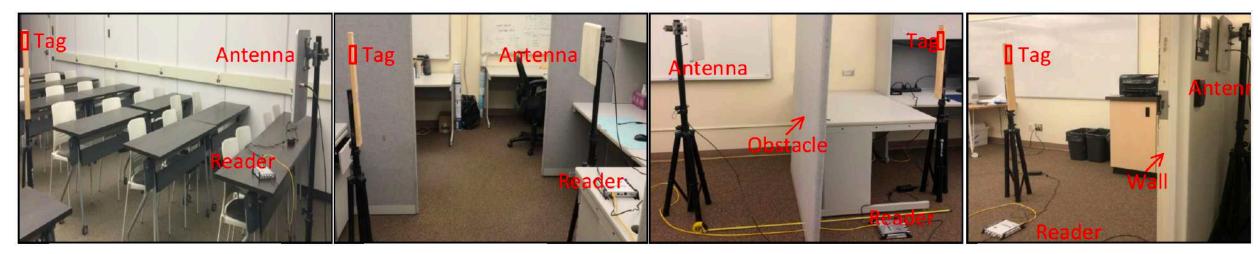
- (1) Orientation of a tag
 - (2) **Environment**
 - (3) Bending shape of tag
 - (4) Surface material that a tag is attached to
 - (5) **Deployment angle** of a tag in the antenna's beam
 - (6) **Deployment height** of a tag above the floor
 - (7) Small movements of tag

Impact of Setup Parameters on RSS/Phase



(1) Orientation of a tag

(2) **Environment**

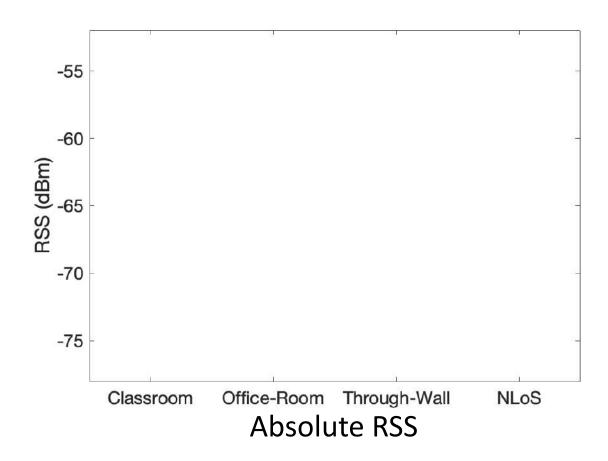


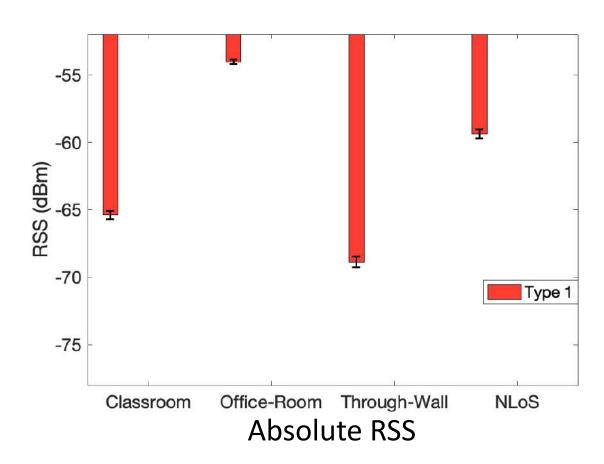
1. Classroom scene

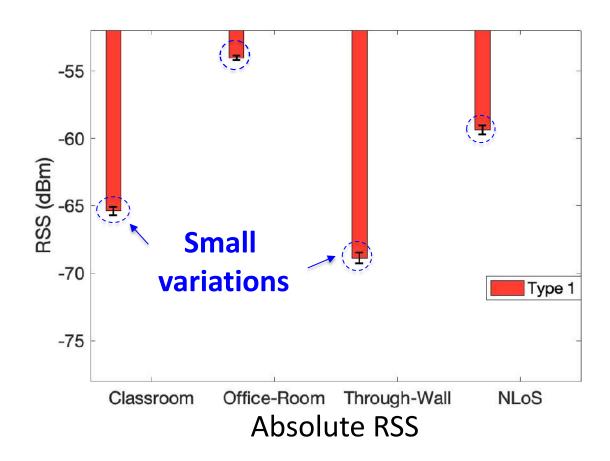
2. Office scene

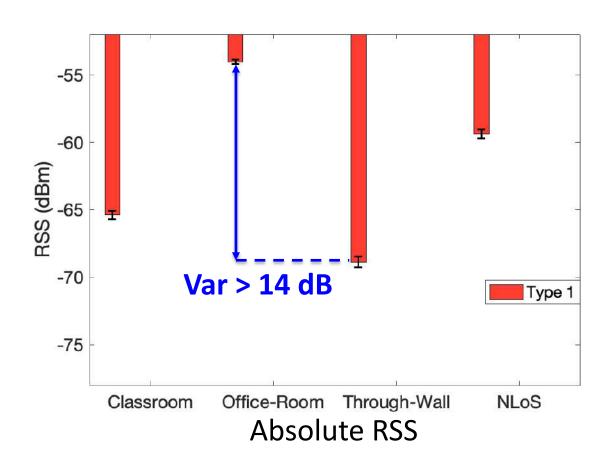
3. Non-line-of-sight (NLoS) scene

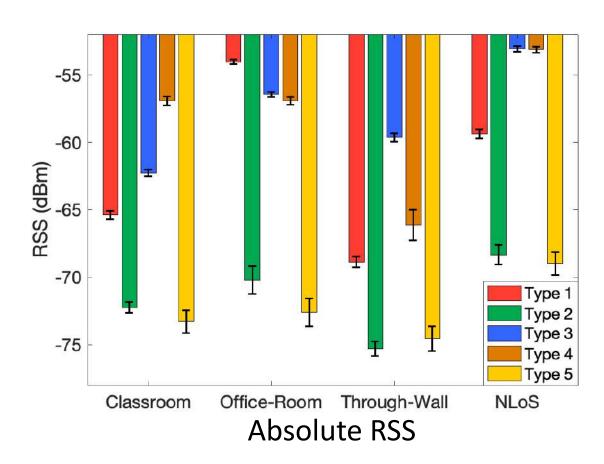
4. Through-wall scene

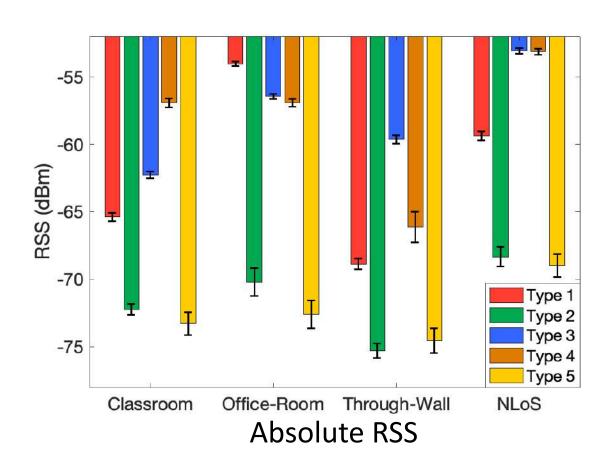


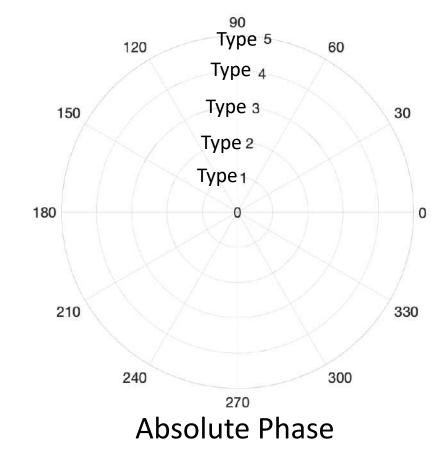


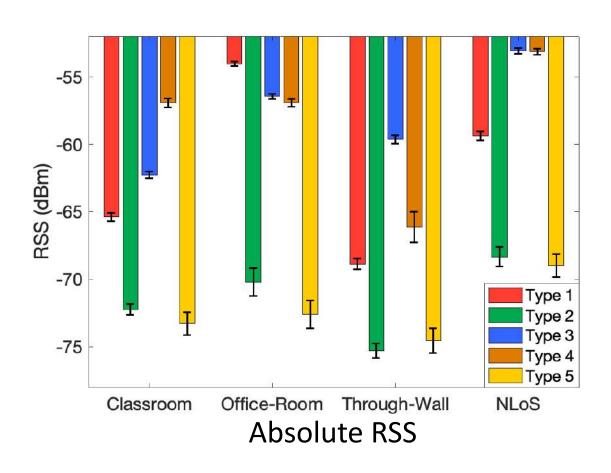


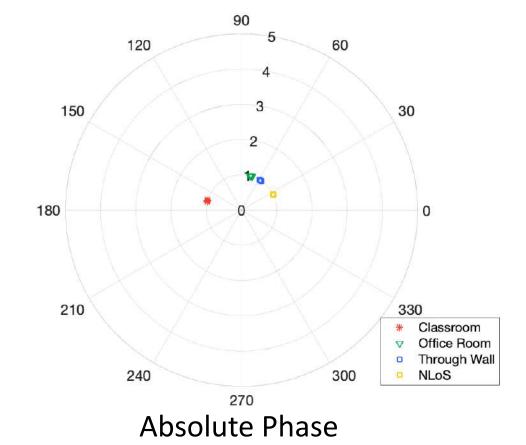


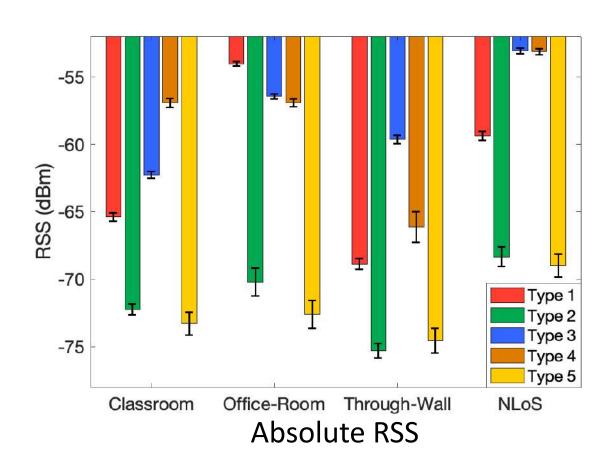


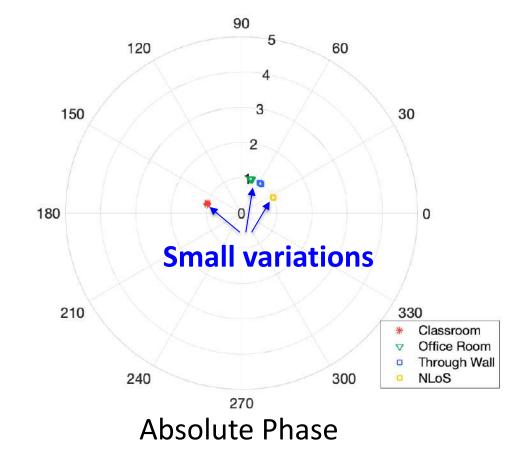


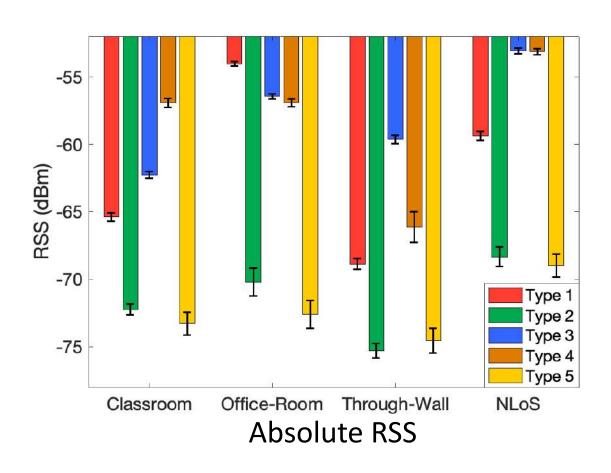


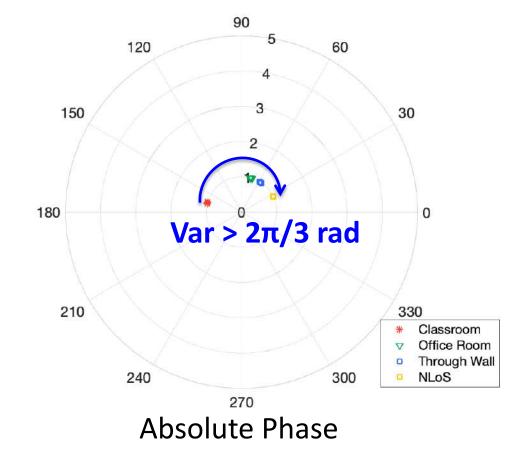


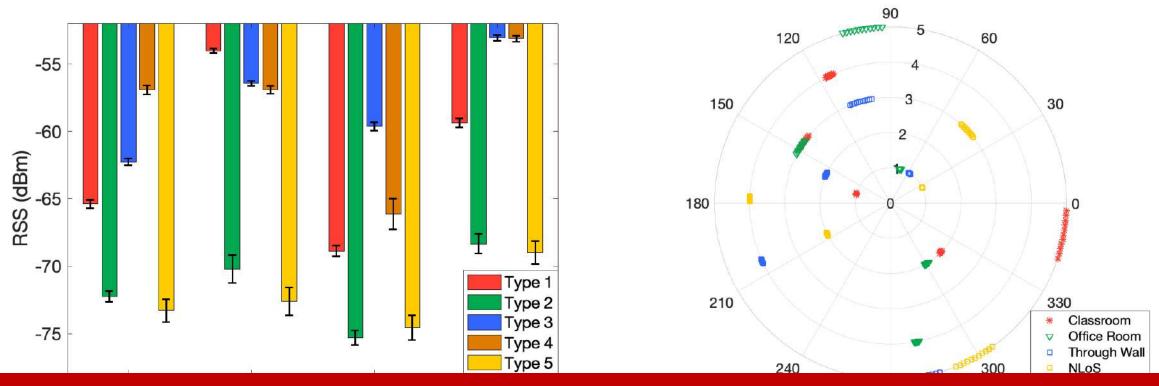




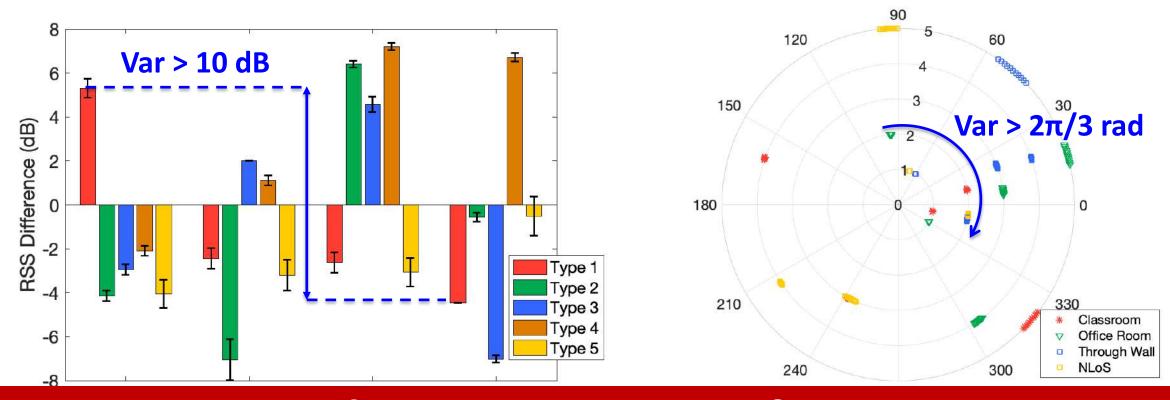








Environment changes cause significant variations in absolute RSS and phase



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
 - (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

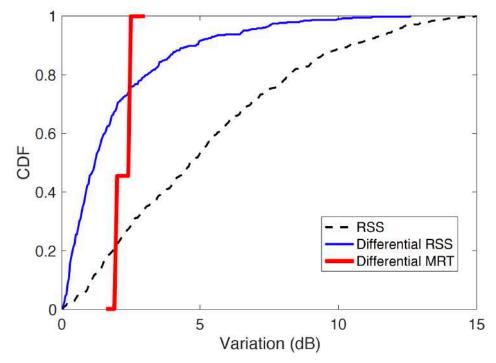
- (1) **Orientation** of a tag
- (2) Environment
- (3) **Bending shape** of tag
- (4) Surface material that a tag is attached to
- (5) **Deployment angle** of a tag in the antenna's beam
- (6) **Deployment height** of a tag above the floor
- (7) Small movements of tag

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.



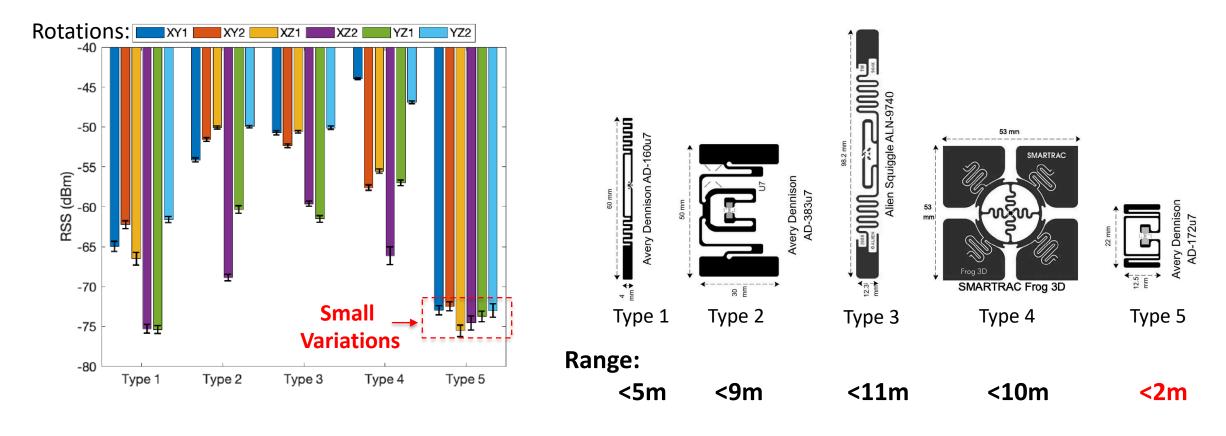
Comparison of RSS, Differential RSS and Differential MRT *in a dynamic environment*.

[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.