Tag-to-Tag Range Estimation For Passive Backscatter Tags

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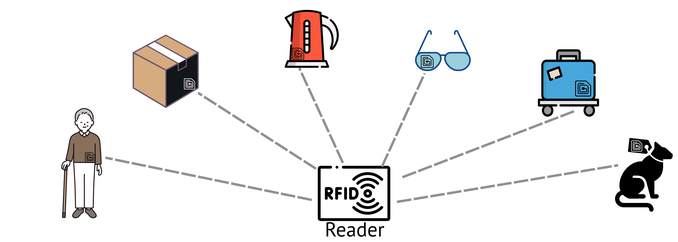
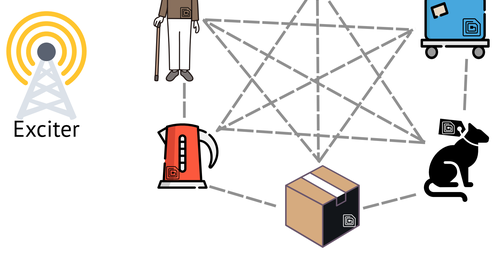
Introduction

Vision: Future IoT will link people, pets, and objects through seamless tagging for universal localization, tracking, and sensing.

Current Approach: Traditional RFID uses cheap, battery-less tags but relies on expensive, high-power transceivers as readers to "talk" with the tags. This dependency on costly hardware limits the technology's scalability.



Passive tag-to-tag backscattering:
(i) Replaces expensive readers with low-cost exciters to power tags.
(ii) Enables inter-tag communication, increasing network density and potentially improving localization and sensing capabilities.



30 tag-to-tag links, up from only 6 tag-to-reader links in traditional RFID.

Applications and motivation:

Gesture and activity recognition.

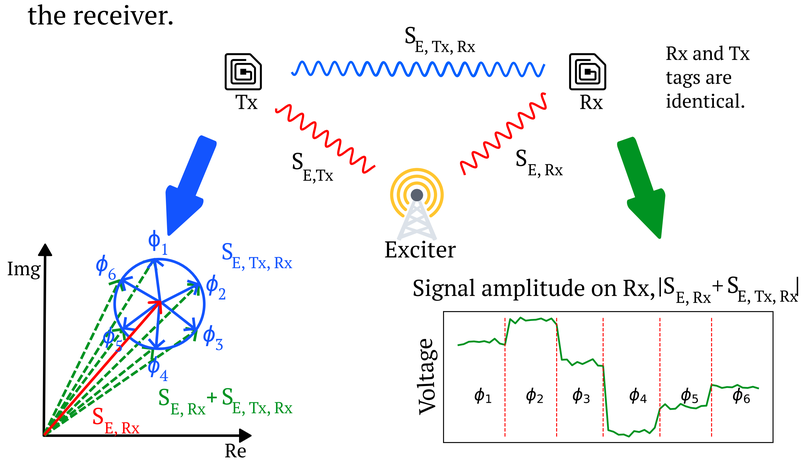
Structural integrity monitoring.

Warehouse stock management.

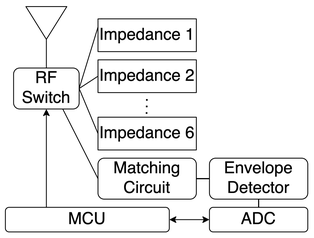
All these applications require accurate ranging and localization of passive tags before performing downstream tasks.

Passive Backscattering

The transmitting tag varies its antenna impedance to change the reflection coefficient and hence the phase (ϕ_i) of the backscattered signal, resulting in a variable signal amplitude at the receiver.



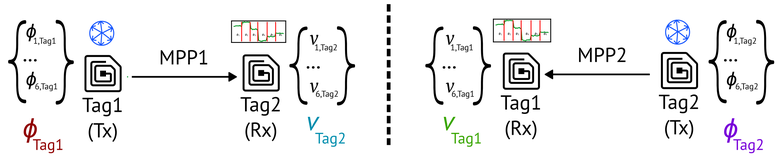
The process of Tx tag going through all of its antenna impedances (or phases) is called **Multi Phase Probing (MPP)**.



The tag prototype consists of an RF switch connected to six distinct impedances for transmission, and a 915 MHz-tuned matching circuit connected to an envelope detector and an ADC for reception.
The RF switch is controlled by an MCU.

Tag-to-Tag Phase Estimation

Our prior works establish methods for tag-to-tag channel phase (θ) estimation [1, 2] as a function of the Rx signal amplitude and the Tx antenna impedance.



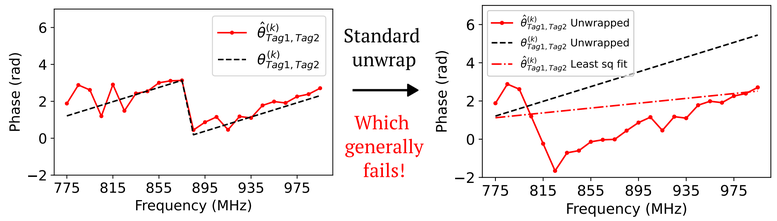
$$f(\phi_{Tag1}, V_{Tag2}, \phi_{Tag2}, V_{Tag1}) = \theta_{Tag1, Tag2} \bmod \pi$$

Ranging

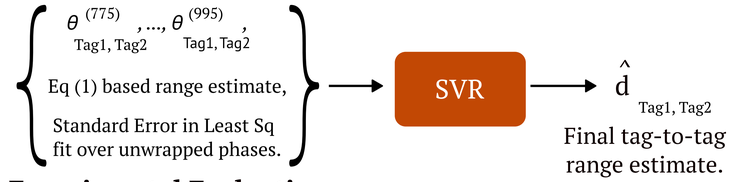
Challenge 1: Tag-to-tag phase estimates are π-wrapped, resulting in *ambiguous* wrapped range estimates.
- We address this challenge using the Frequency Domain Phase Difference of Arrival (FD-PDoA) technique.

$$d_{Tag1, Tag2} = \frac{c}{2\pi} \frac{\partial \theta_{Tag1, Tag2}}{\partial f} \quad (1)$$

Calculated from the slope of tag-to-tag channel phase estimates across discrete frequencies.

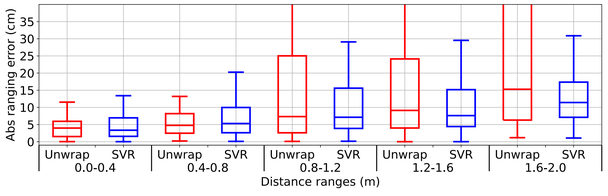


Challenge 2: Standard unwrapping fails due to phase estimation errors caused by high multipath reflections in indoor environments.
- We propose a novel, multipath resistant, Support Vector Regression based range estimation pipeline.



Experimental Evaluation:

Evaluated in 14 unique locations.



Median error close-to or less than 10cm for upto 2m tag-to-tag distance.

References

[1] A. Ahmad, X. Sha, M. Stanaćević, A. Athalye, P. M. Djurić, and S. R. Das, "Enabling passive backscatter tag localization without active receivers," in Proceedings of the 19th ACM Conference on Embedded Networked Sensor Systems, New York, NY, USA: ACM, Nov. 2021. doi: 10.1145/3485730.3485950.
[2] Y. Xie, Y. Li, M. Singh, S. R. Das, P. M. Djurić, and M. Stanaćević, "Robust and energy-efficient channel estimation in RF backscatter tag-to-tag network," IEEE J. Radio Freq. Identif., vol. 9, pp. 1–1, 2025.