RIO: A Pervasive RFID-based Touch Gesture Interface

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1  TEXAS
The University of Texas at Austin

2 NEC Laboratories America
Relentless passion for innovation

MobiCom 2017

LOTS of Connected Devices by 2020

LOTS of Connected Devices by 2020

~30 Billion*

*Ericsson Research

Smart Spaces

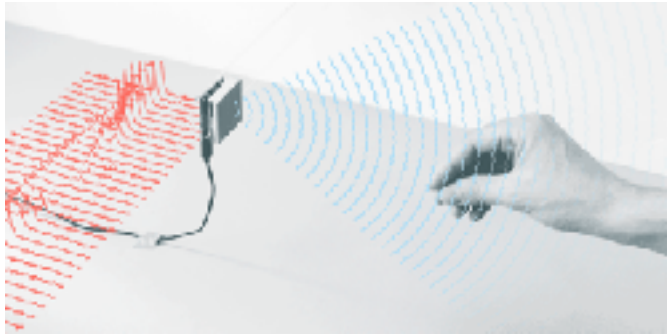
Smart Spaces

Smart Hospitals

Smart Offices

Smart Retail

Can we effectively transform everyday object into a touch Interface ?



Wireless

Capacitive

Vision

IMU

Issues with these modalities

Issues with these modalities

- Not easy to **customize**
- Not **low cost**
- Extensive **training** phase
- Need to be **recharged** frequently …

Passive RFID tags as touch interface

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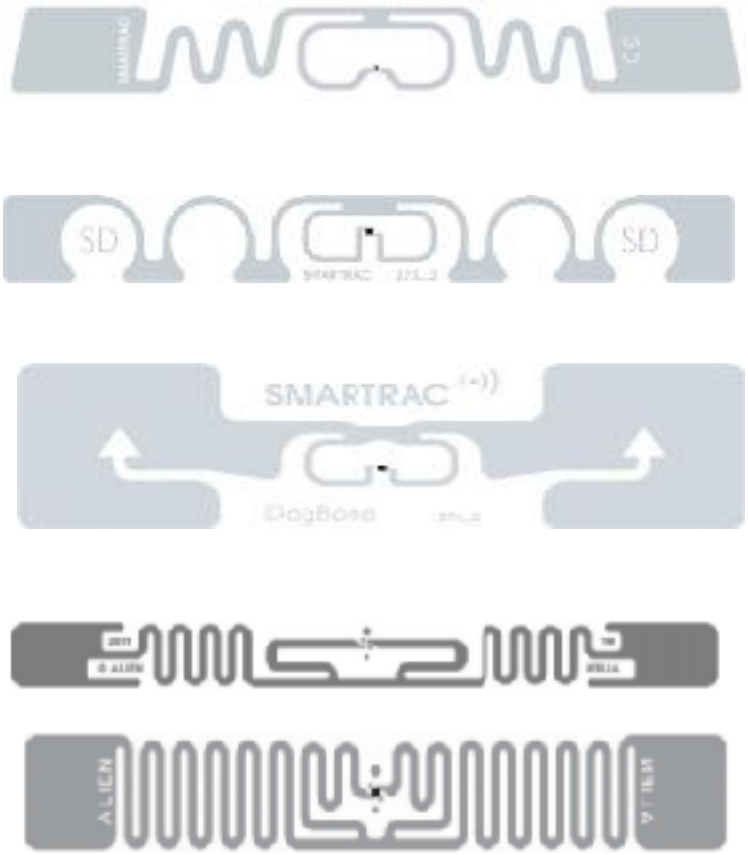


COTS Tags

Custom Tags

COTS Reader/Antenna

And that interface …

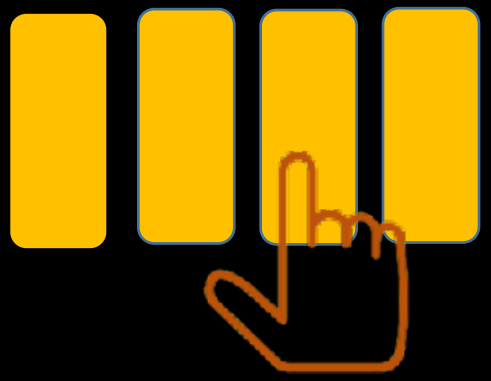
And that interface …

- Customizable and less costly
- Battery-free
- Supports fine-grained tracking
- Multi interface support

Button

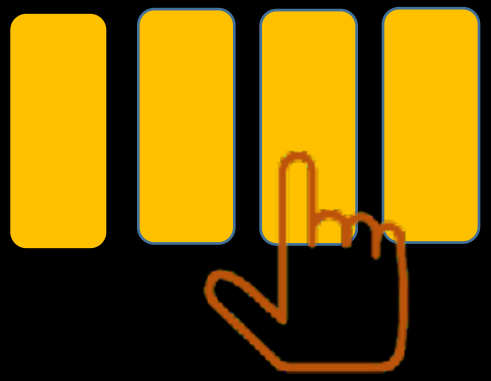
Button

Keyboard



Button

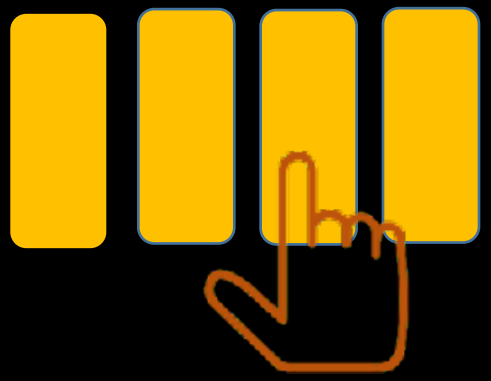
Keyboard



Slider

Button

Keyboard

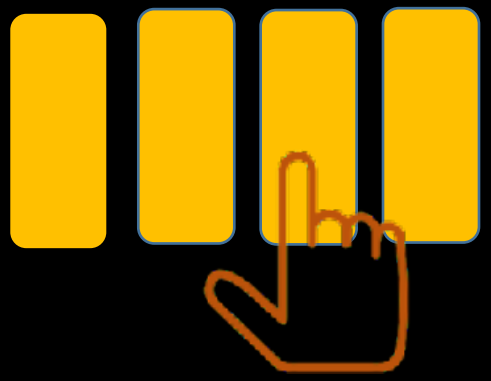


Slider

Dial

Button

Keyboard



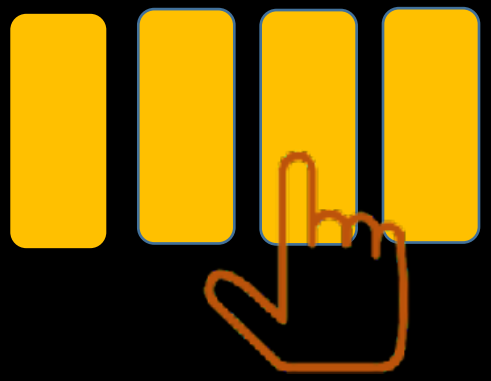
Slider

Dial

Multiple Sliders

Button

Keyboard



Slider

Dial

Multiple Sliders

Shapes

Key Idea and Reasoning

Touch and Single Tag Tracking

Tracking within Multiple Tags

Evaluation

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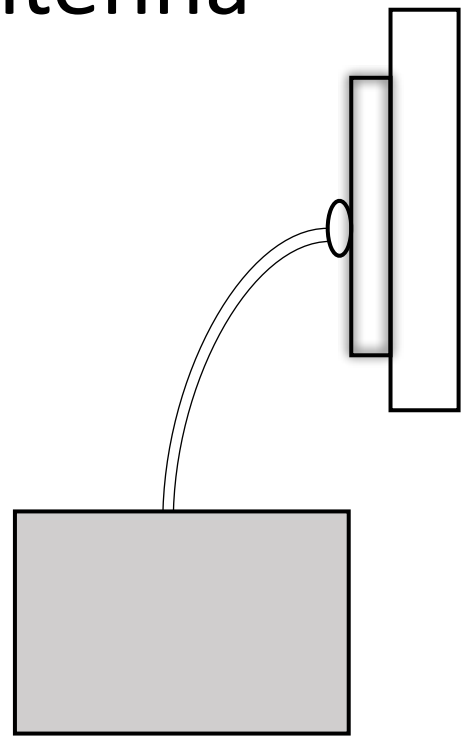
Tracking within Multiple Tags

Evaluation

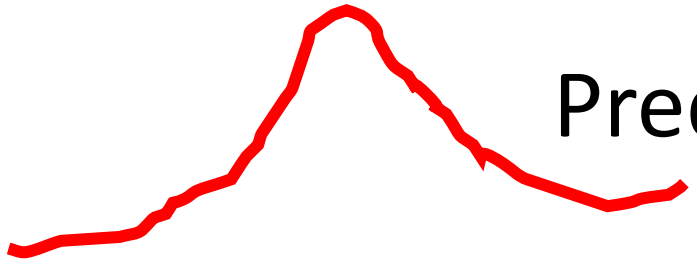
0

Antenna



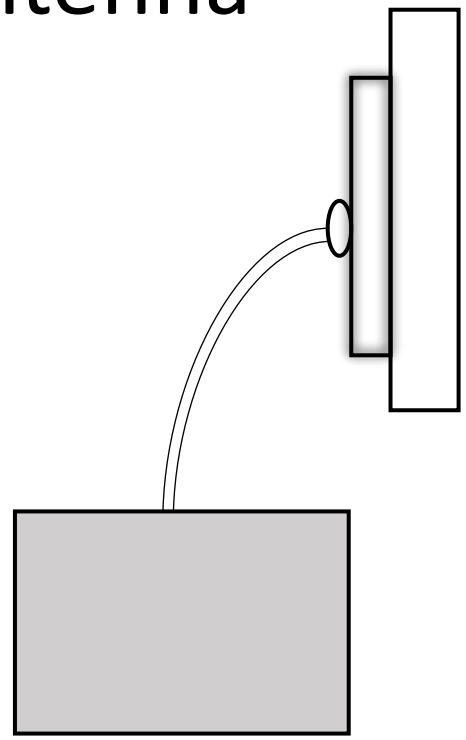
Reader

Tag

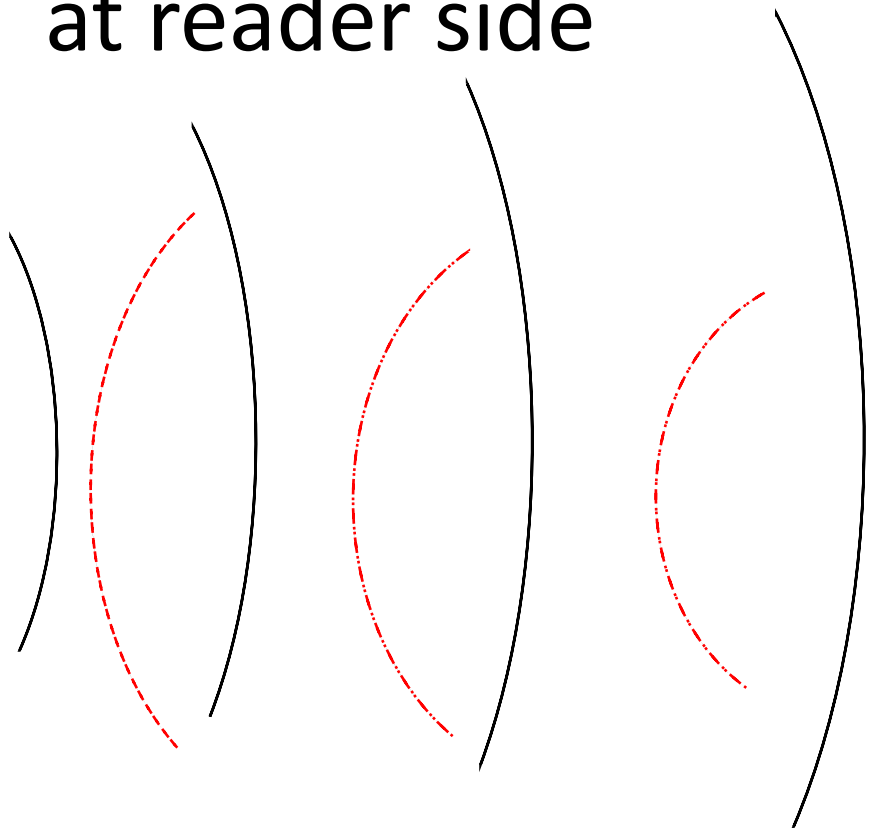


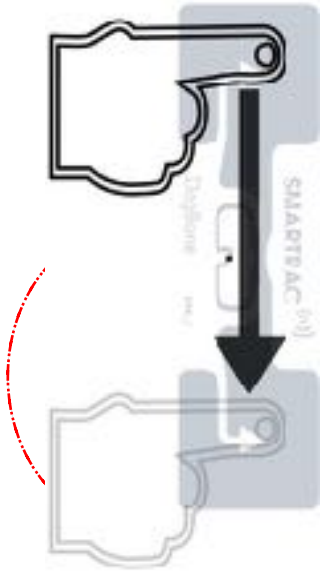
Predictable phase change at reader side

Antenna



Reader



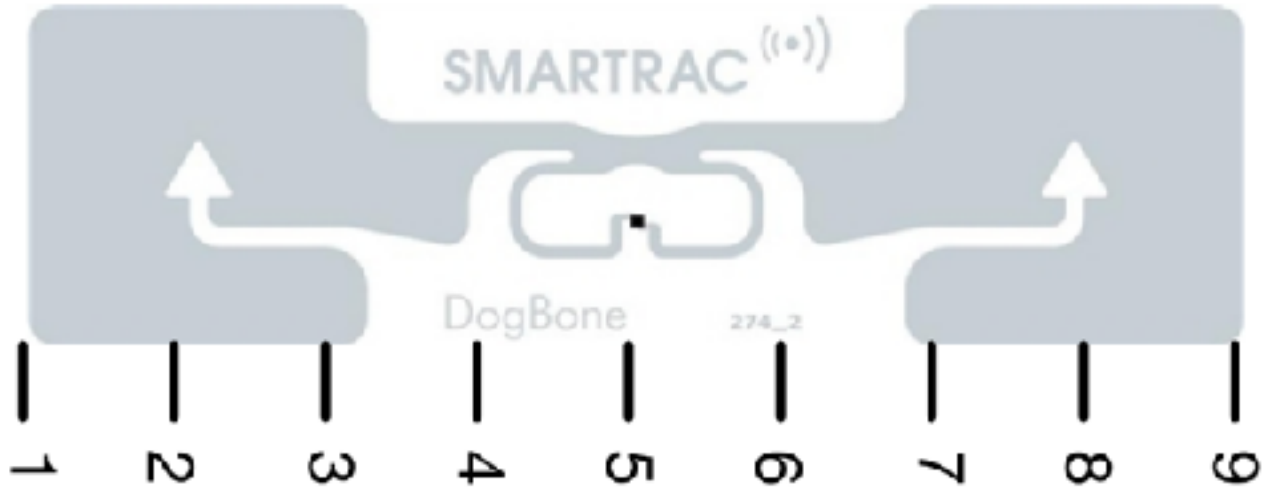


Tag

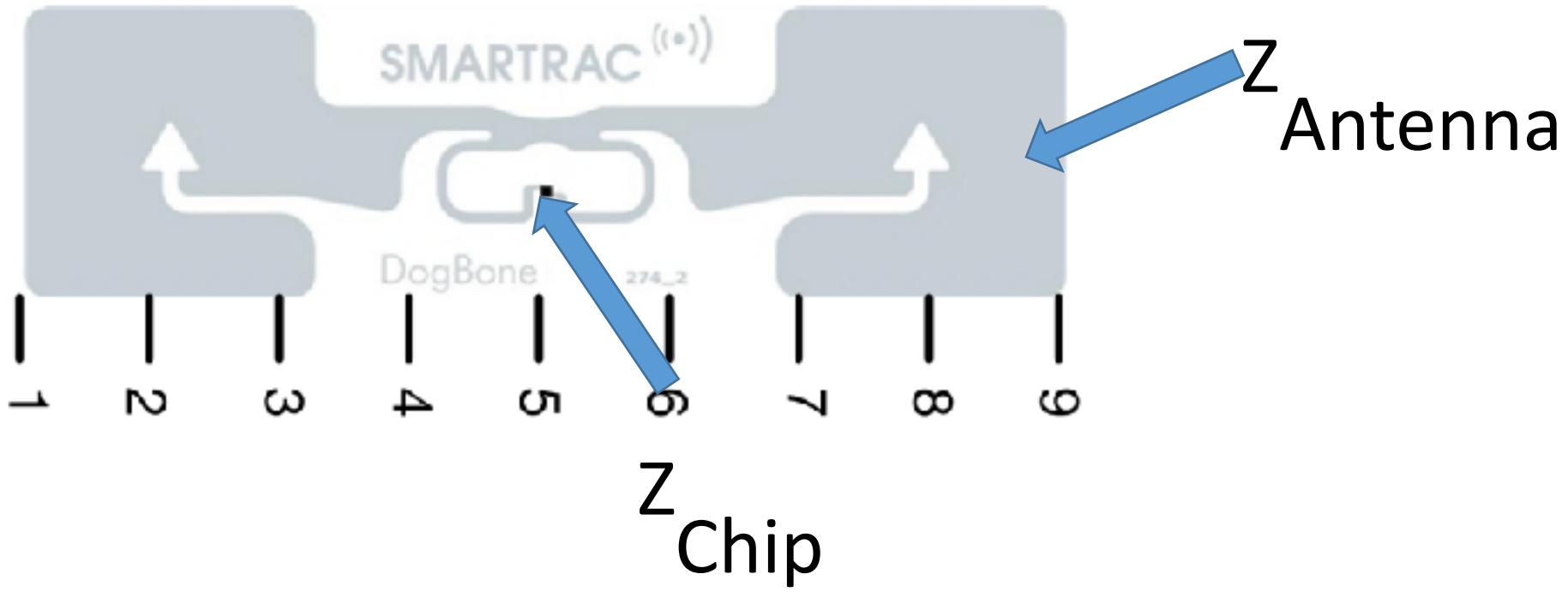
Finger Swipe on Tag

Why does it happen ?

Why does it happen ?



Why does it happen ?



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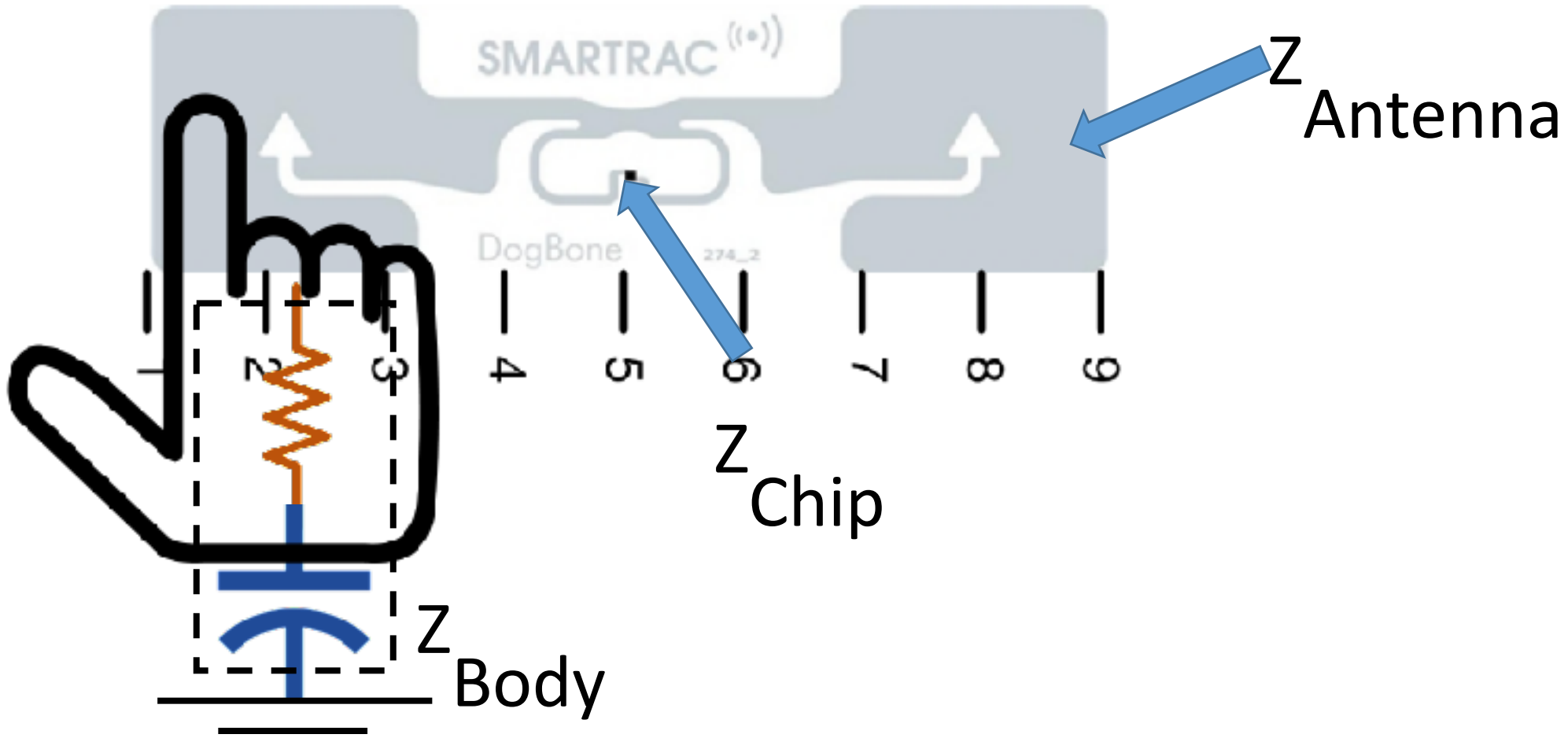

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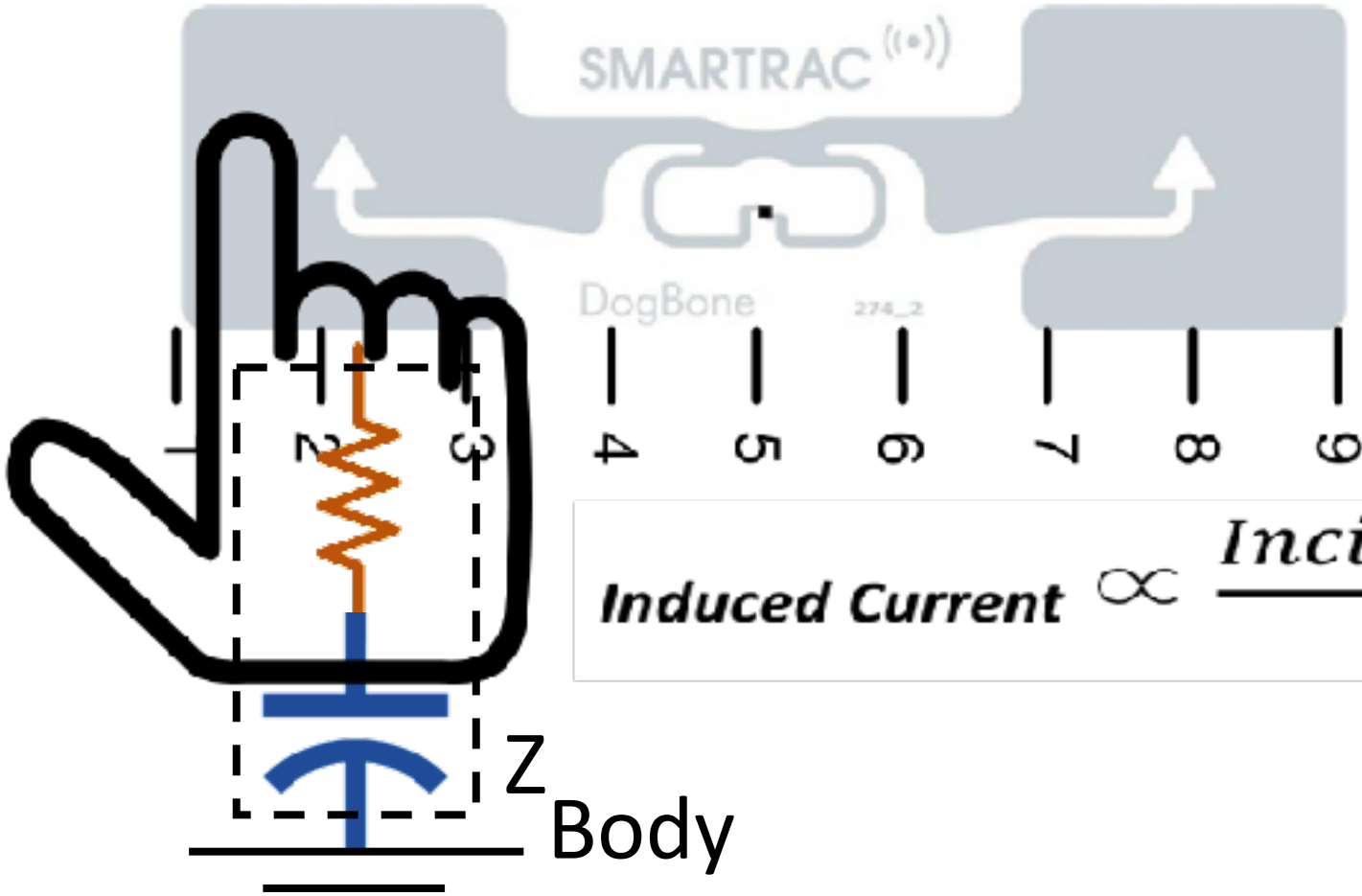
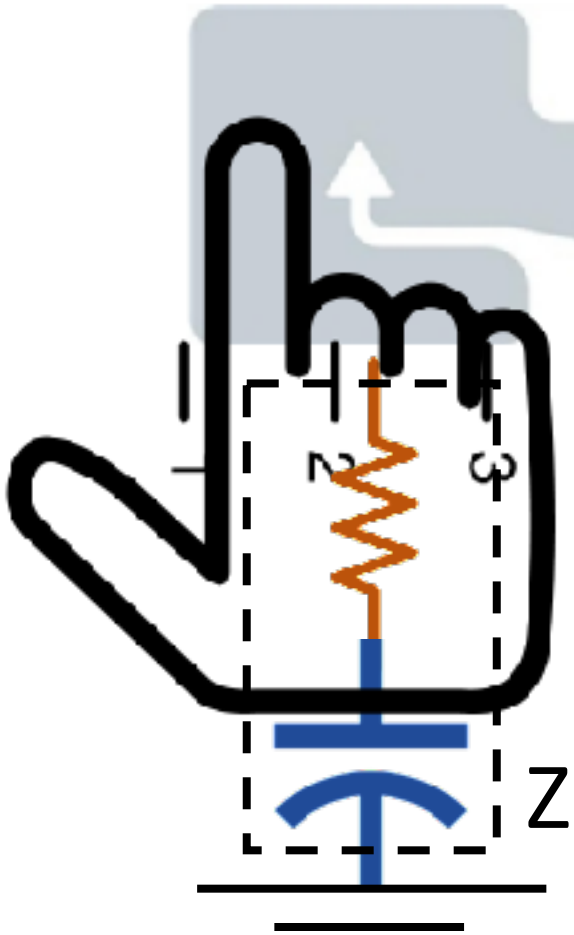


$$\textbf{Induced Current} \propto \frac{Incident\ Electric\ Field}{Z_{chip} + Z_{Antenna}}$$

Why does it happen ?

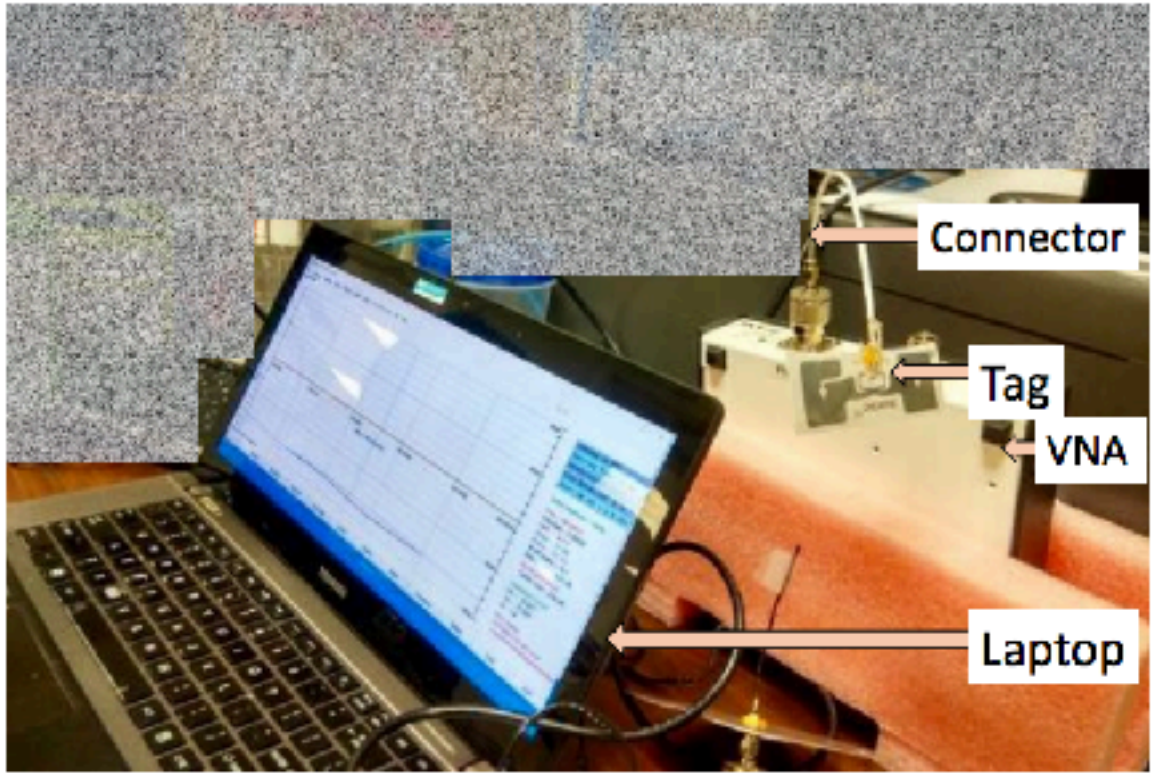


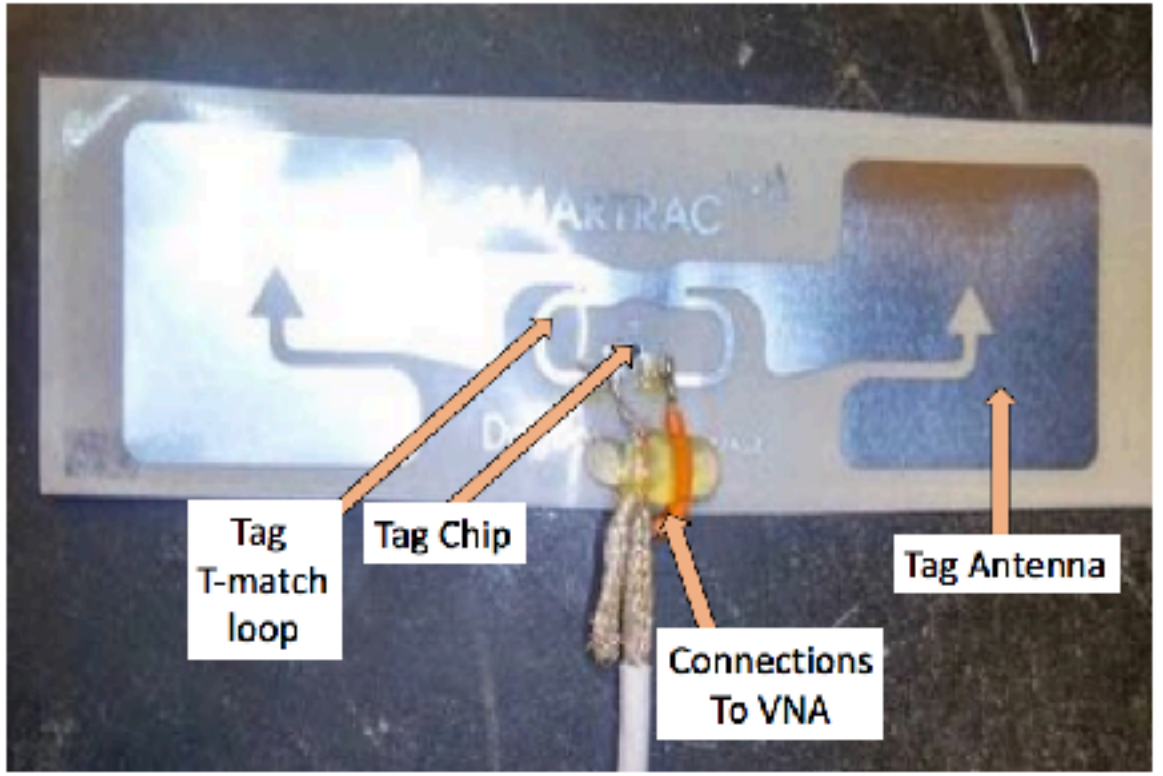
Backscattered Electric field and Phase

$$\textbf{Induced Current} \propto \frac{Incident\ Electric\ Field}{Z_{chip} + Z_{Antenna}}$$

VNA based measurements

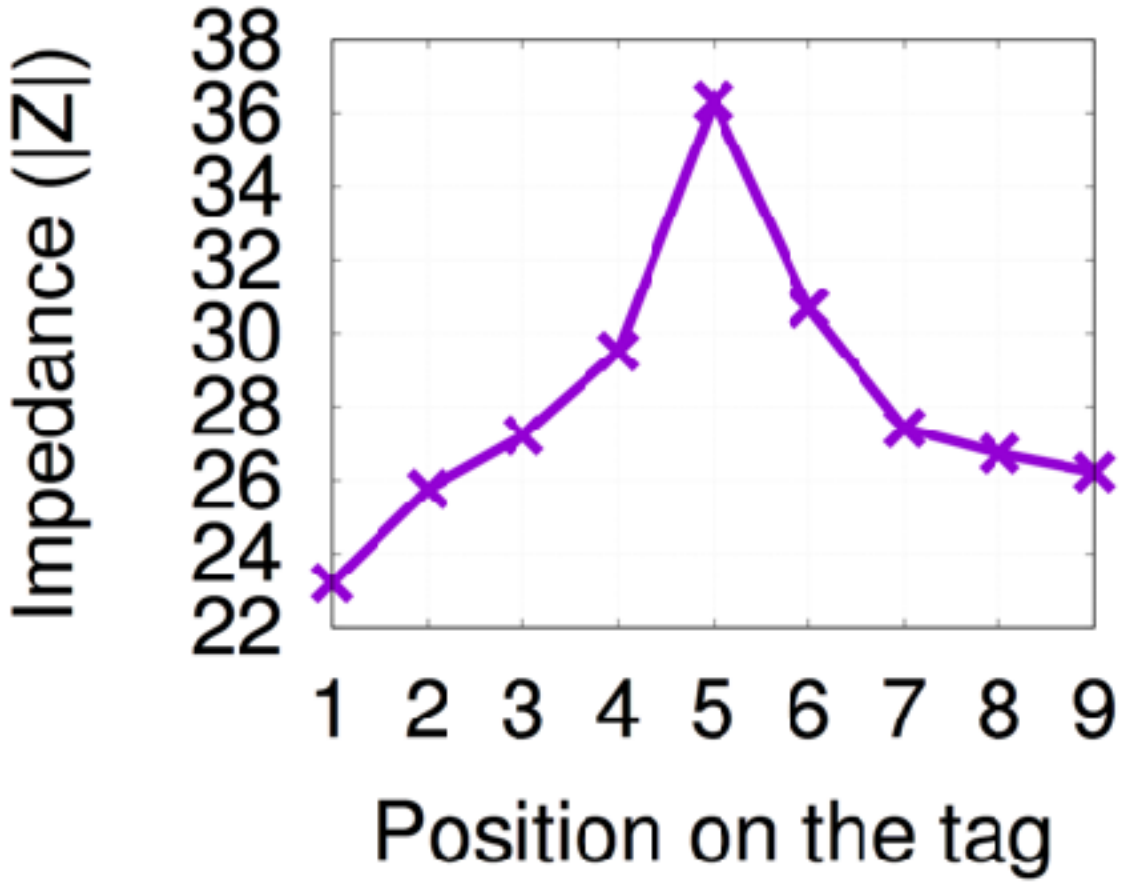
VNA based measurements



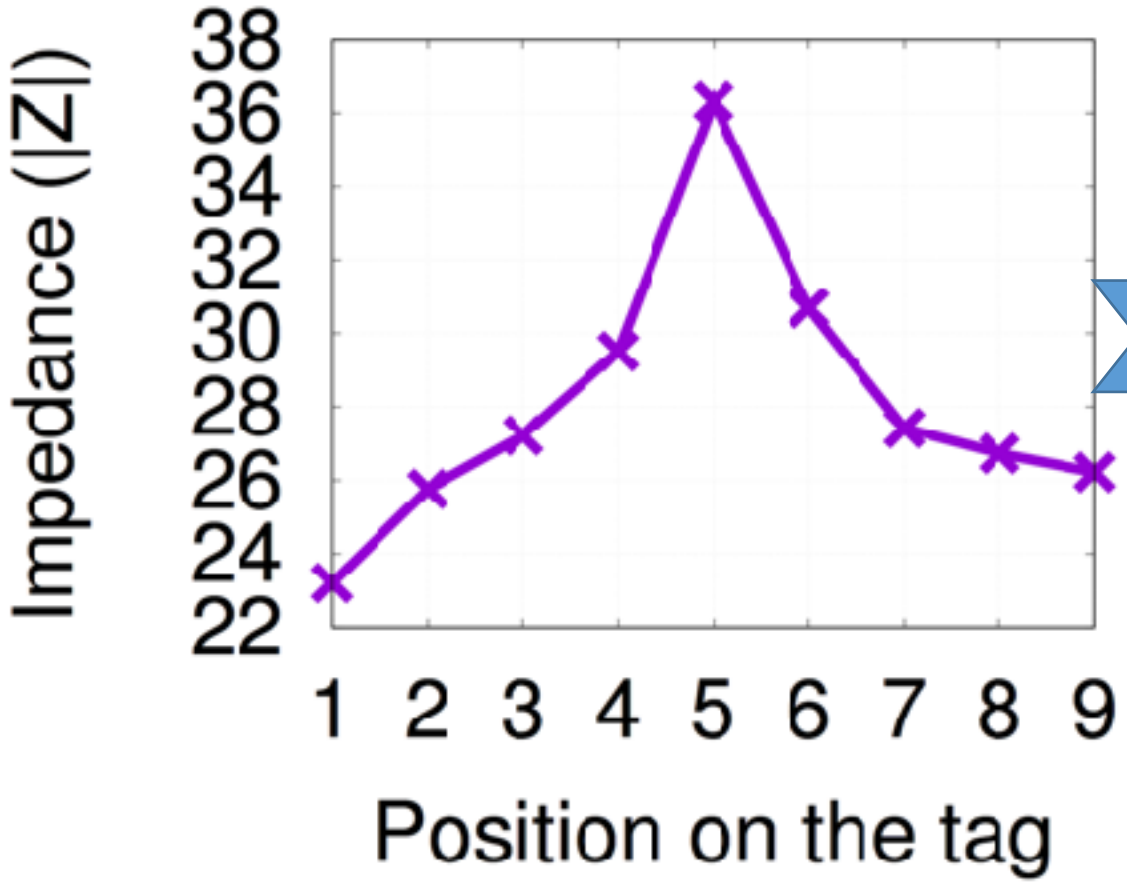


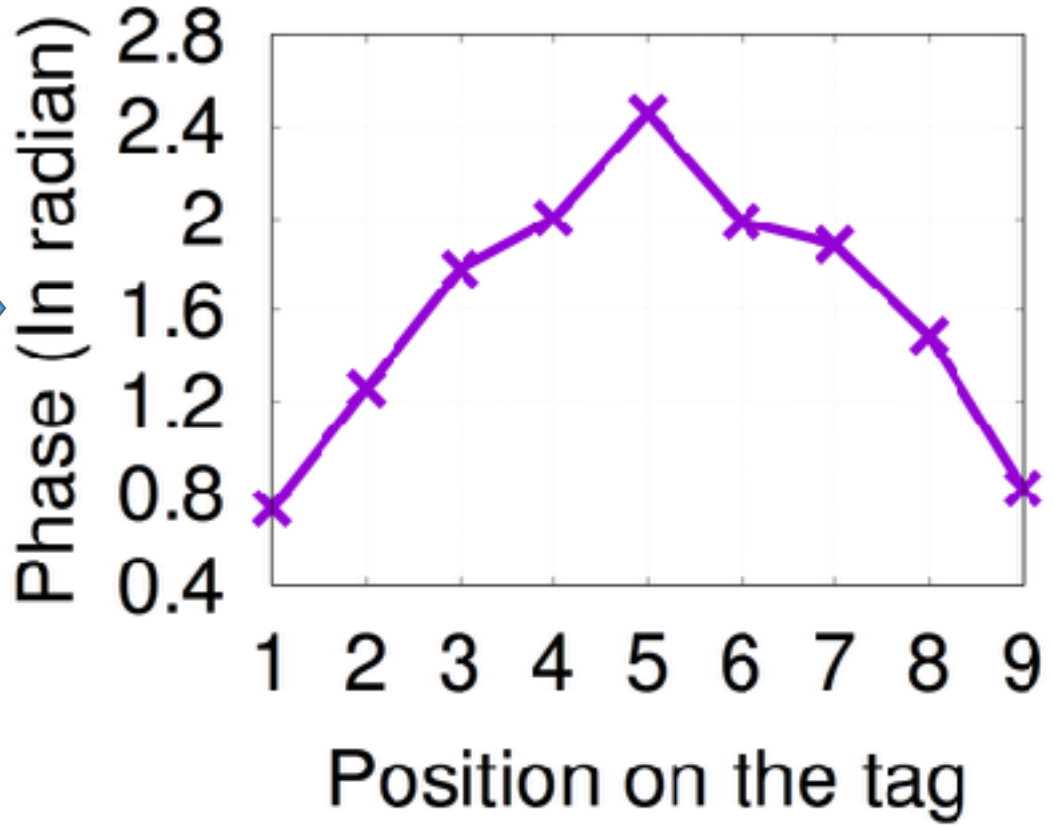
VNA based measurements

VNA based measurements



VNA based measurements





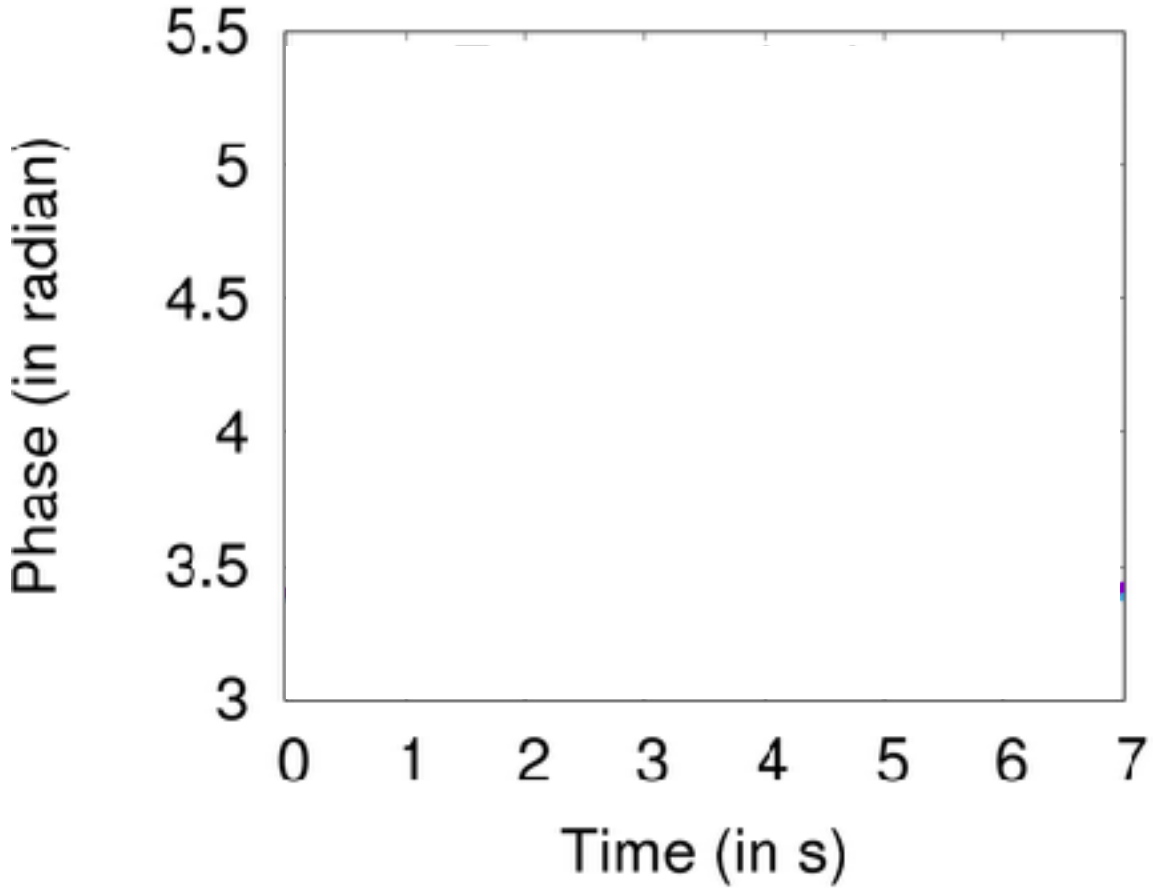
Key Idea and Reasoning

Touch and Single Tag Tracking

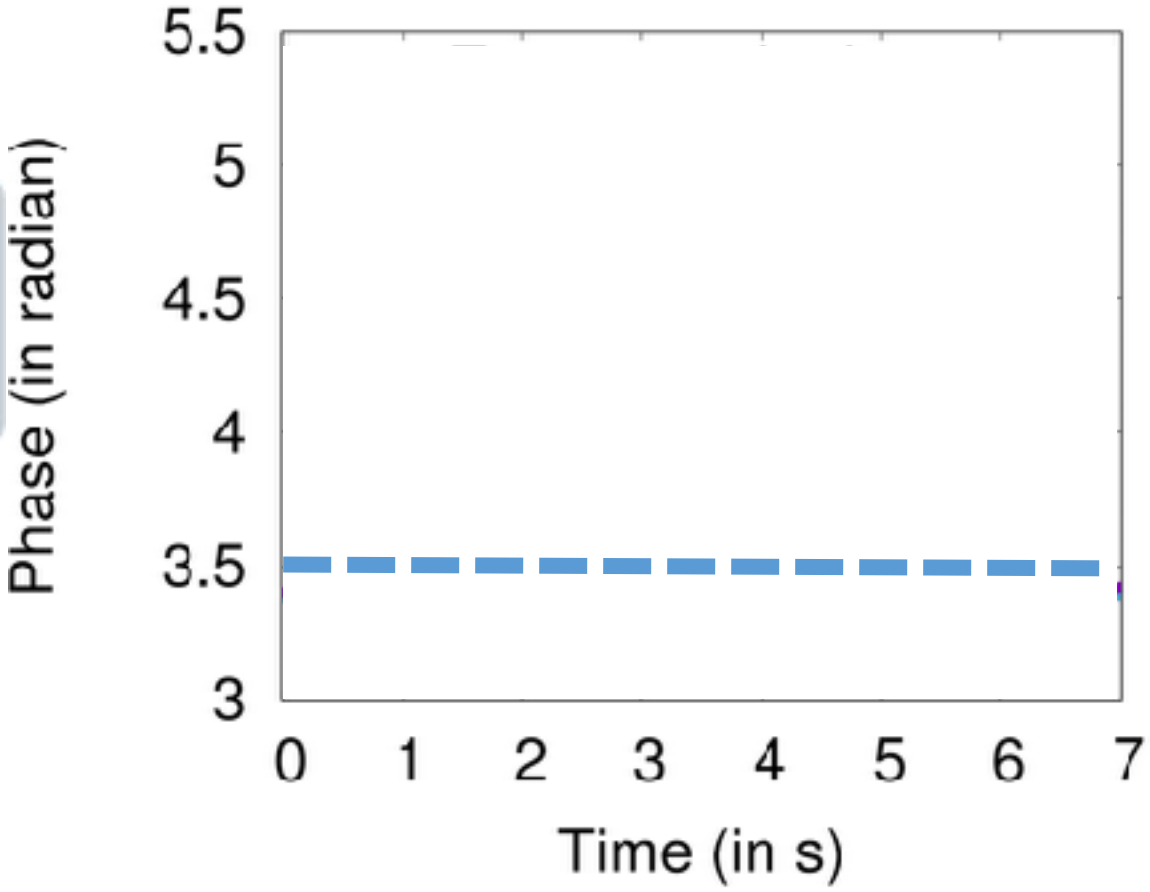
Tracking within Multiple Tags

Evaluation

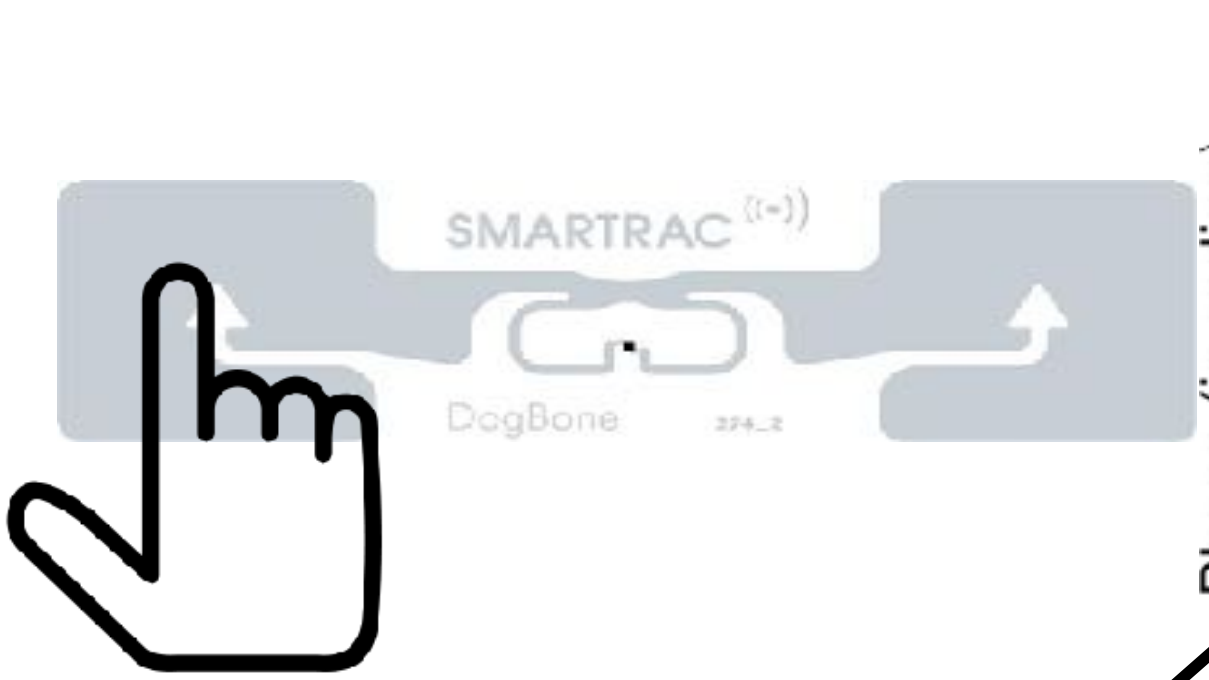
How to detect touch ?

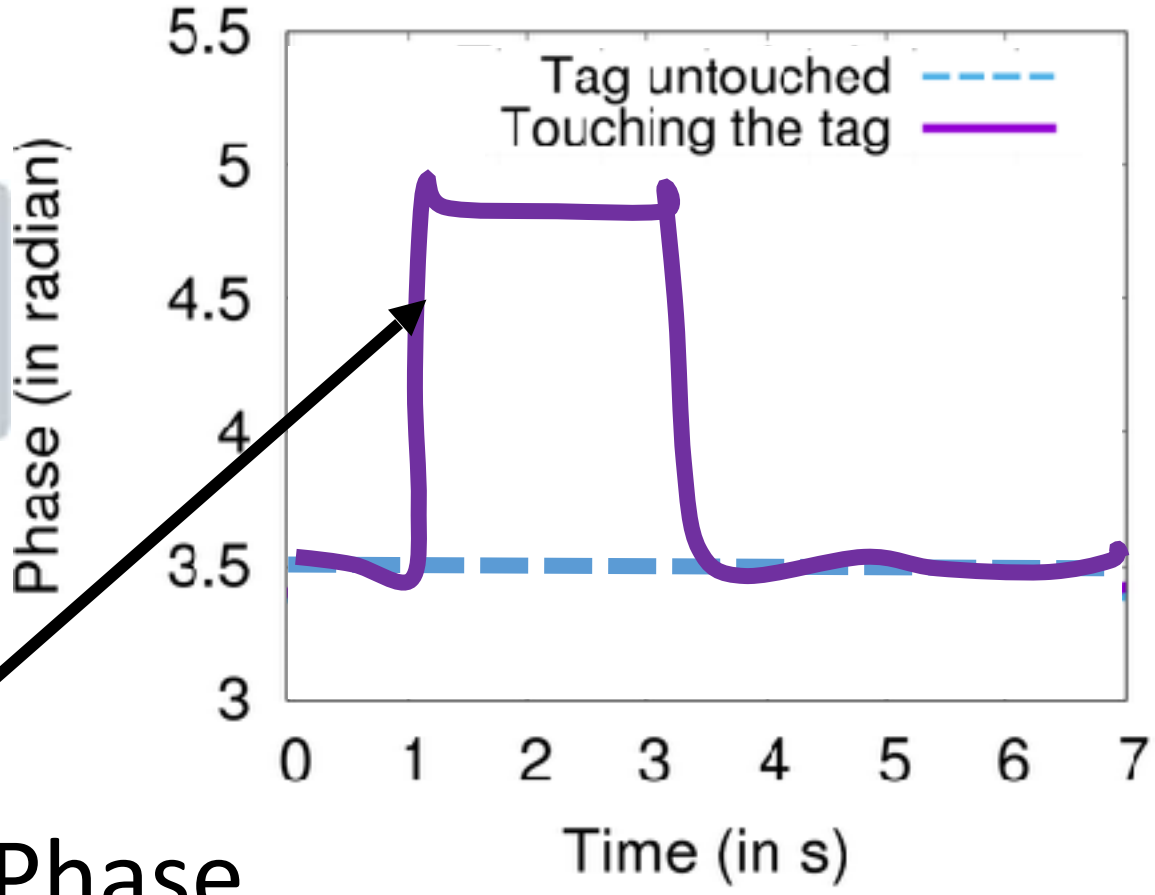


How to detect touch ?



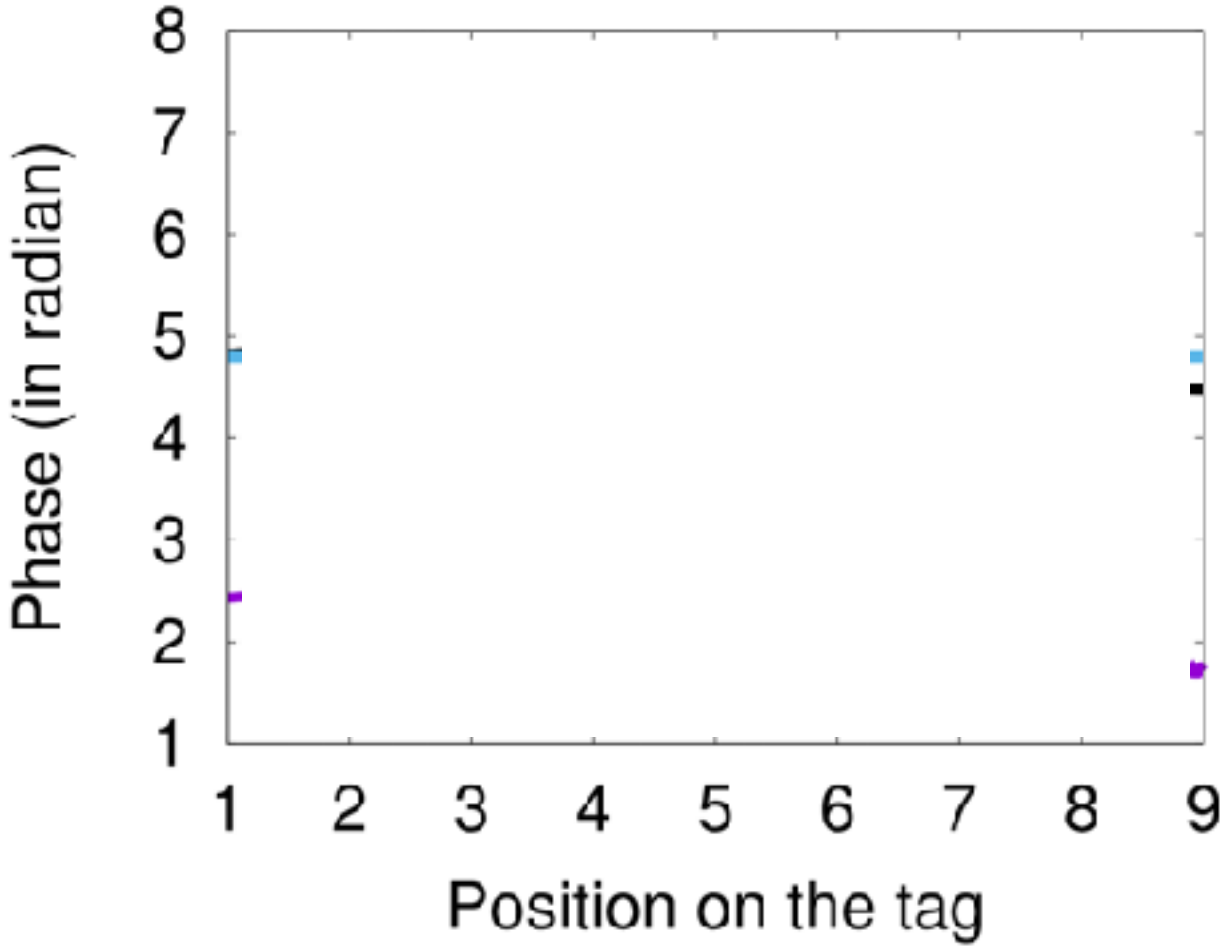
How to detect touch ?



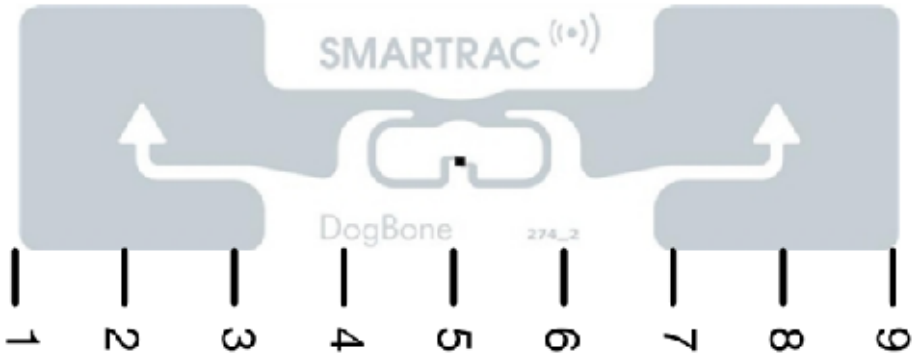


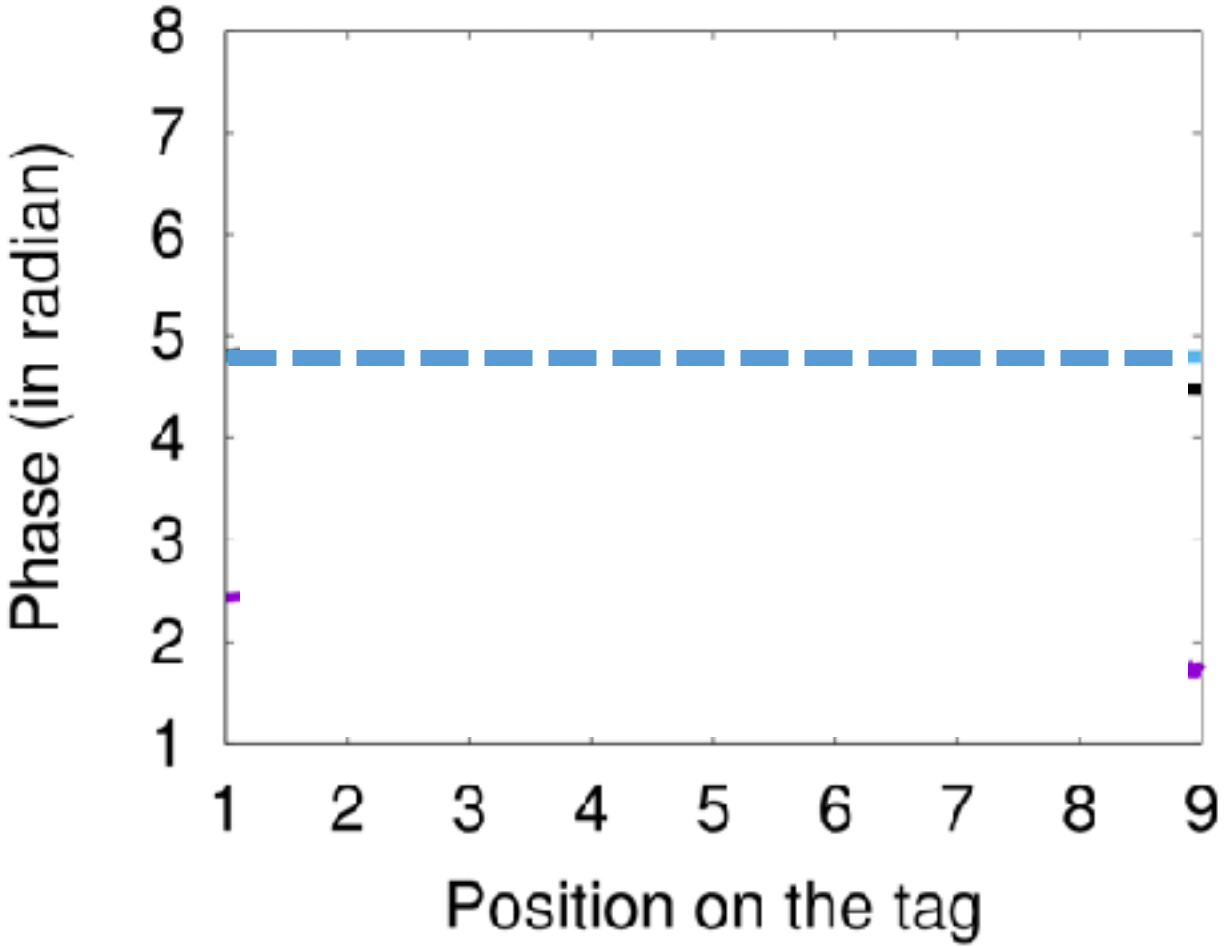
Sudden Jump in Phase

How to detect tracking ?



How to detect tracking ?





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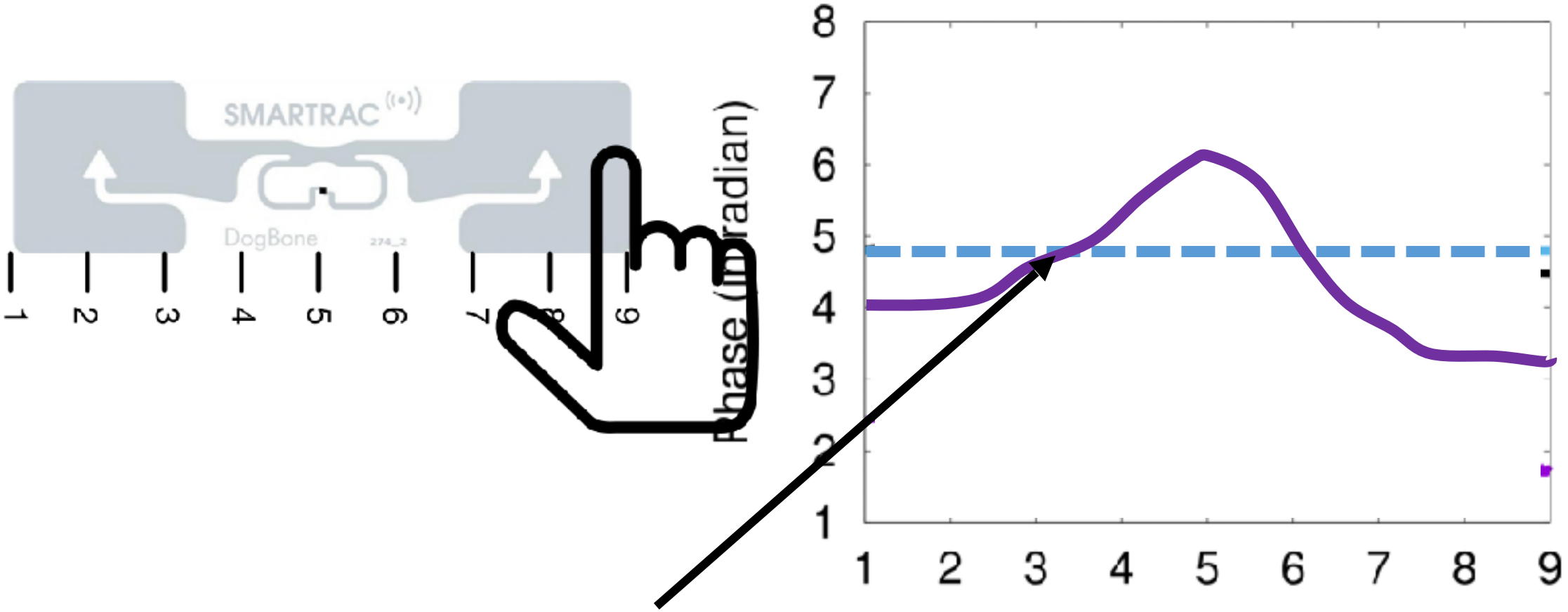
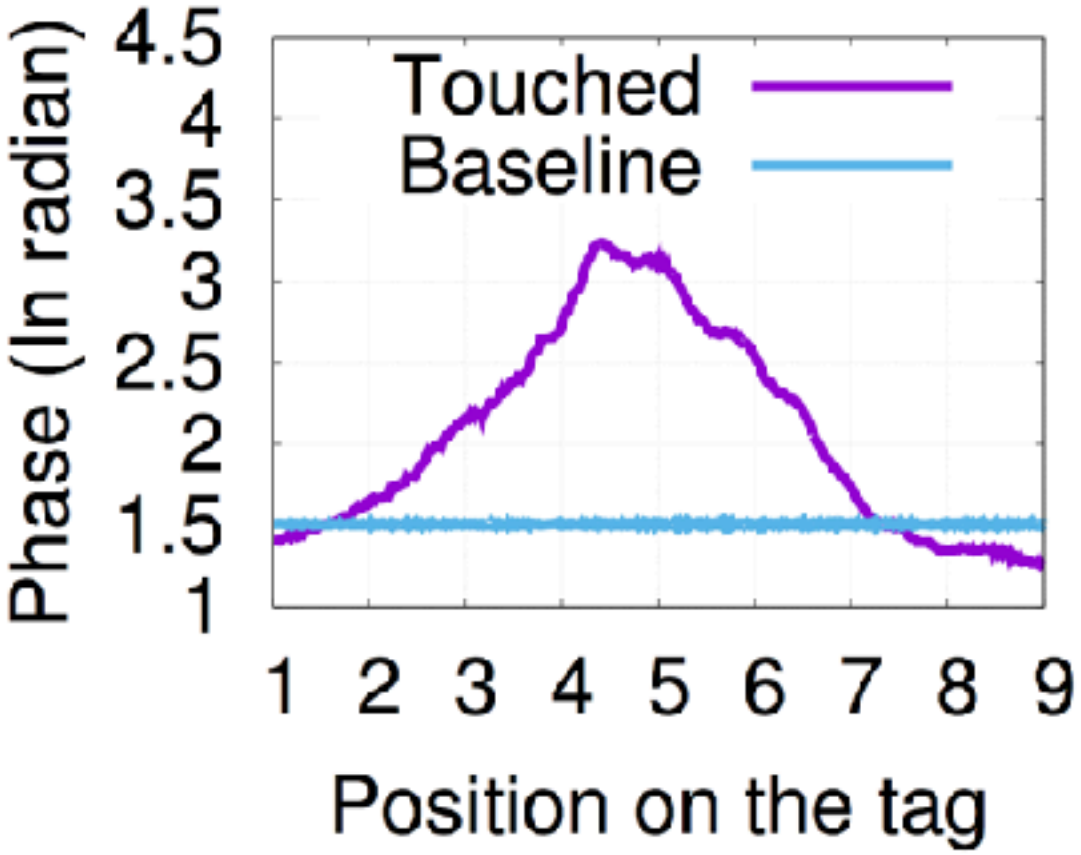


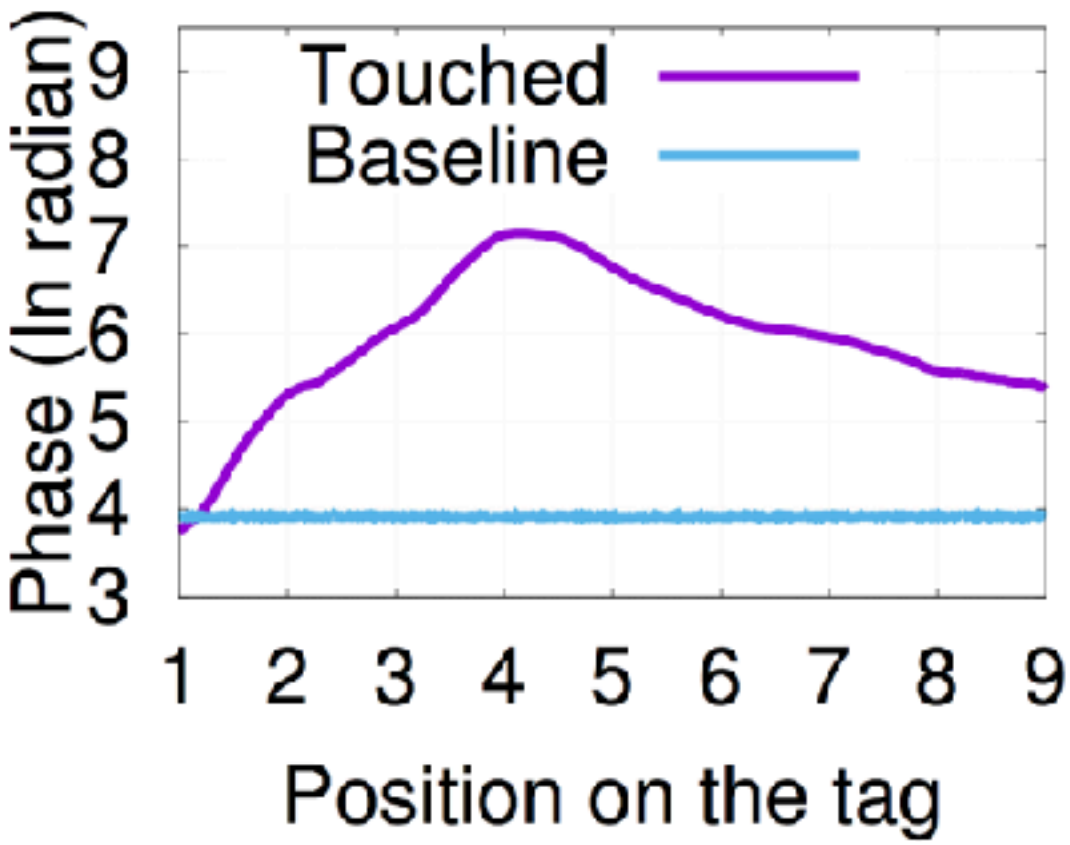
Predictable Phase Pattern

This change is also present in NLoS

This change is also present in NLoS

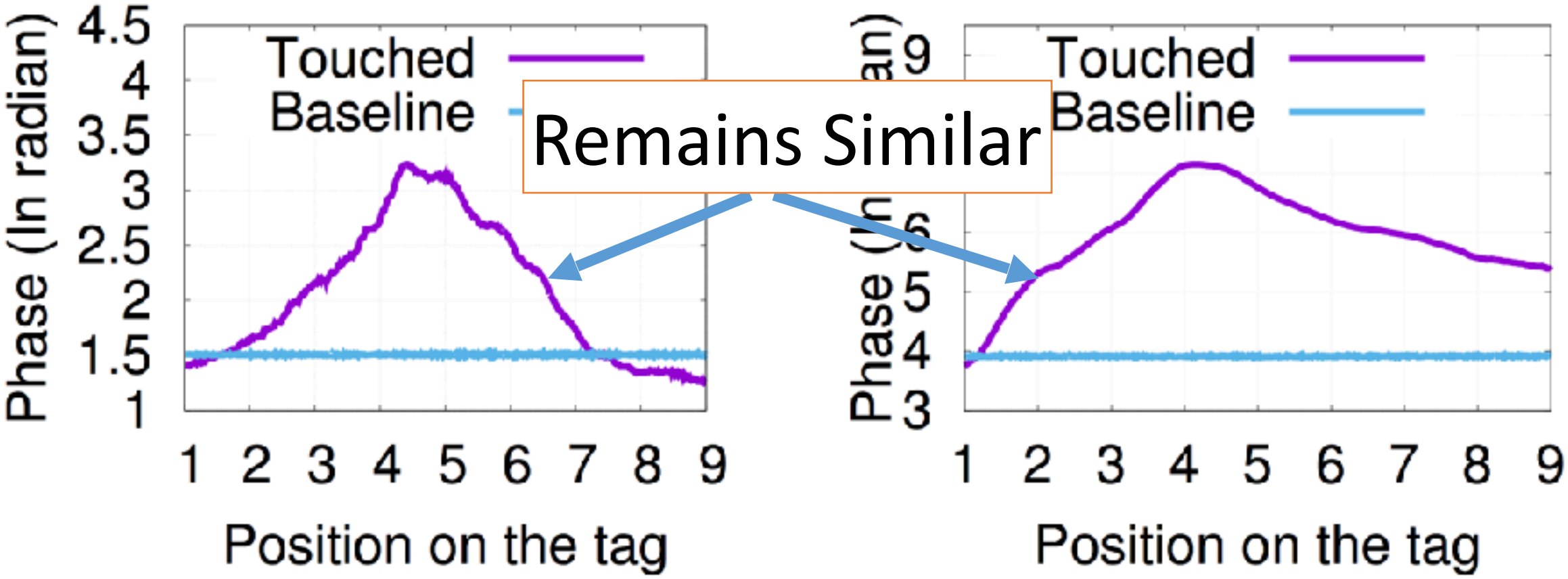


Behind a Wall



Behind a Door

This change is also present in NLoS



Behind a Wall

Behind a Door

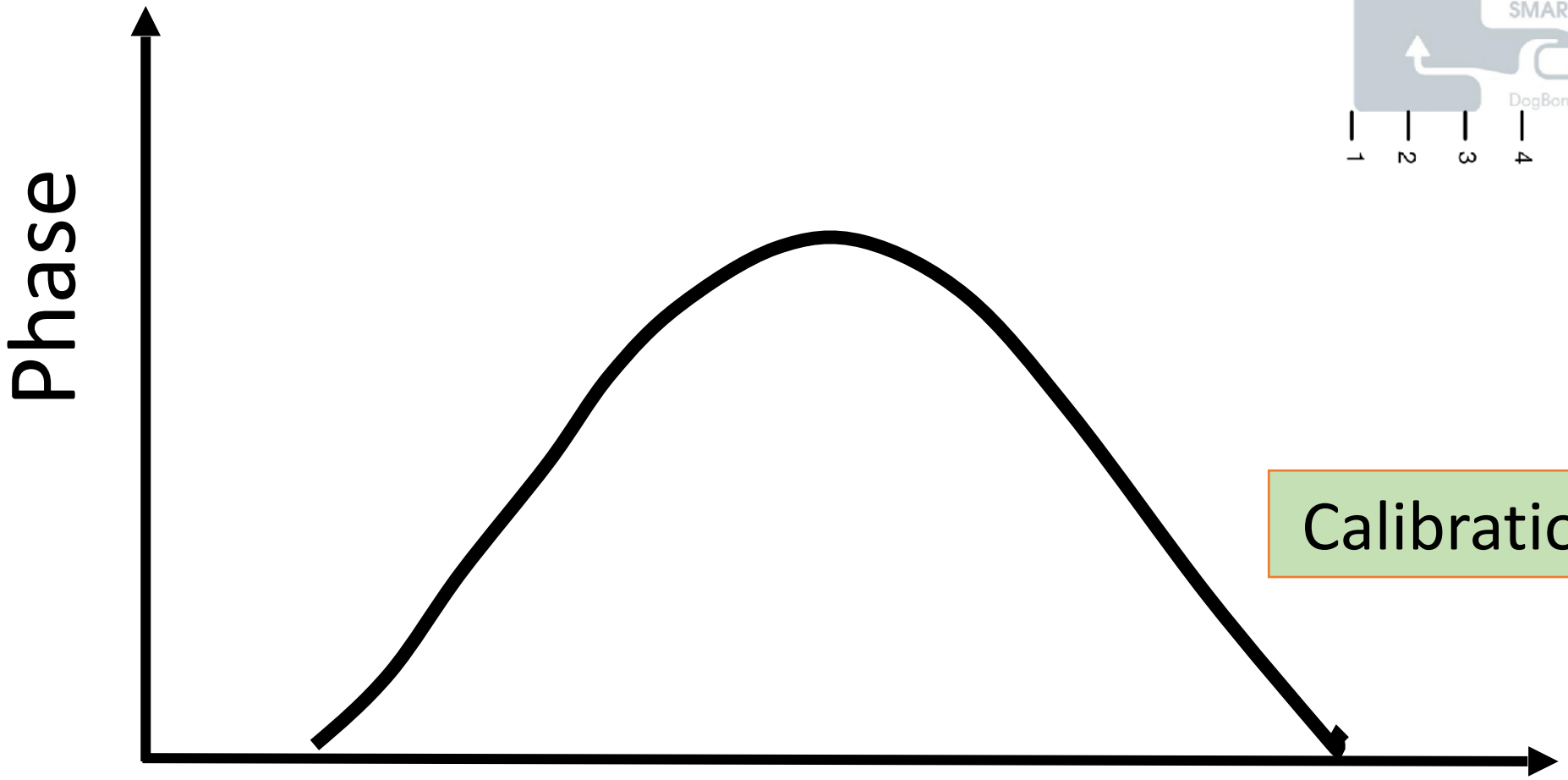
Single tag tracking algorithm sketch

Single tag tracking algorithm sketch

Phase

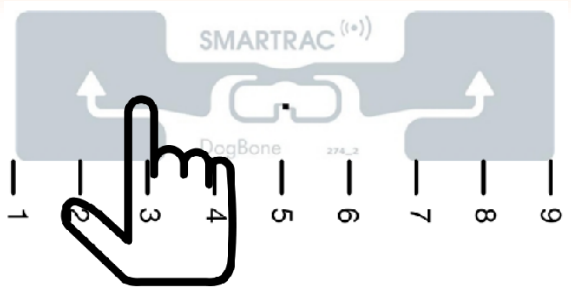
Tag Position

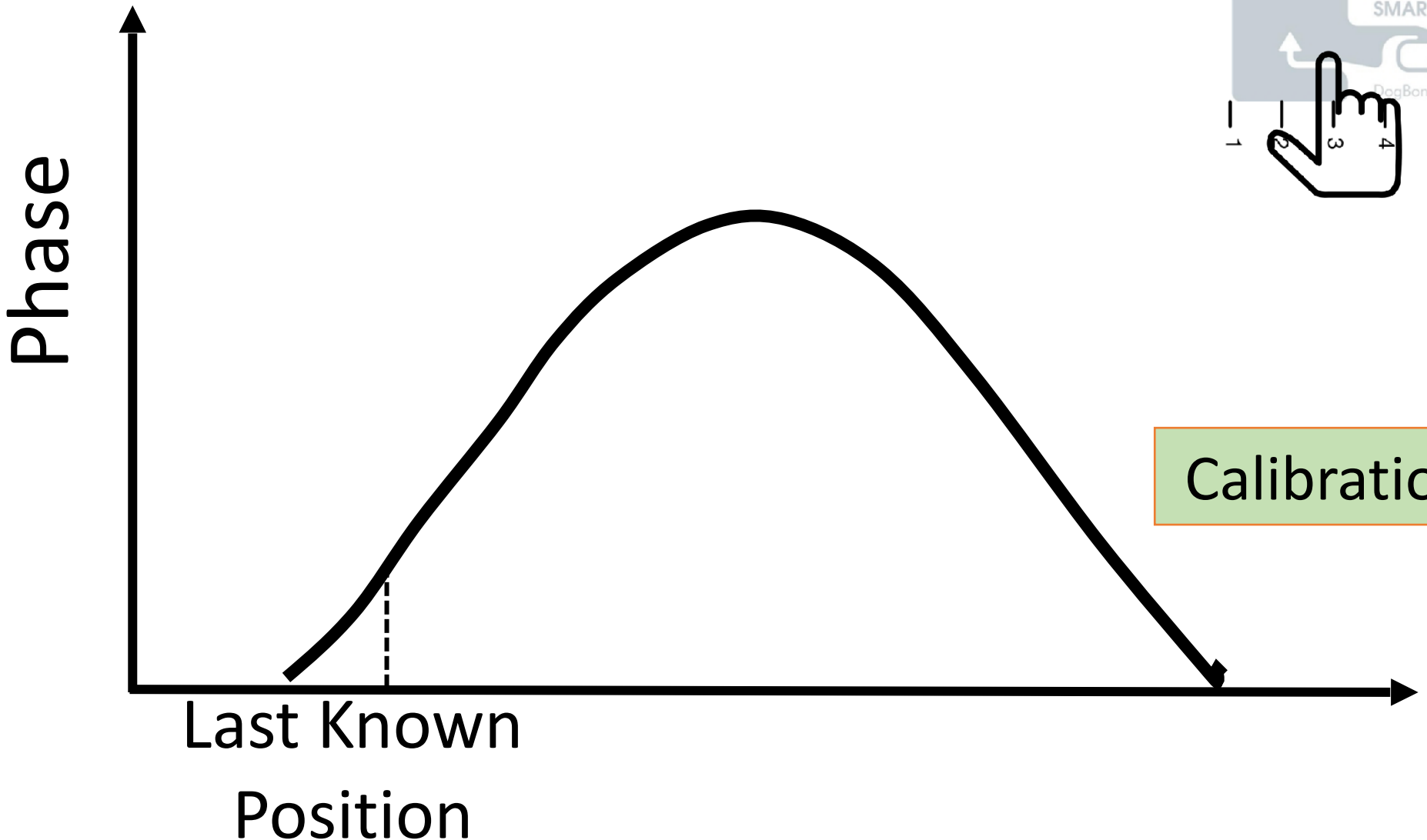
Single tag tracking algorithm sketch



Calibration Phase

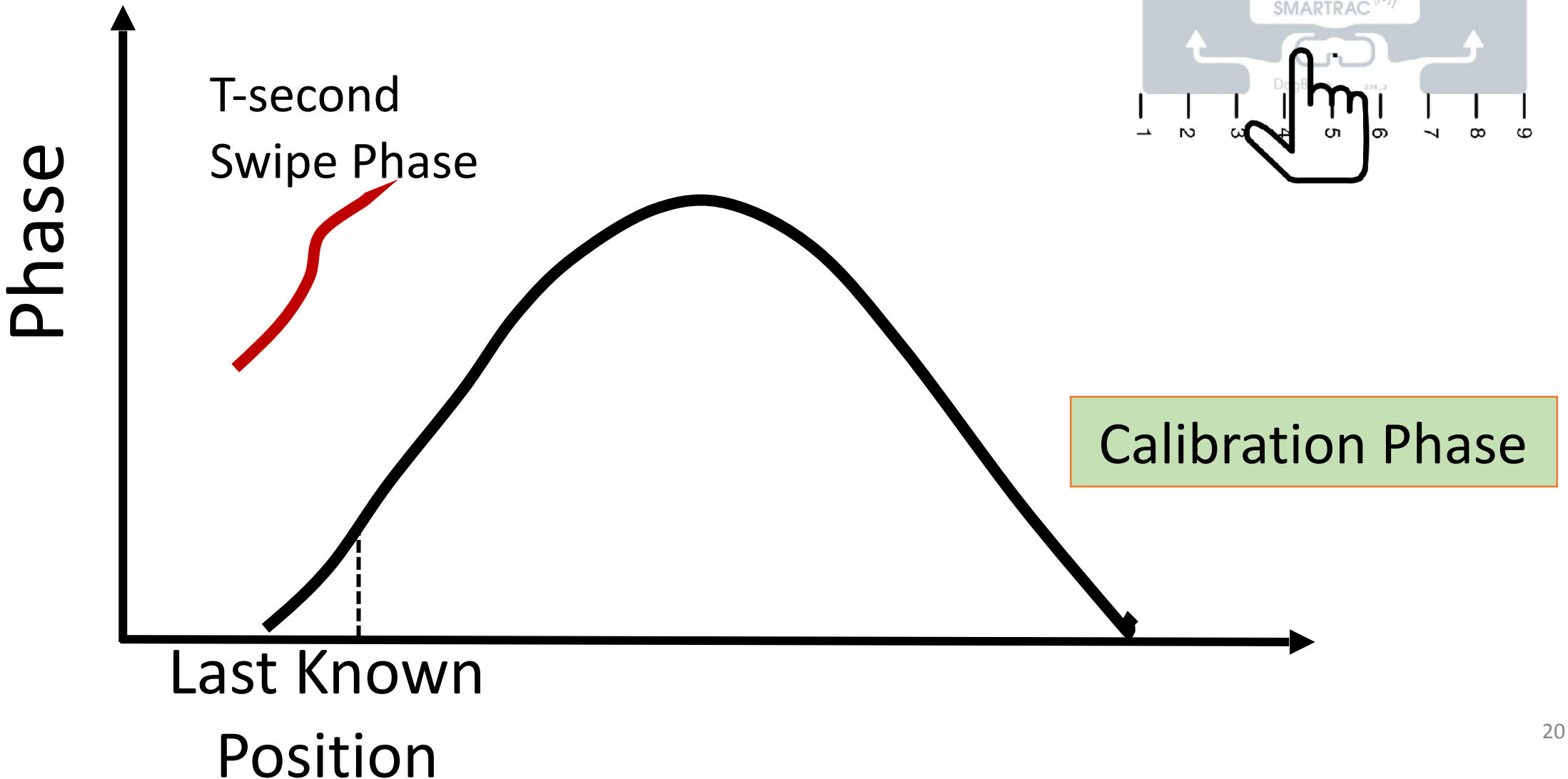
Single tag tracking algorithm sketch



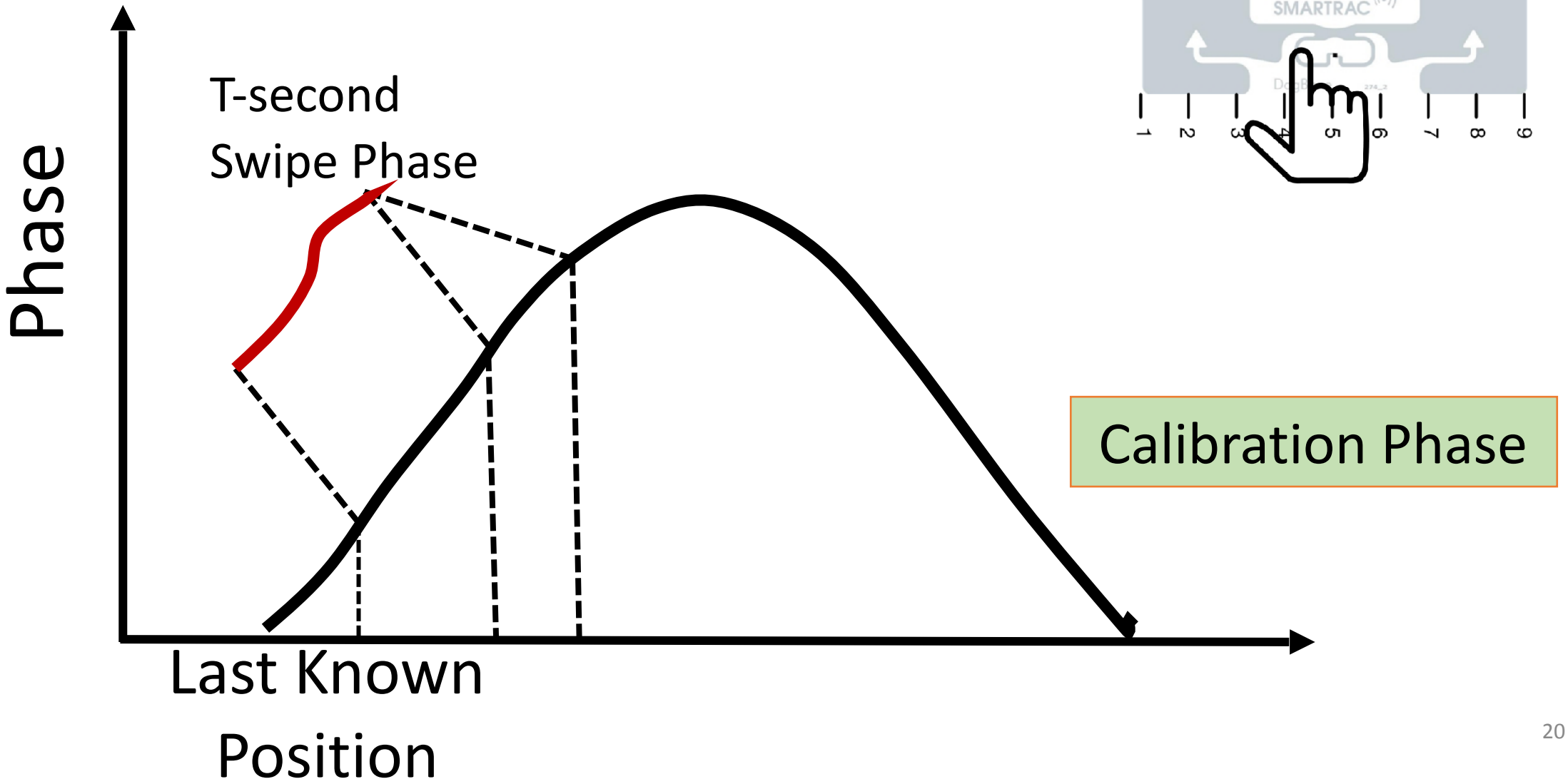


Calibration Phase

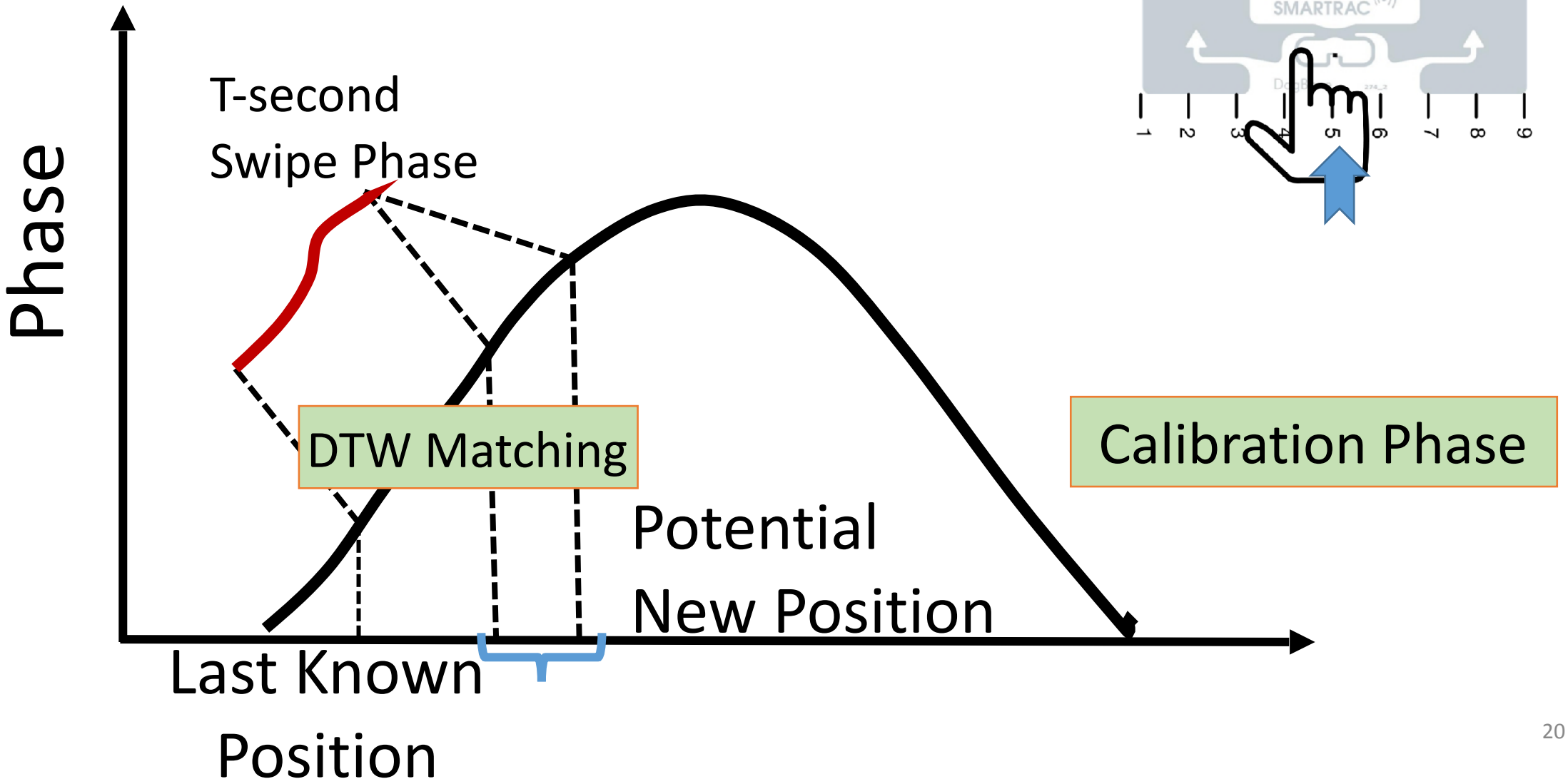
Single tag tracking algorithm sketch



Single tag tracking algorithm sketch



Single tag tracking algorithm sketch



Key Idea and Reasoning

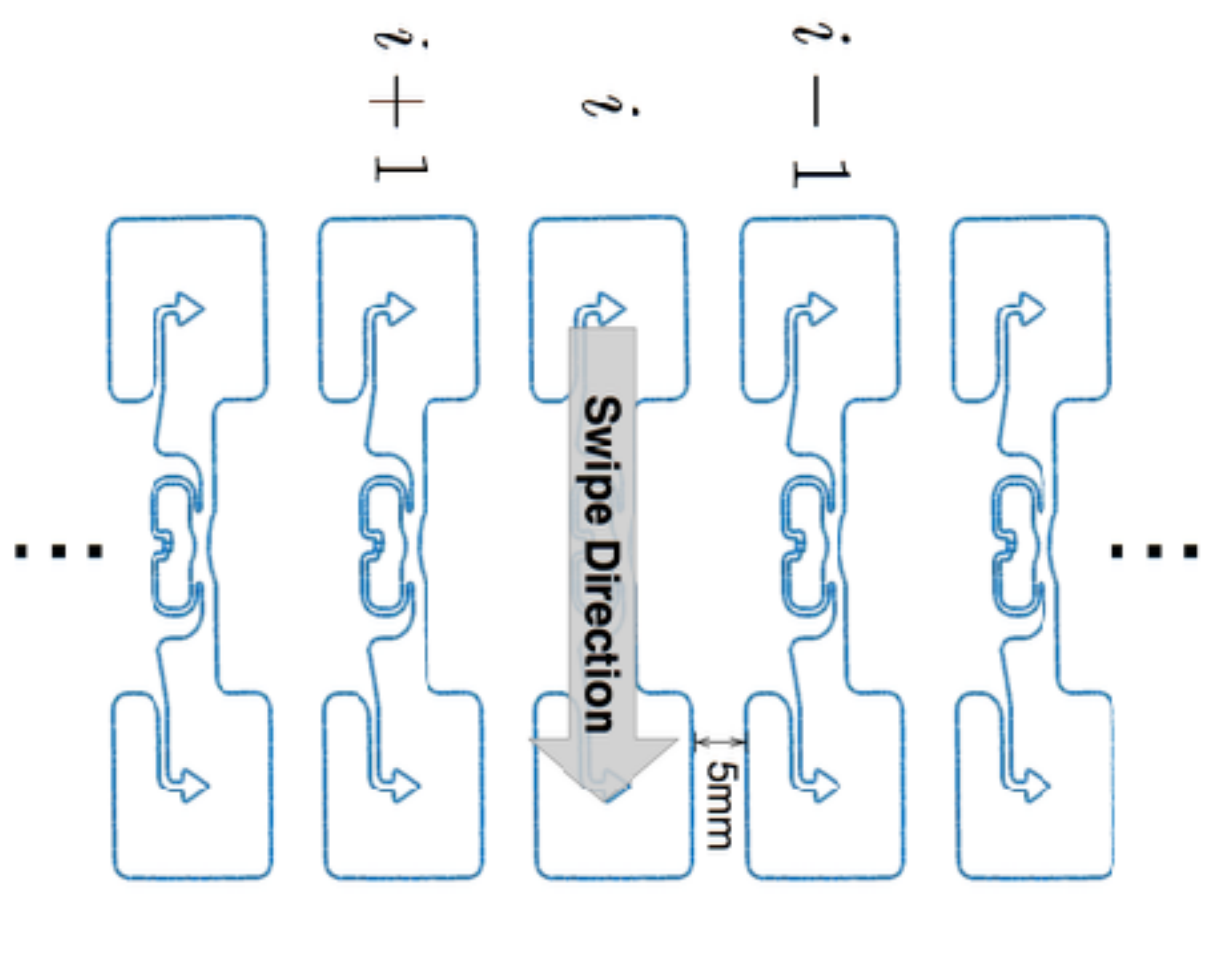
Touch and Single Tag Tracking

Tracking within Multiple Tags

Evaluation

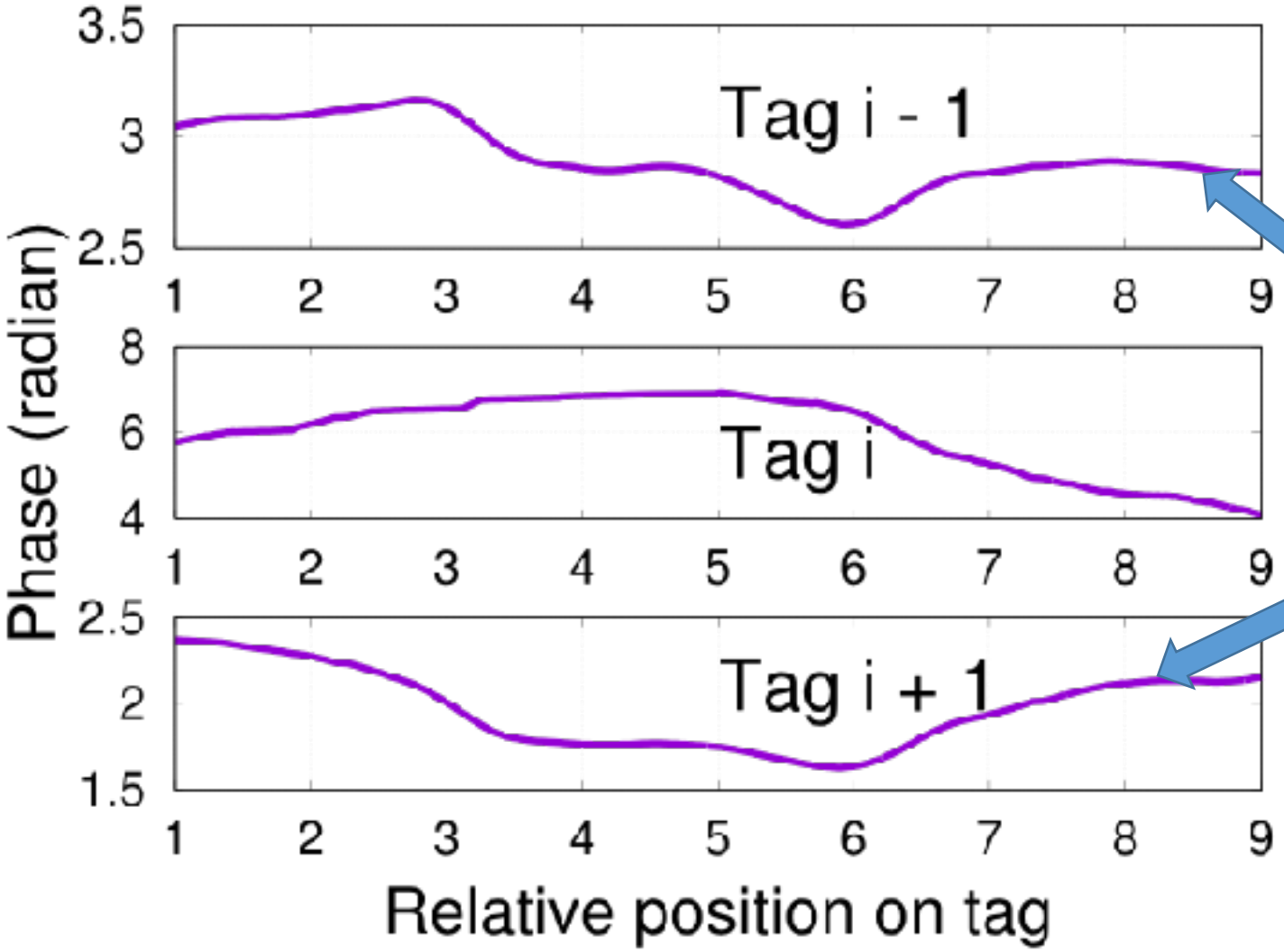
Tracking within Multiple Tags

Tracking within Multiple Tags



Mutual coupling phenomenon

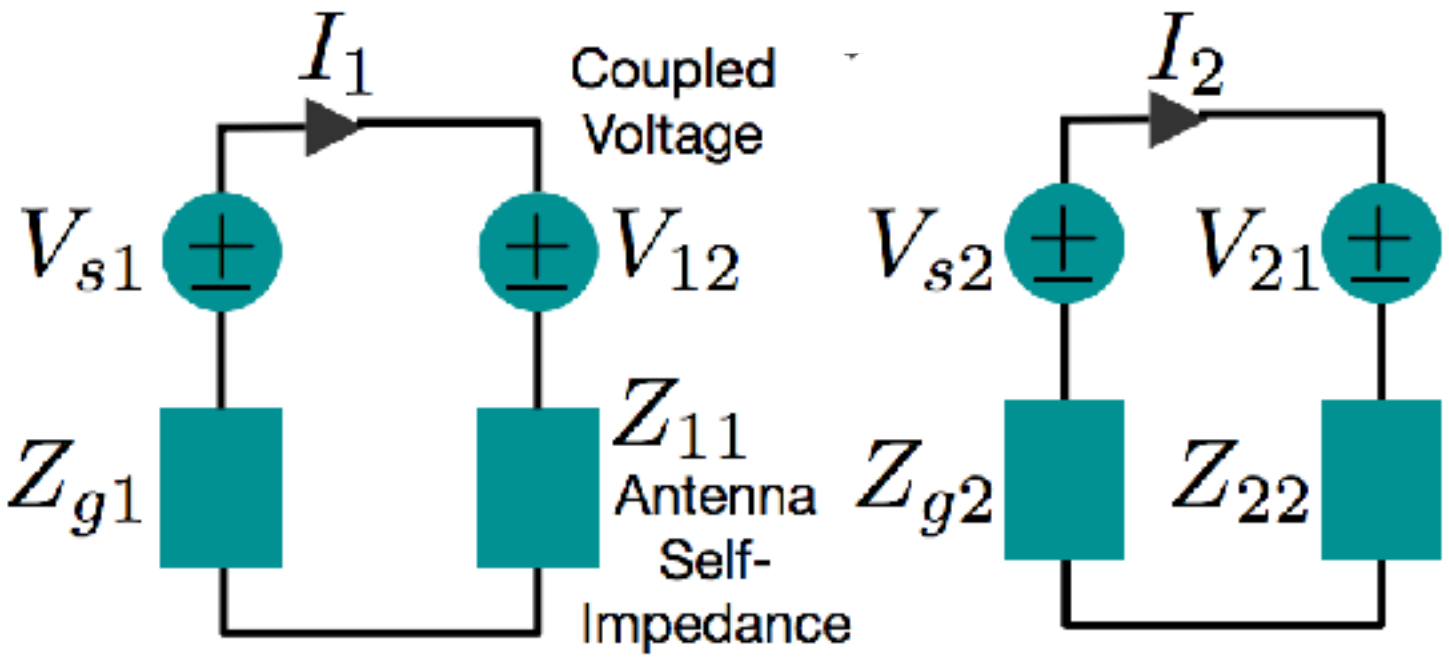
Mutual coupling phenomenon



Neighboring tags show reverse phase pattern

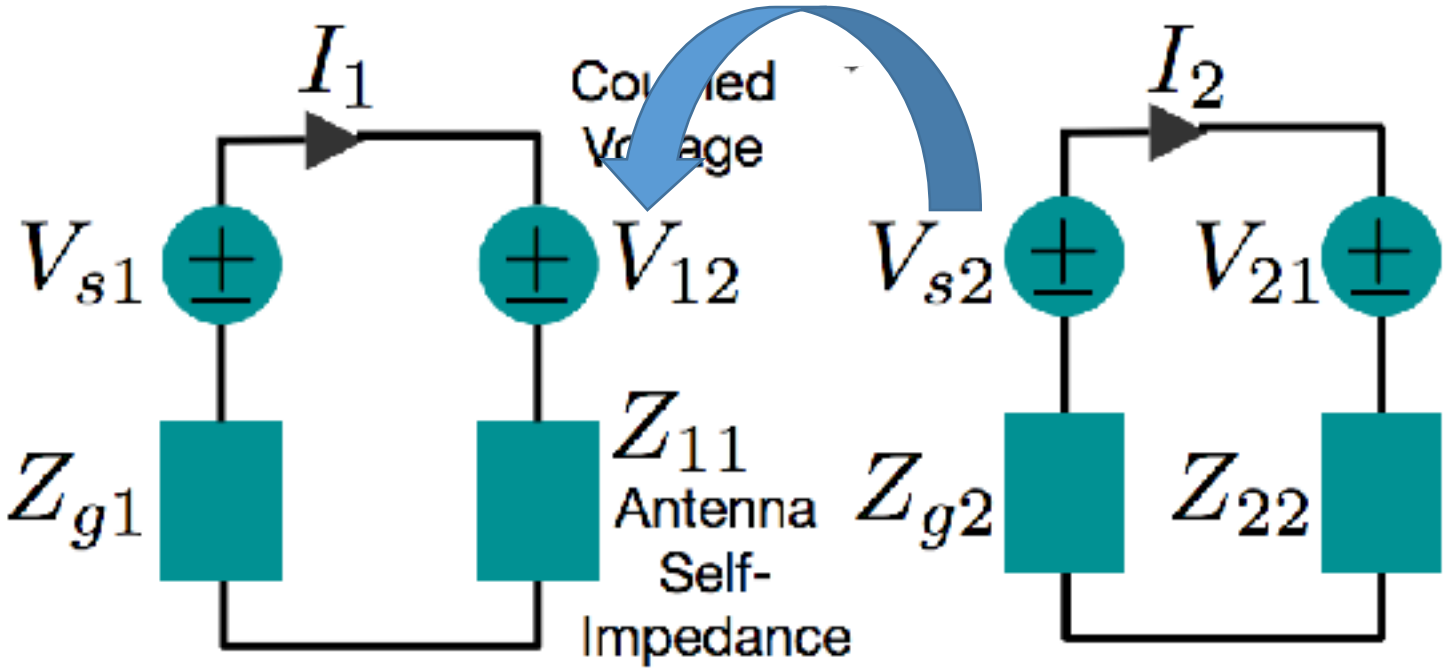
Why does it happen ?

Why does it happen ?



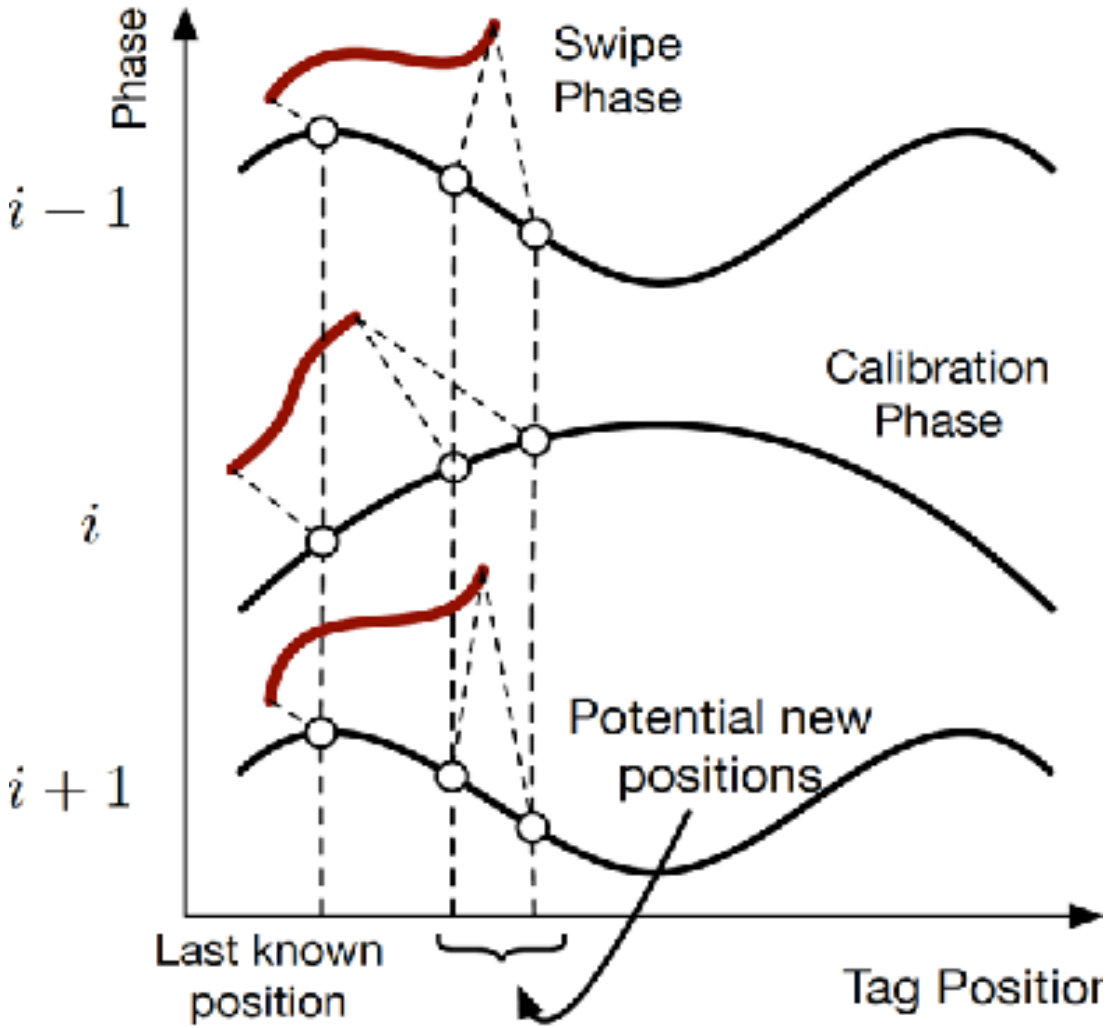
Why does it happen ?

Coupled mutual impedance has
reverse impact in back-scattered phase

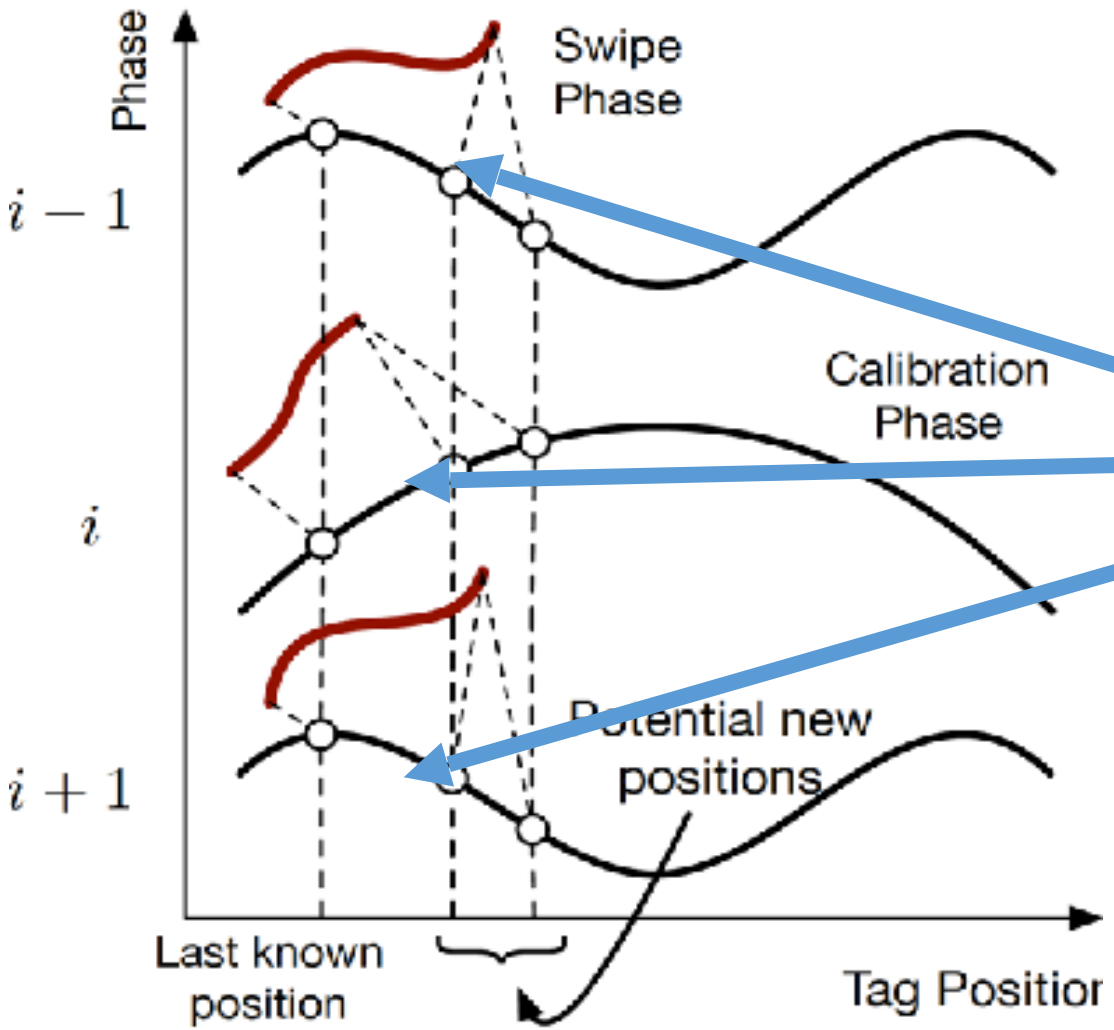


Multi tag tracking algorithm sketch

Multi tag tracking algorithm sketch



Multi tag tracking algorithm sketch



Apply joint DTW matching

Key Idea and Reasoning

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Tracking within Multiple Tags

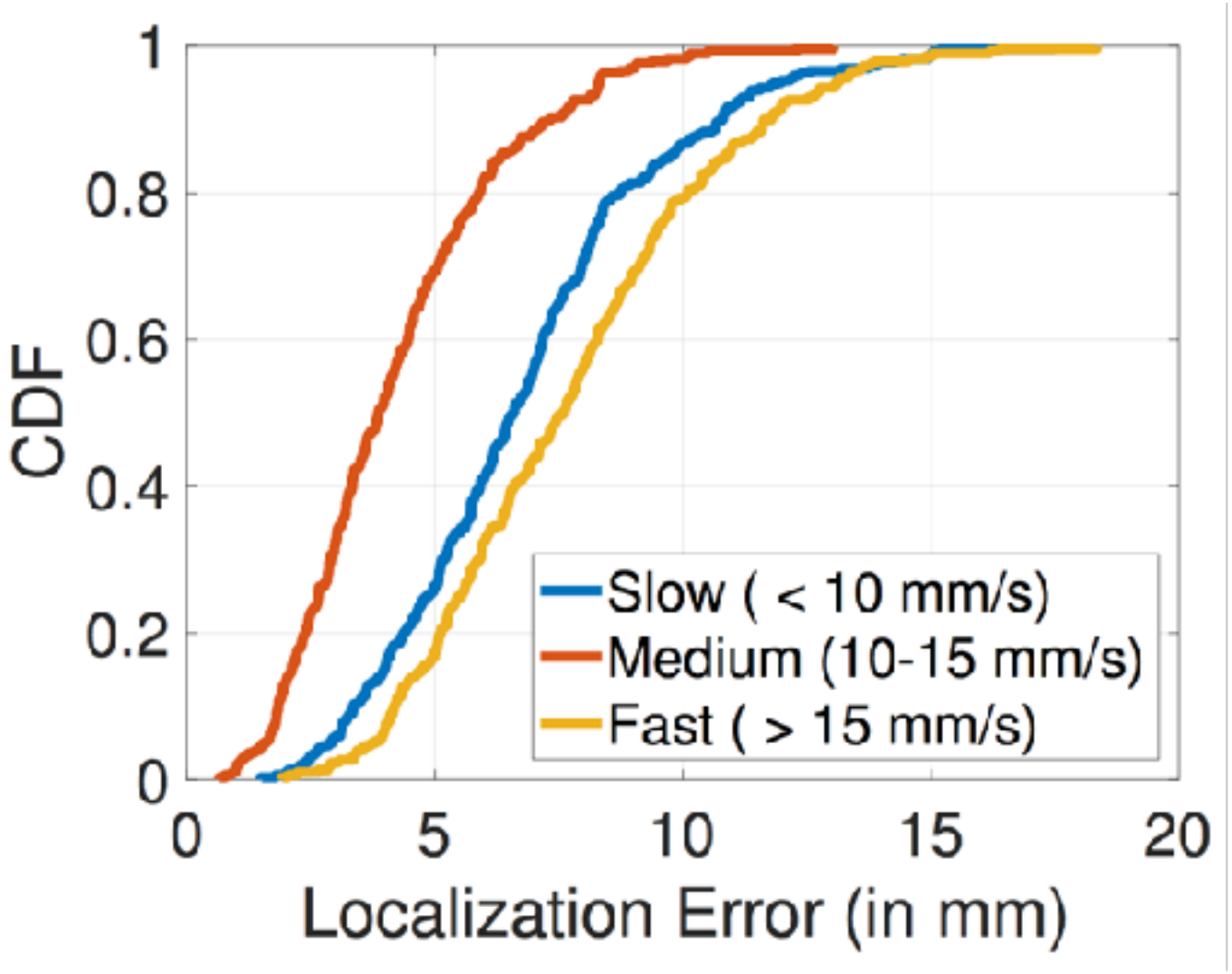
Evaluation

Experimental Setup

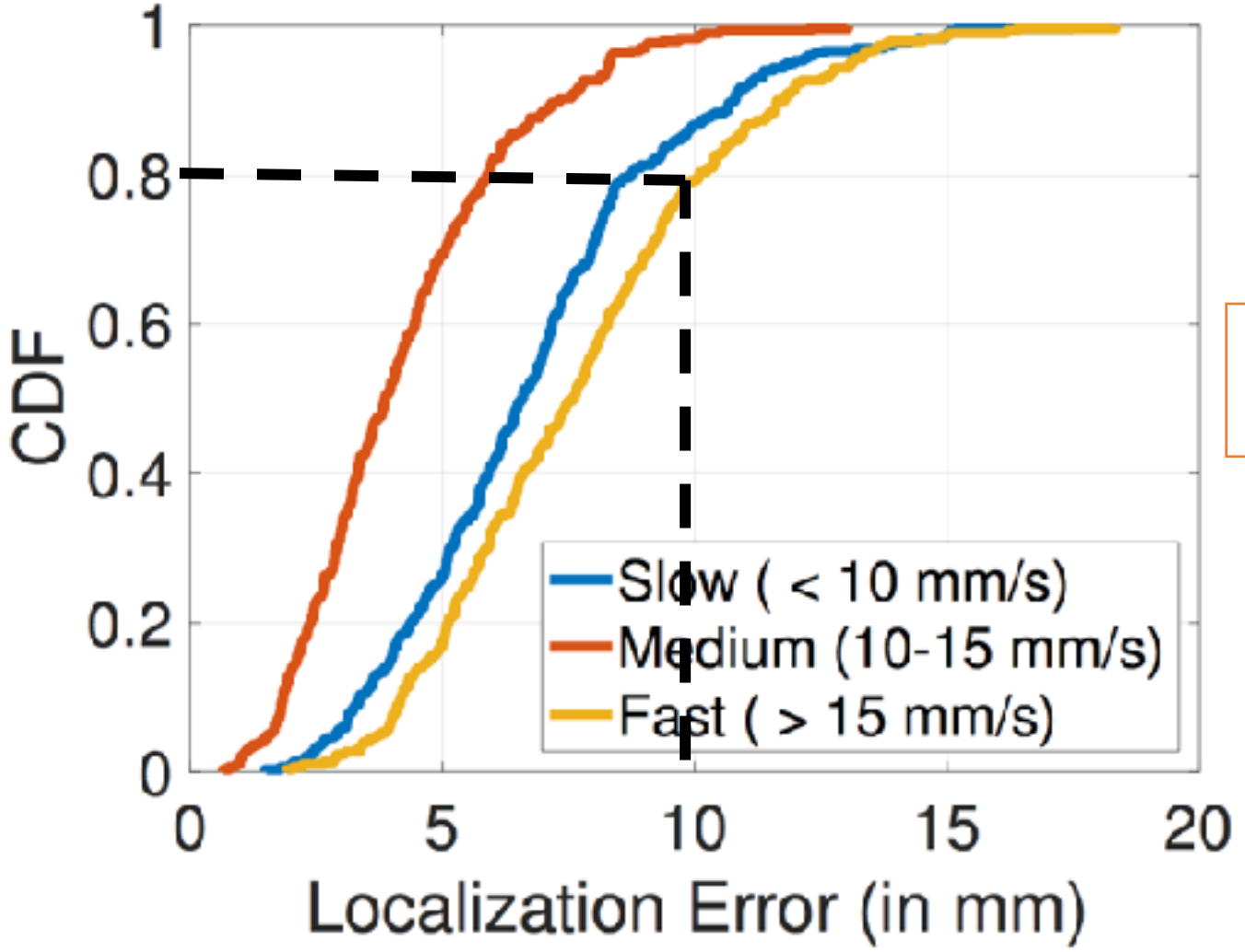
Experimental Setup

Single Tag Tracking Accuracy

Single Tag Tracking Accuracy



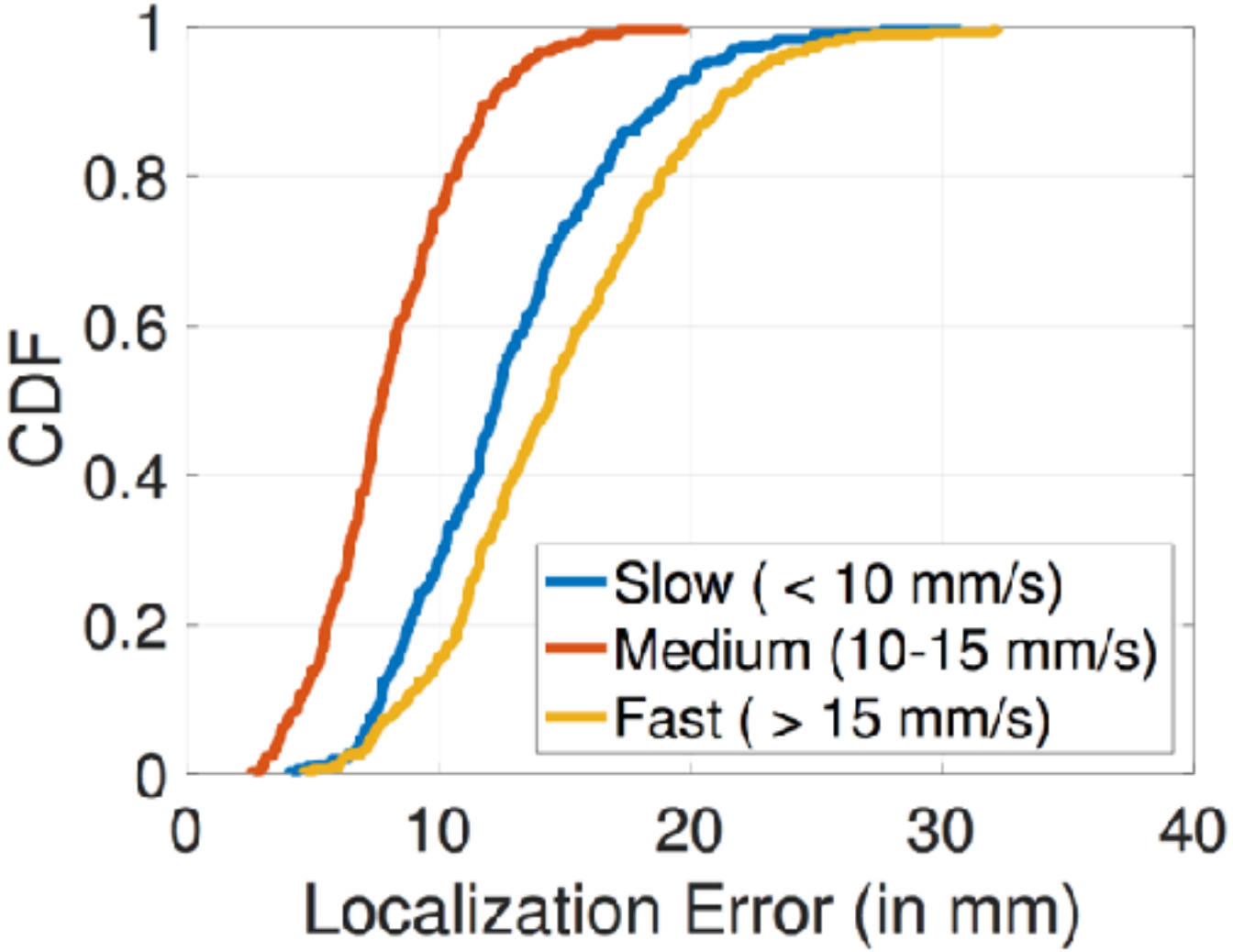
Single Tag Tracking Accuracy



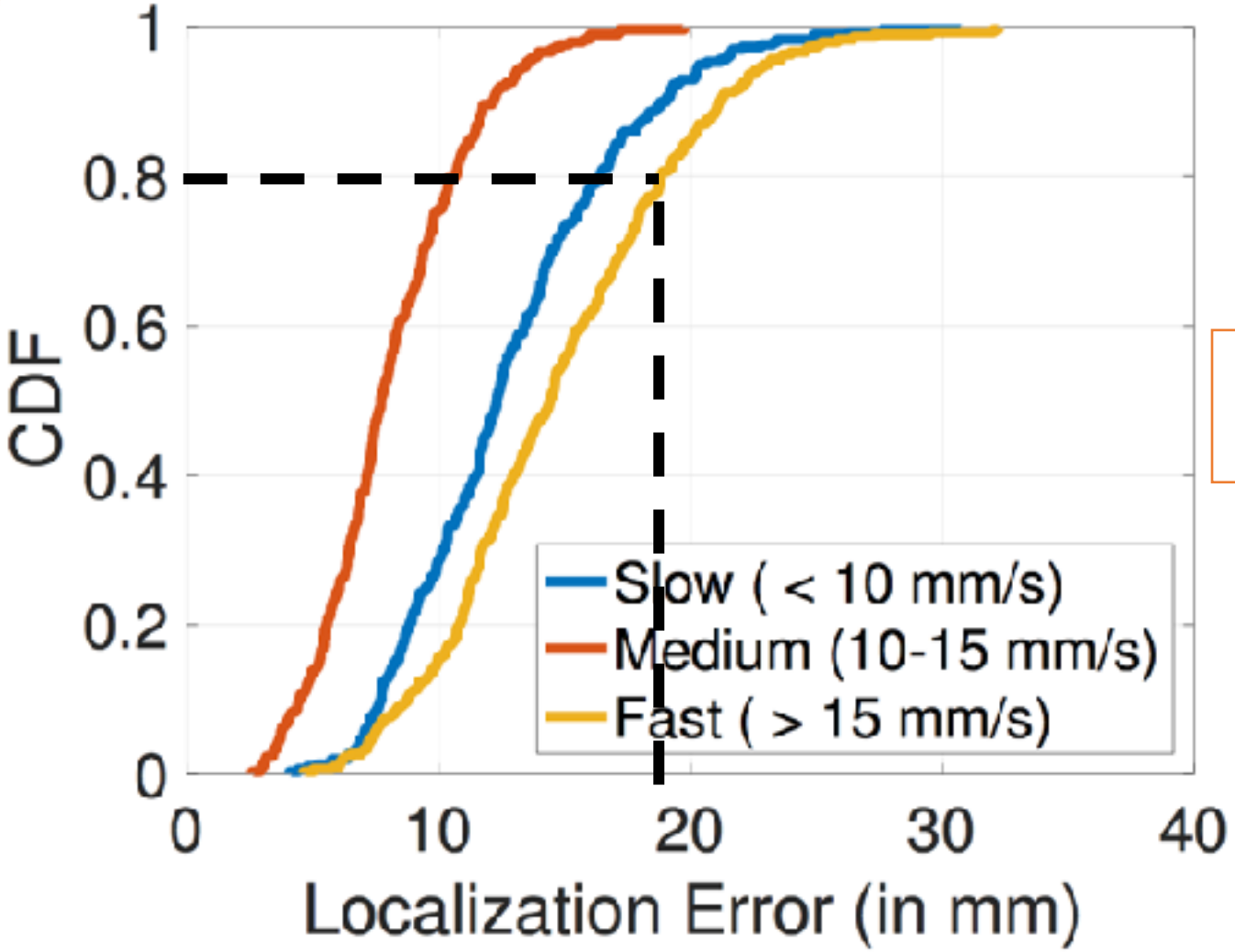
Error ~10 mm

Multi Tag Tracking Accuracy

Multi Tag Tracking Accuracy



Multi Tag Tracking Accuracy

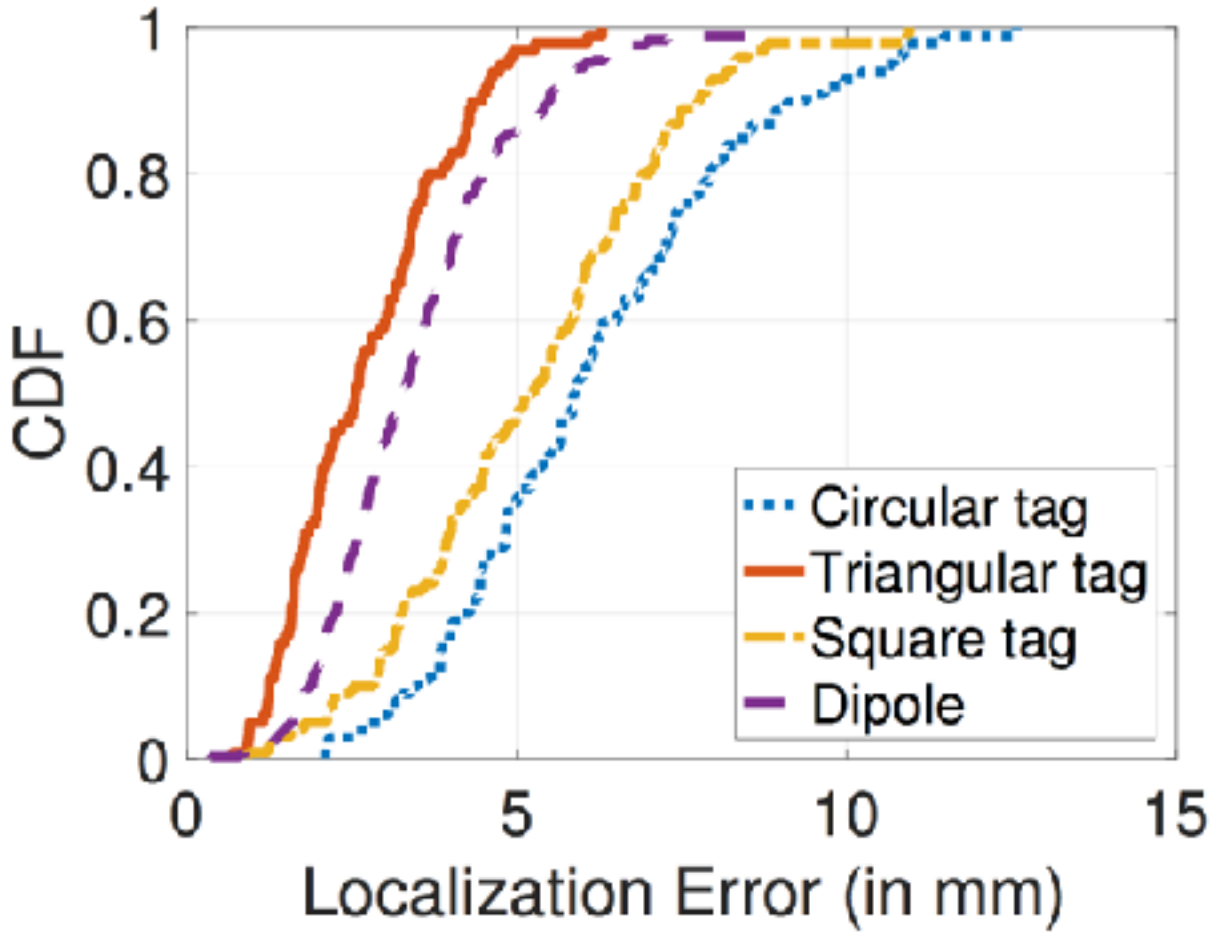


Error ~18 mm

Custom Tag Tracking Accuracy

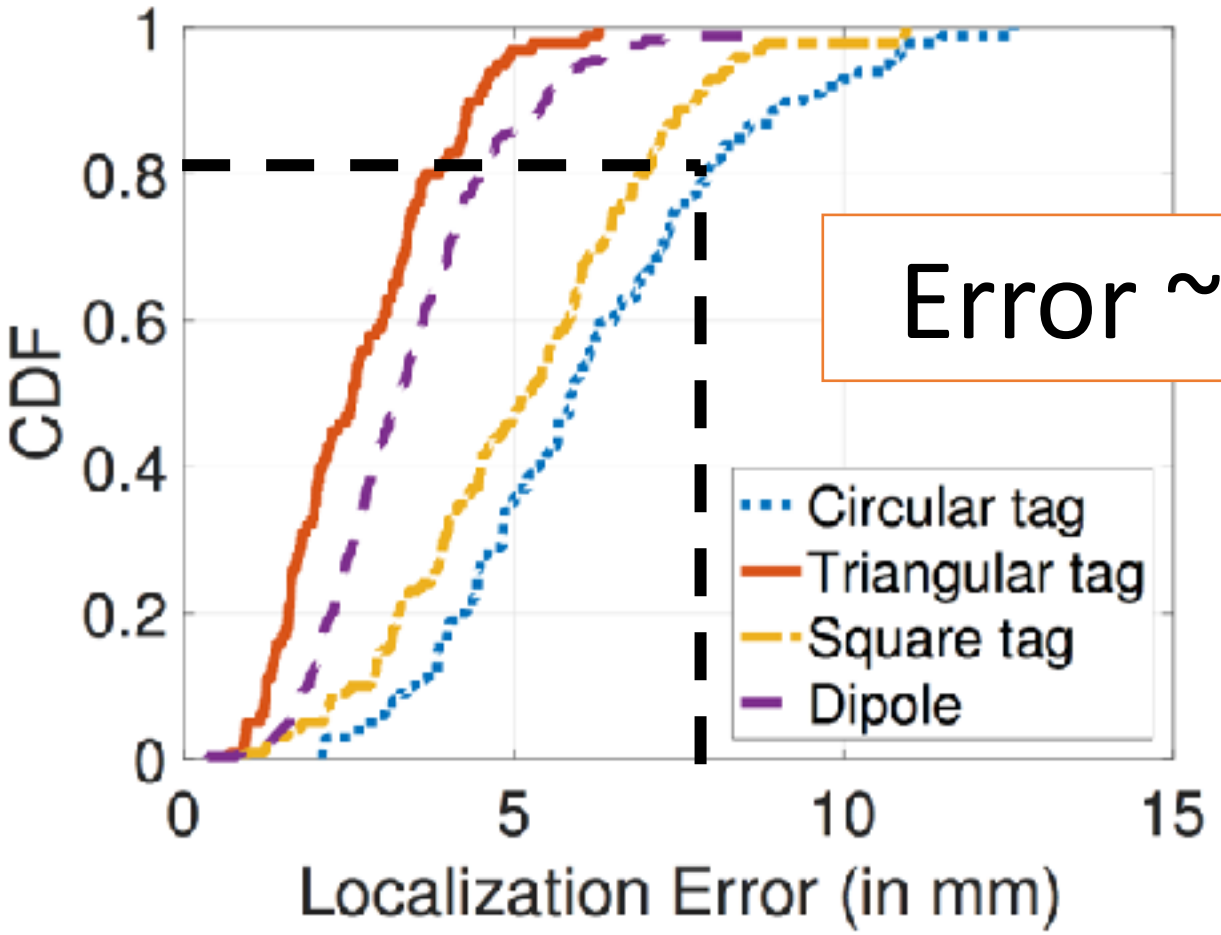
Custom Tag Tracking Accuracy

Custom Tags



Custom Tag Tracking Accuracy

Custom Tags



Error ~10 mm

Related Works

Related Works

- RFID based gesture recognition – Data-driven learning
  - ShopMiner (SenSys ‘15), FEMO (SenSys ‘15), CBID (ToN ‘16) …
- RFID tag tracking – Tracks tag movement
  - RF-IDraw (SIGCOMM ‘14), Tagyro (Mobicom ‘16), PolarDraw (CoNext ‘16) …
- RFID based UI (Closest) – ML on a fixed set of gestures
  - PaperID (CHI 2015), IDSense (CHI 2016) …

Future works

- Multi-touch tracking
- General 2D gesture tracking
- Tracking in different environment scenarios
- Building customized tags for other use cases

Key takeaways

- Impedance Tracking based Touch Primitive
- Mutual coupling can be exploited
- Custom designed tags may enable different applications

Thanks! Questions ?

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