Indoor Localization Based on LoRa 2.4 GHz

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Oana Iova, Fabrice Valois

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Journées LPWAN 2025

Plan

- Introduction
- Crash course on Indoor localization
- Hands on Experiments
- Work in Progress

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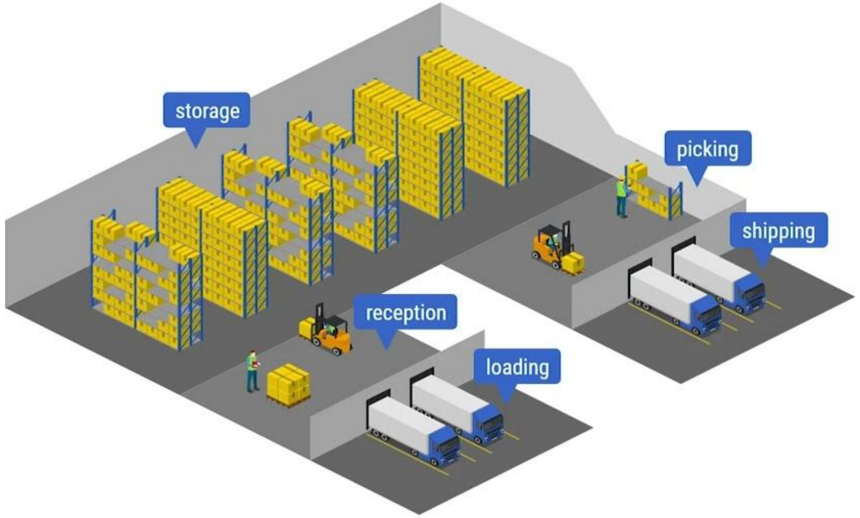
Context

Why do we need indoor localization?

Lost Tag: (x?, y?)

Airport



Warehouse

Buildings

Motivation

Why use LoRa 2.4Ghz?

	LoRa 2.4GHz	LoRa	GNSS	Sigfox	5G	WiFi	BLE	UWB	RFID
Dominant Use: Indoor or Outdoor	In & Out	Out	Out	Out	Out	In	In	In	In
Location accuracy (m)	2	20-200	2-3	500	1	5	2	0.3	0.01
Operating Range (km)	2-5	10-15	‘000s	10-15	0.2-0.3	0.2	0.2-0.3	0.03	0.2
Network Density (aka anchors)	Very Low	Very Low	Ultra Low	Very Low	Very Low	High	High	Very High	Very High

Ref: https://www.youtube.com/watch?v=cyayif_nla8&list=LL&index=6

Motivation

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Motivation

Why use LoRa 2.4Ghz?

Higher Bandwidth Compared to Sub-GHz LoRa

2.4 GHz allows for higher bandwidth configurations, enabling **faster data rates** and **shorter time-on-air**, which is beneficial for real-time localization (Good Trade-off between Range vs. Accuracy)

Support for Ranging

SX1280 chipset supports **time-of-flight based ranging**, enabling direct distance estimation between nodes, which is **key for accurate localization**.

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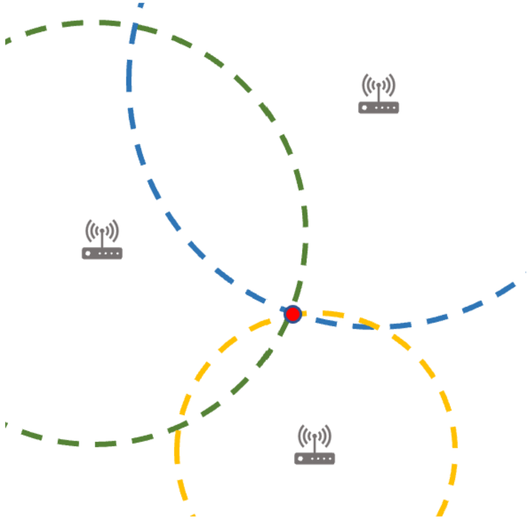
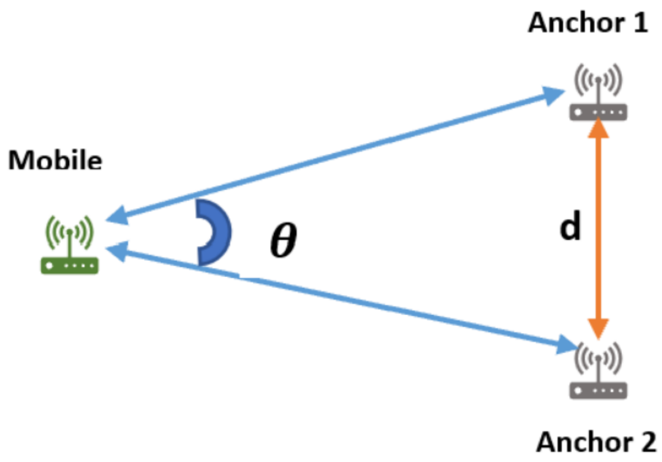
Indoor Localization Techniques

Trilateration



https://www.uni-kiel.de/de/tf/forschen/institut-informatik/verteilte-systeme

Angulation



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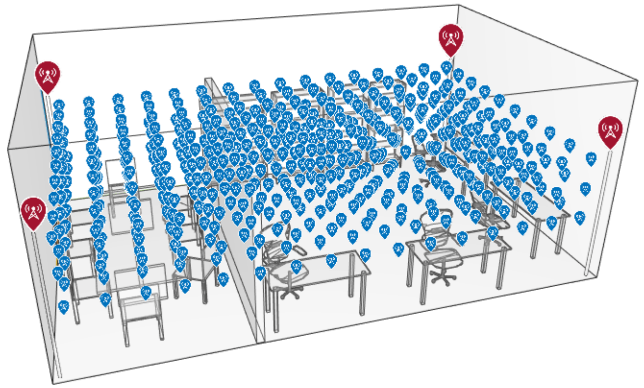
Fingerprining



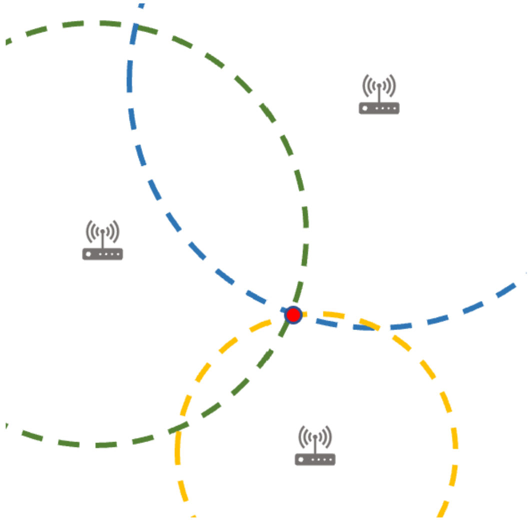
https://de.mathworks.com/help/wlan/ug/three-dimensional-indoor-positioning-with-802-11az-fingerprinting-and-deep-learning.html

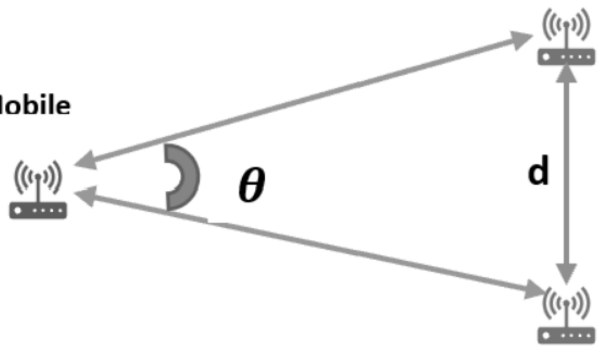
Indoor Localization Techniques

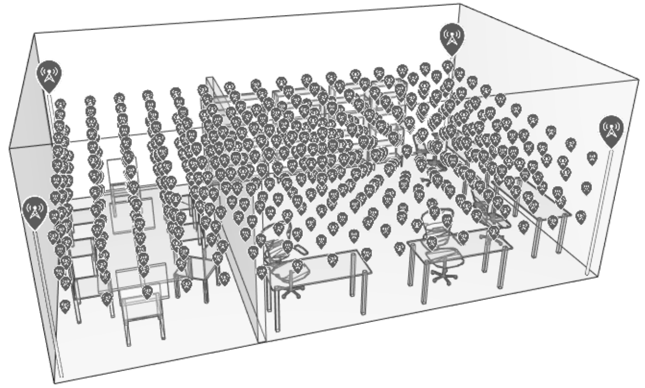
Trilateration

Angulation

Fingerprining



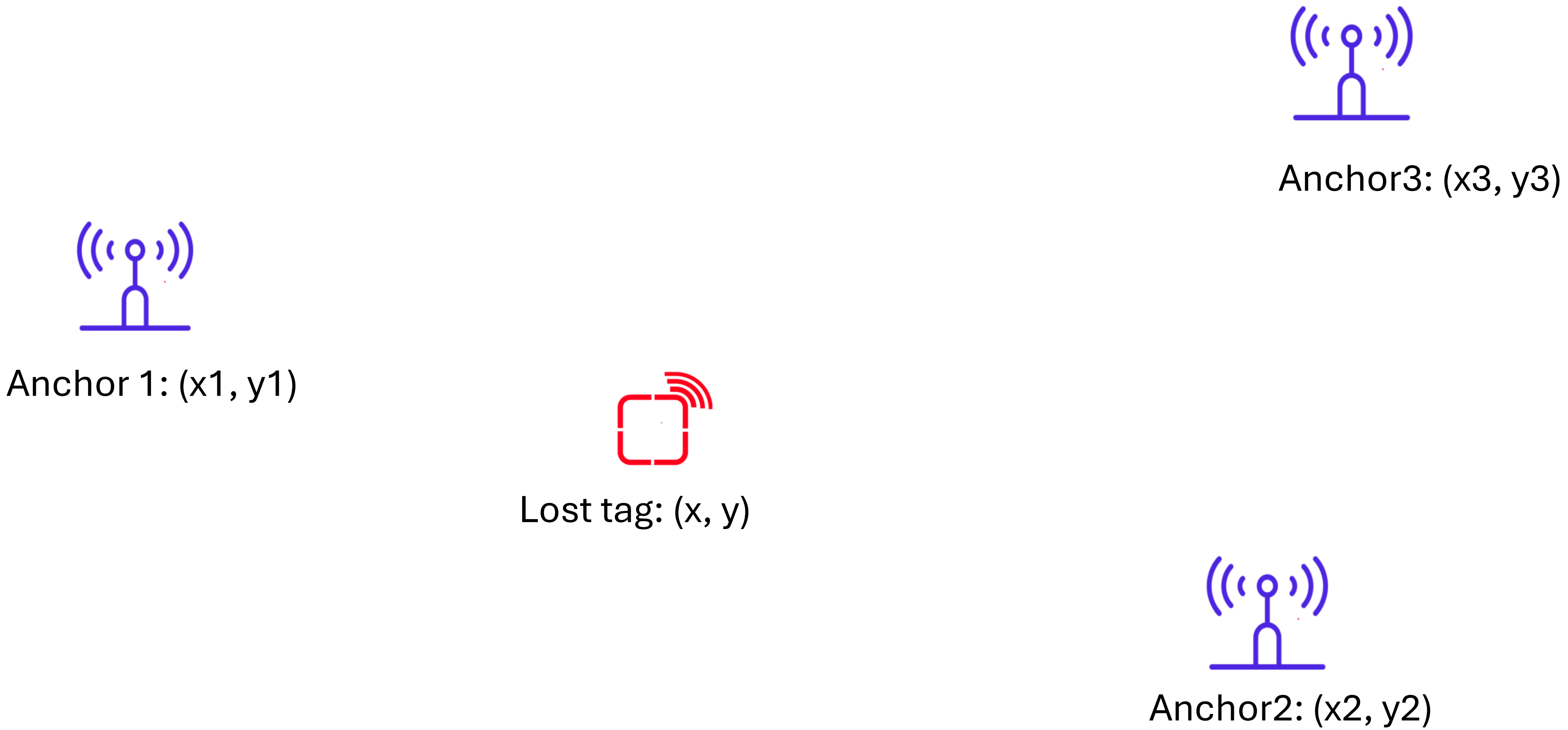




In our work, we will focus first on ***Trilateration***

Trilateration

Where is my Tag?



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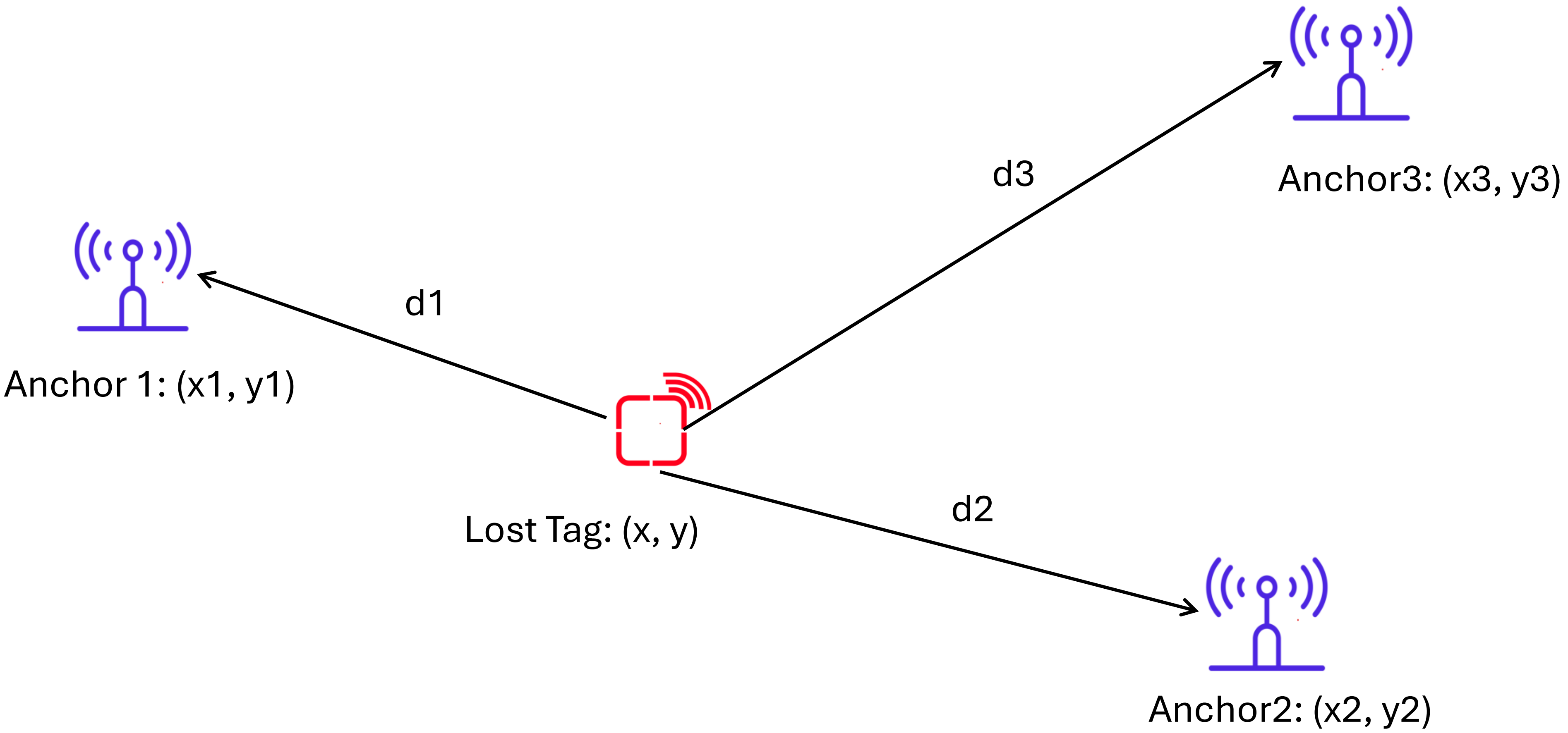

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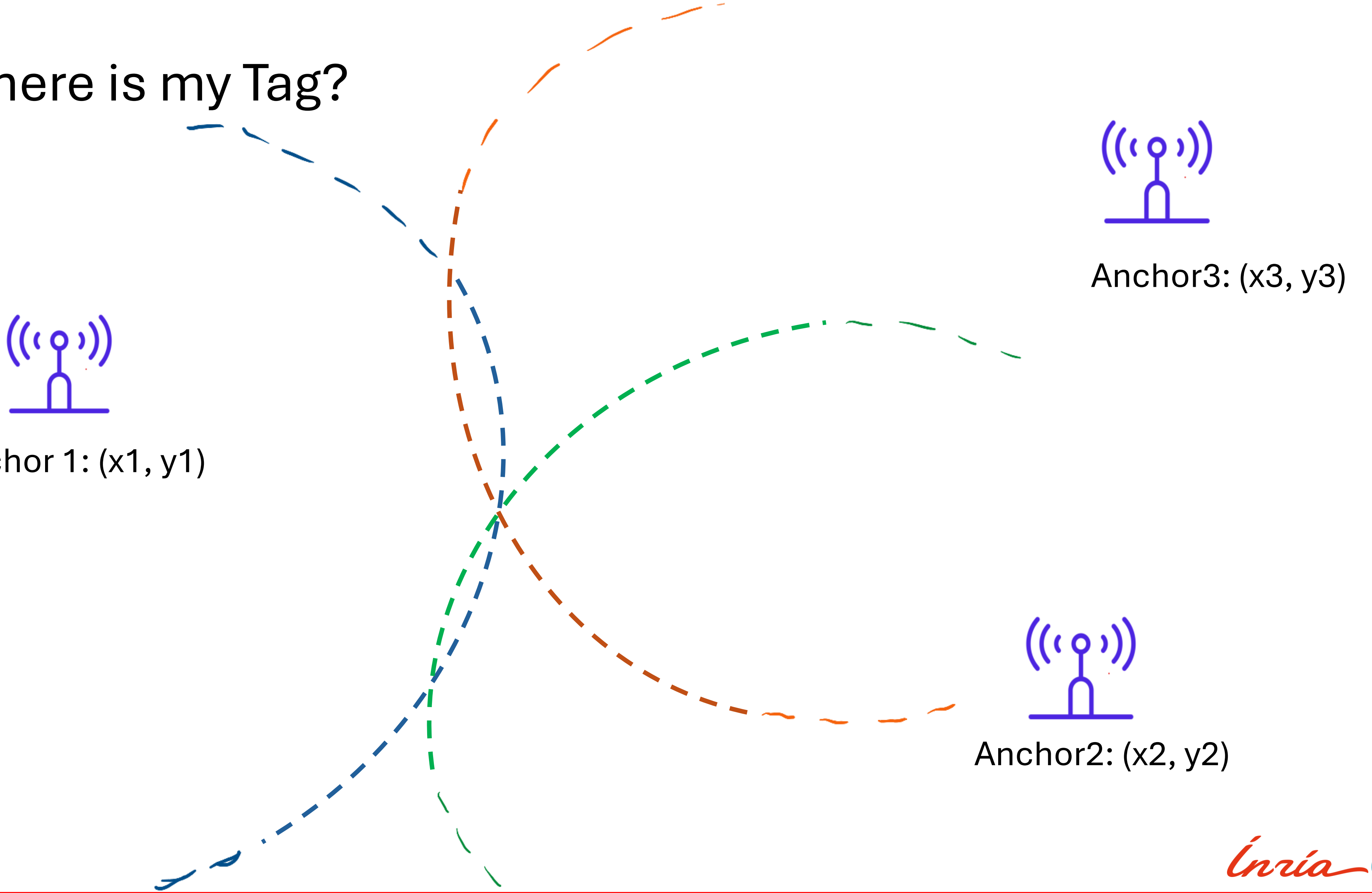

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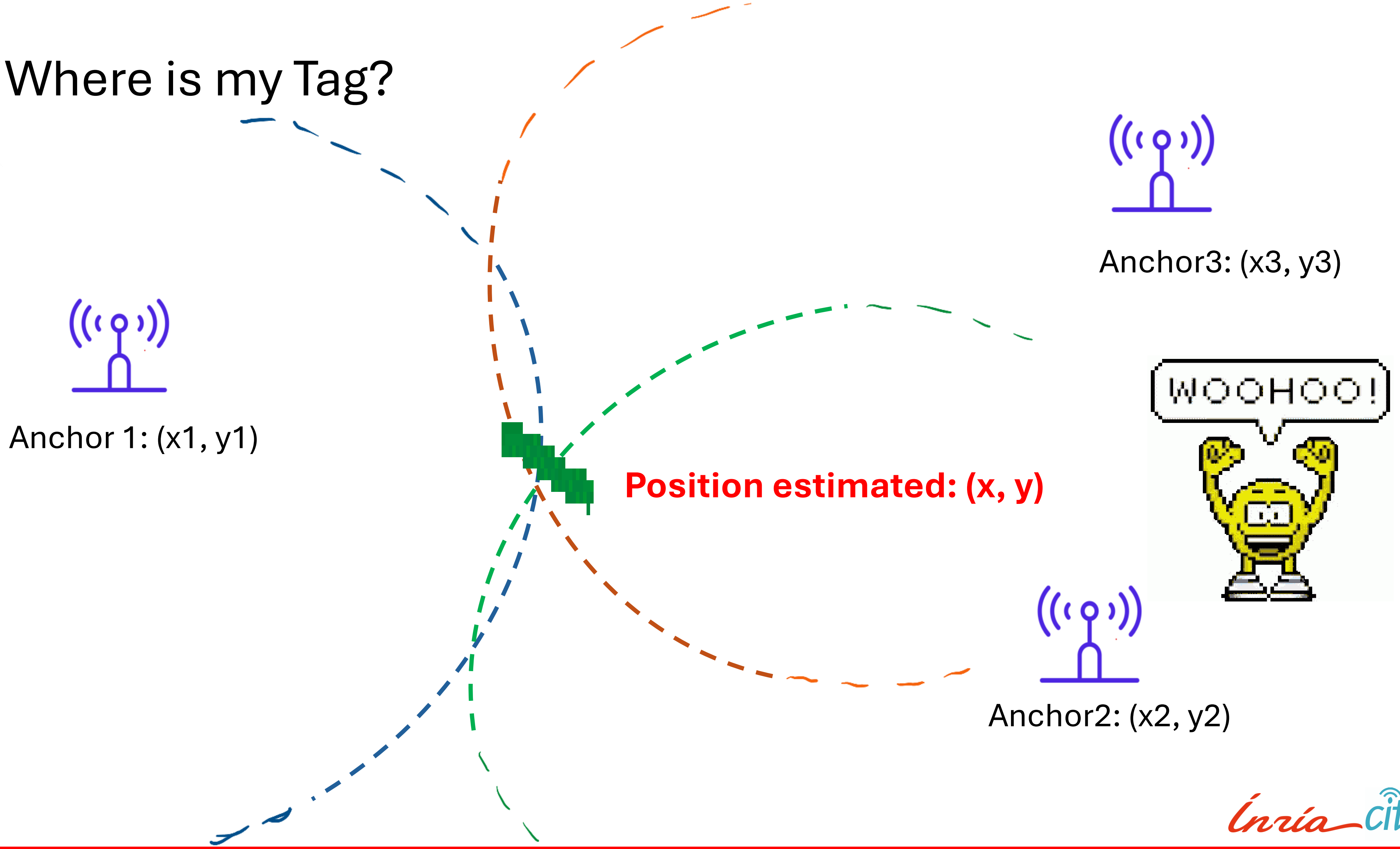
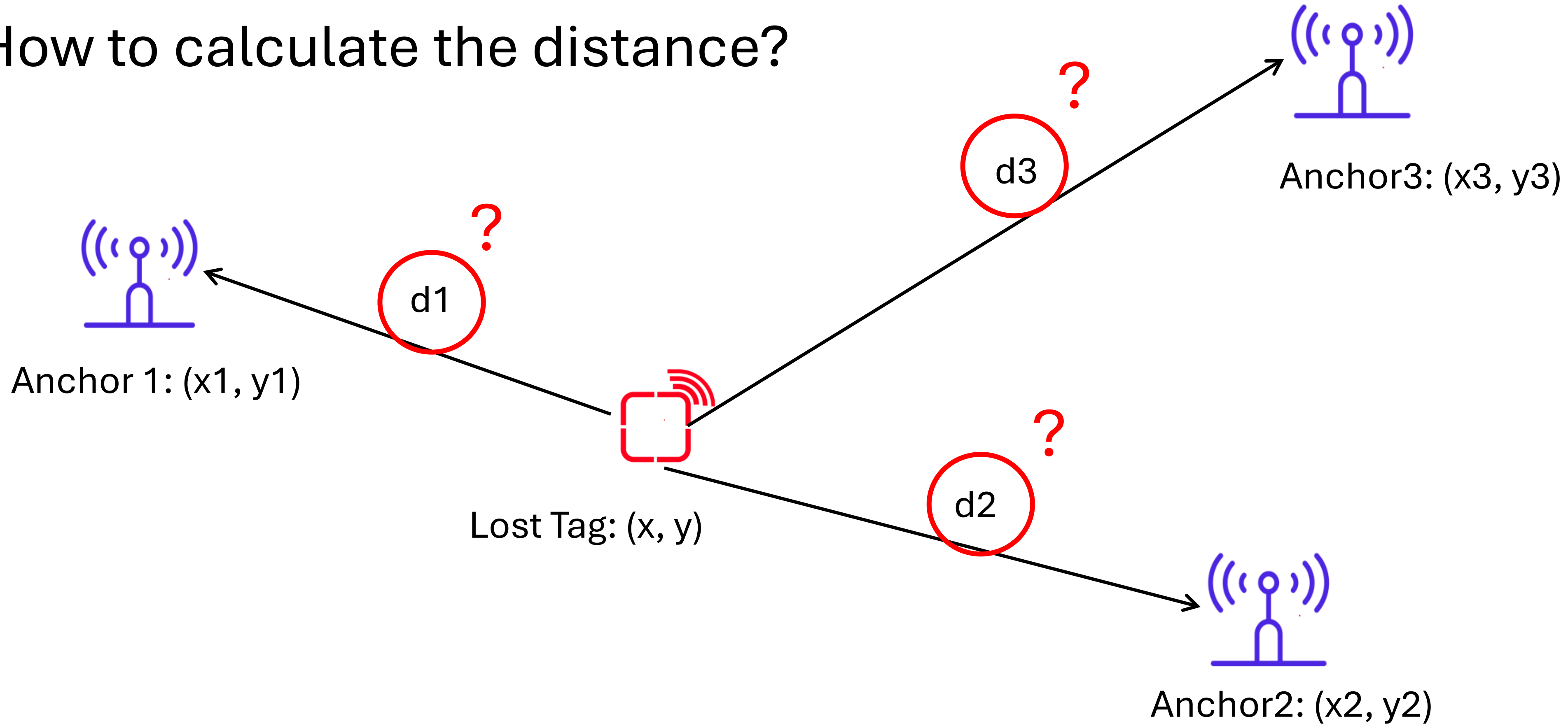


Indoor Ranging

How to calculate the distance?



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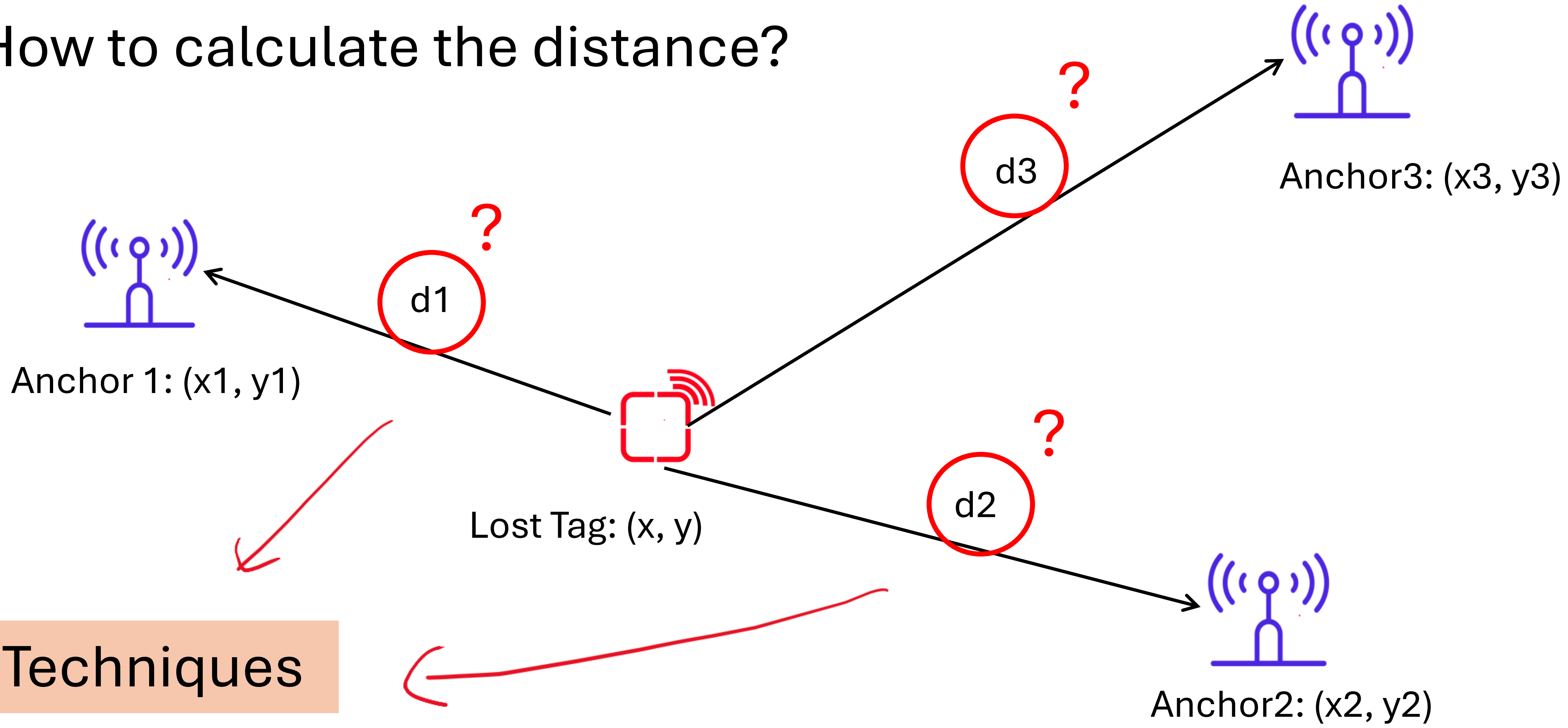
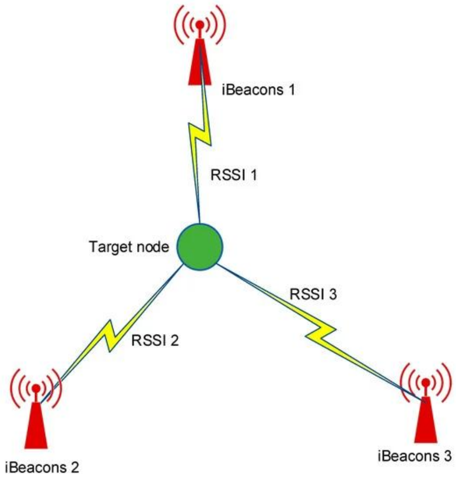


Ranging Techniques

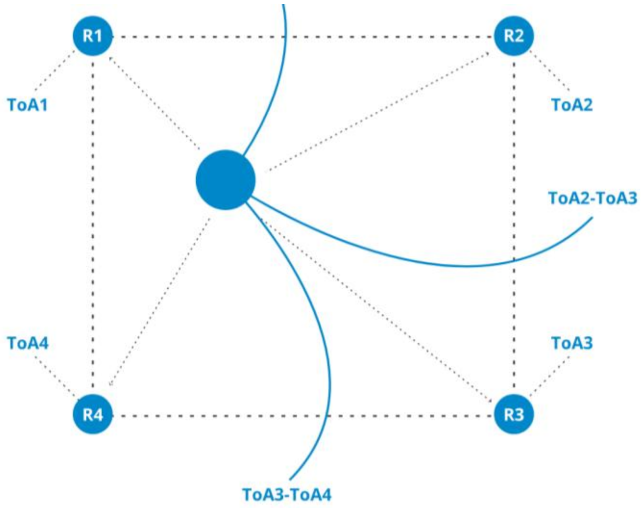
Indoor Ranging

- Ranging Techniques

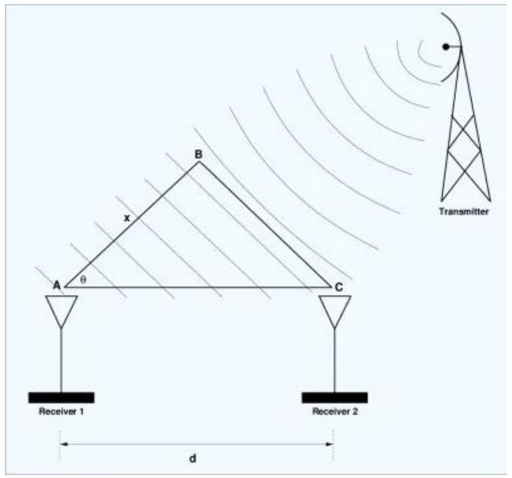
Received Signal Strength (RSS)



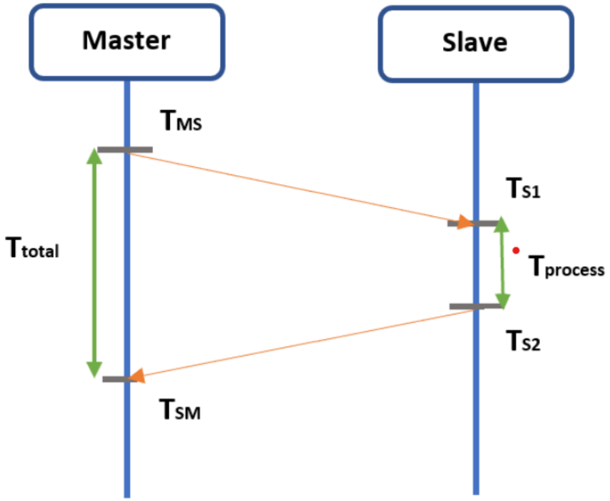
Time Difference of Arrival (TDoA)



Angle of Arrival (AoA)



Time of Flight (ToF)



Indoor Ranging

- Ranging Techniques

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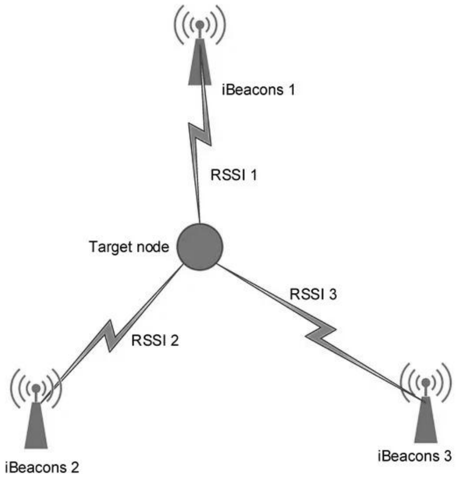

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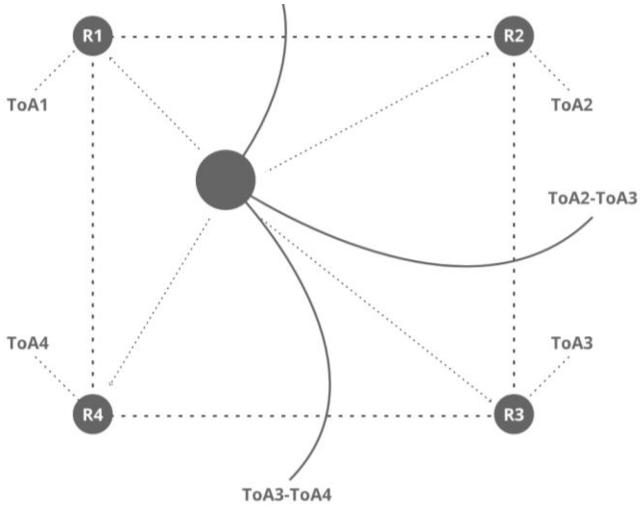

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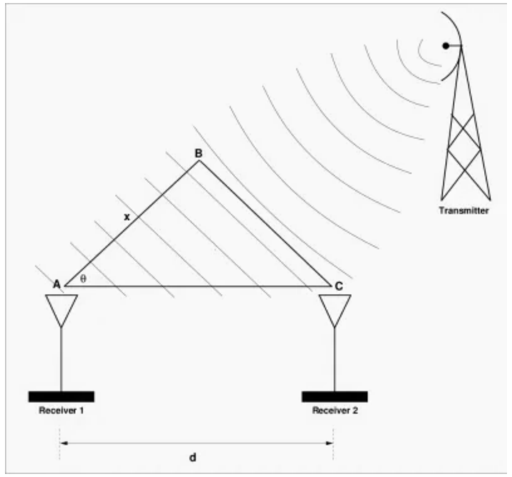

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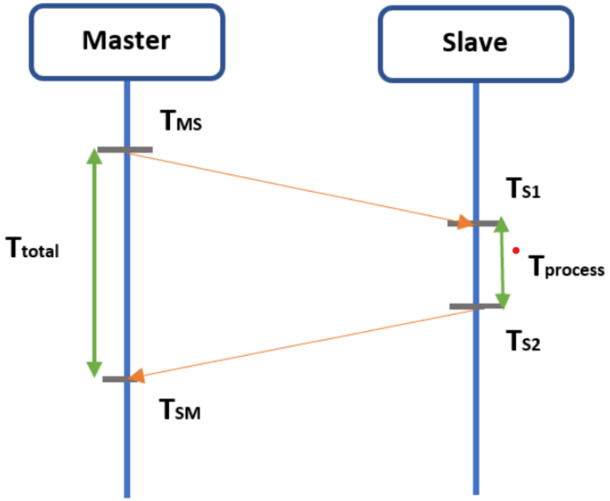

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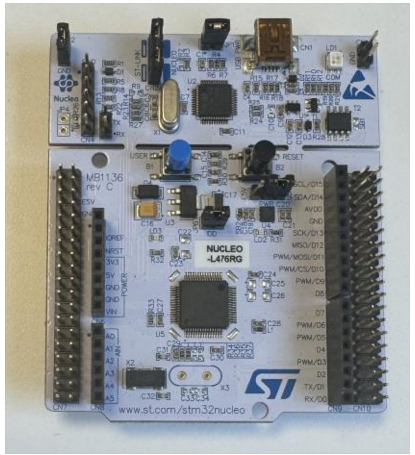
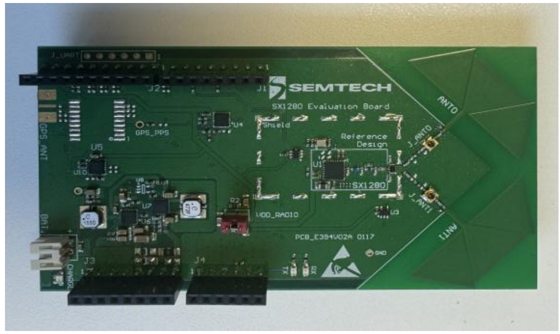
Hardware - SX1280 Dev kit



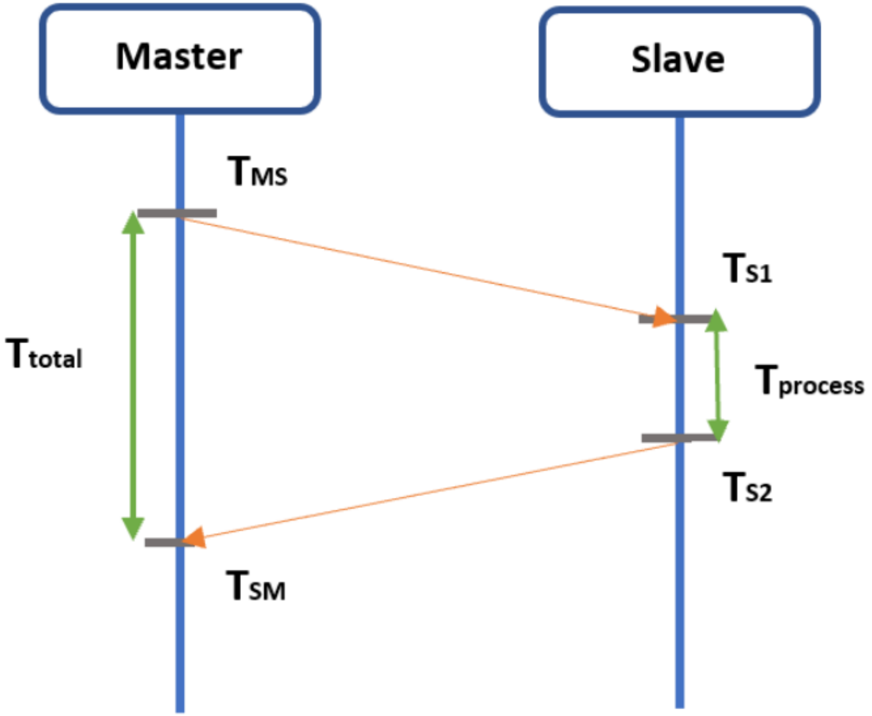
Microcontroller:
STM32 Nucleo-64
Development Board



Radio board:
SX1280RF1ZHP RF Module

Semtech's SX1280 transceiver has an inbuilt ranging engine

SX1280 Ranging - ToF



SX1280 ranging feature is based upon the measurement of a round trip time of flight (RTToF) between a pair of SX1280 transceivers.

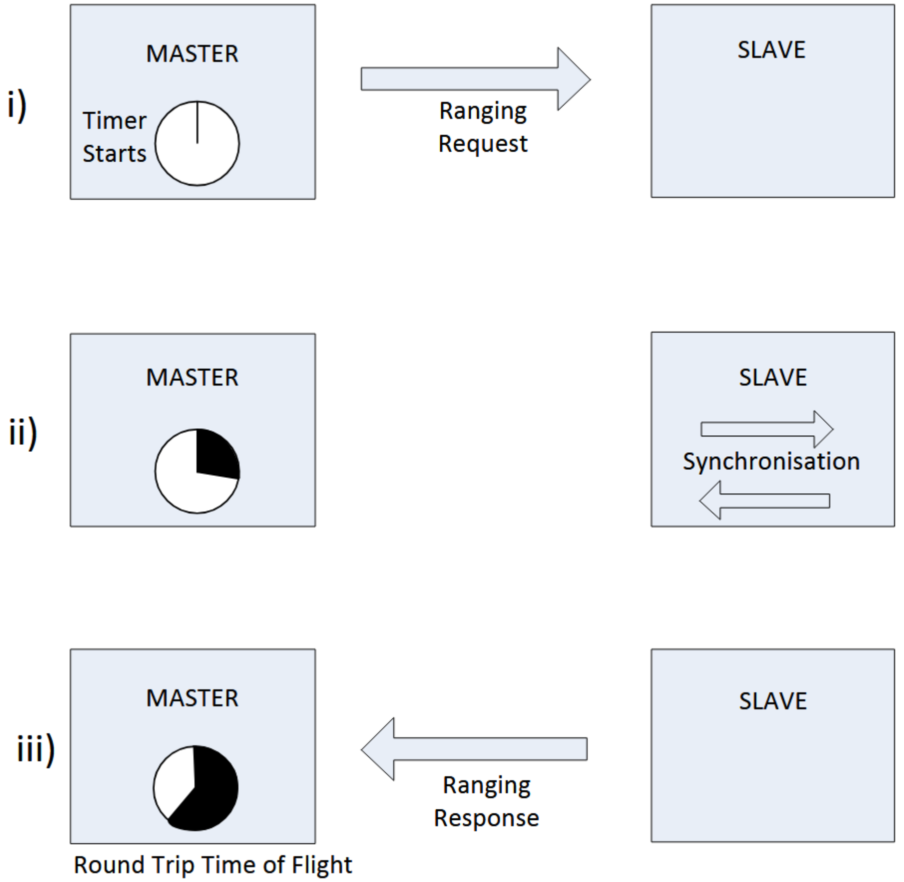


Figure 1: Principle of SX1280 Ranging

Semtech, AN1200.31 SX1280 EVK Ranging How To, v1.0, 2019

General Configuration

	Existing
Tx Power	-18dBm → **13 dBm**
SF	5 → 10
BW	400 KHz, **800 KHz**, **1600 KHz**
CR	**4/5**, 4/6, 4/7, 4/8

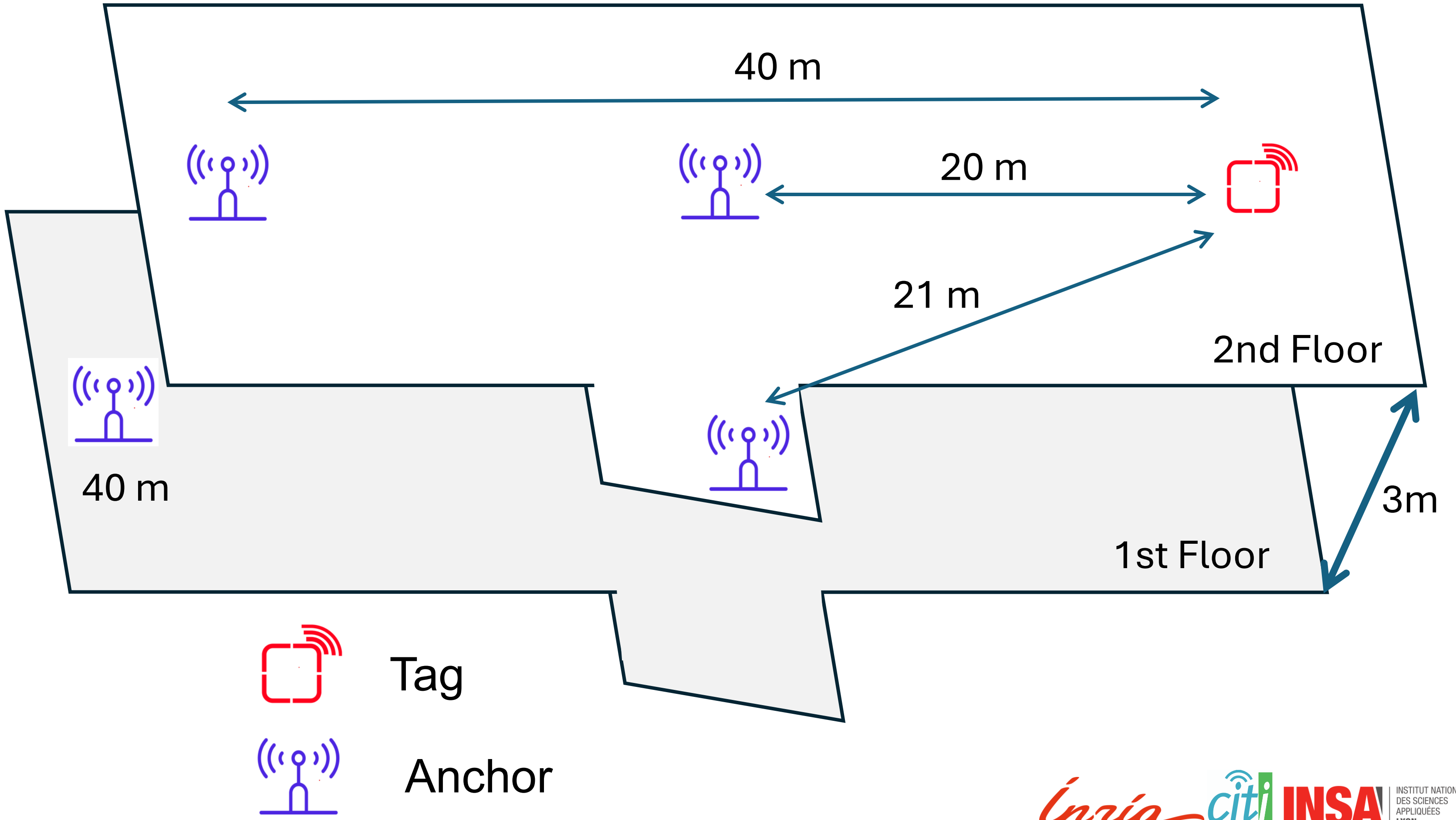
SF: 6 →10
BW: 800, 1600

→ 25 measurements for each configuration

Experiments: Scenario

Environment description:

- ❑ LoS: 20 m
- ❑ LoS: 40m
- ❑ NLoS: 21m (same floor)
- ❑ NLoS: 40m (1st Floor)



Mean Values

20m Line of Sight

SF\BW	800	1600
6	19.81/0.82	19.54/0.57
7	22.20/0.68	20.66/0.40
8	21.66/0.58	22.32/0.83
9	23.90/1.34	23.12/2.26
10	23.56/1.81	23.52/1.20

21m Non-Line of Sight

SF\BW	800	1600
6	26.22/1.01	27.07/1.98
7	26.96/0.76	27.44/0.98
8	27.96/0.63	27.60/0.89
9	26.72/0.84	24.96/0.83
10	26.44/1.07	24.58/0.70

40m Line of Sight

SF\BW	800	1600
6	35.72/2.29	37.21/2.42
7	34.64/0.82	36.82/1.19
8	35.25/0.74	39.36/1.09
9	36.26/0.58	34.26/0.36
10	37.07/0.62	37.40/0.88

40m Non-Line of Sight

SF\BW	800	1600
6	42.14/1.87	44.06/4.04
7	39.50/1.25	41.02/3.01
8	45.85/14.27	45.98/0.88
9	47.49/0.95	42.94/0.62
10	48.41/1.06	44.90/0.71

Best Configuration

Scenario	Optimal Config	Accuracy (%)	Precision (%)
20m LOS	**SF6/ BW1600**	97.7	97.1
40m LOS	**SF8/ BW1600**	98.4	97.2
40m NLOS	**SF7/ BW800**	98.8	96.8
21m NLOS	**SF10/ BW1600**	83.0	97.1

Comparison With State of The Art

20m Line of Sight

SF\BW	800	1600
6	19.81	19.54
7	22.20	20.66
8	21.66	22.32
9	23.90	23.12
10	23.56	23.52

Table 1: 20m LoS
(our experiment)

20 m	400kHz	800kHz	1600kHz
SF5	27.67	27.53	33.48
SF6	26.23	29.52	37.11
SF7	25.42	28.71	37.18
SF8	28.21	31.23	33.19
SF9	27.67	30.15	26.95
SF10	24.78	32.40	22.10

Table 2: 20m LoS
Ashok Vaishnav, “Design and Evaluation of an Indoor Localization System using 2.4 GHz LoRa”

Comparison With State of The Art

21m Non-Line of Sight

SF\BW	800	1600
6	26.22	27.07
7	26.96	27.44
8	27.96	27.60
9	26.72	24.96
10	26.44	24.58

Table 3: 21m NLoS
(our experiment)

20 m	400kHz	800kHz	1600kHz
SF5	31.91	23.61	34.32
SF6	28.75	28.80	40.20
SF7	27.04	31.73	39.77
SF8	22.98	34.93	34.16
SF9	13.07	33.62	25.96
SF10	6.535	13.47	17.35

Table 4: 20m NLoS
Ashok Vaishnav, “Design and Evaluation of an Indoor Localization System using 2.4 GHz LoRa”

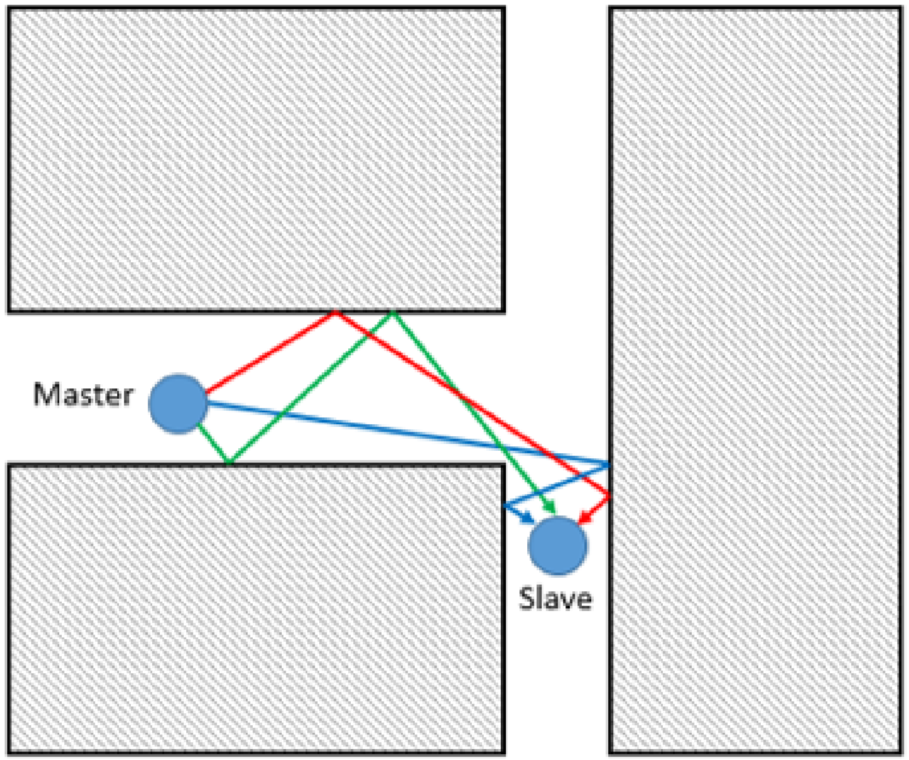
Discussion

➢ Challenges

Multipath: Reflections cause ranging errors.

Clock resolution: Time-based measurements need precise clocks.

Environment dependency: People, obstacles affect ranging reliability.



Semtech, Theory and Principle of Advanced Ranging, internal document, 2021

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Work in Progress

- Conduct further experiments using the SX1280 in various conditions.
- Explore methods to improve the accuracy of ranging.
- Design an indoor localization algorithm based on the enhanced ranging technique.

Thank You!