# GPS-free Geolocation using LoRa in Low-Power WANs

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# Outline

- **1. Introduction**
- 2. LoRaWAN for geolocation
- 3. System design
- 4. Multilateration in LoRaWAN networks
- 5. Tests and results
- 6. Conclusions

# 1. Introduction

- Elderly assisted living → Global Navigation Satellite System (GNSS) available
  - Main problem → Battery lifetime

- **Goal** → Design and implement a tracking IoT system in a LPWAN capable of transmitting the current position using low power technologies

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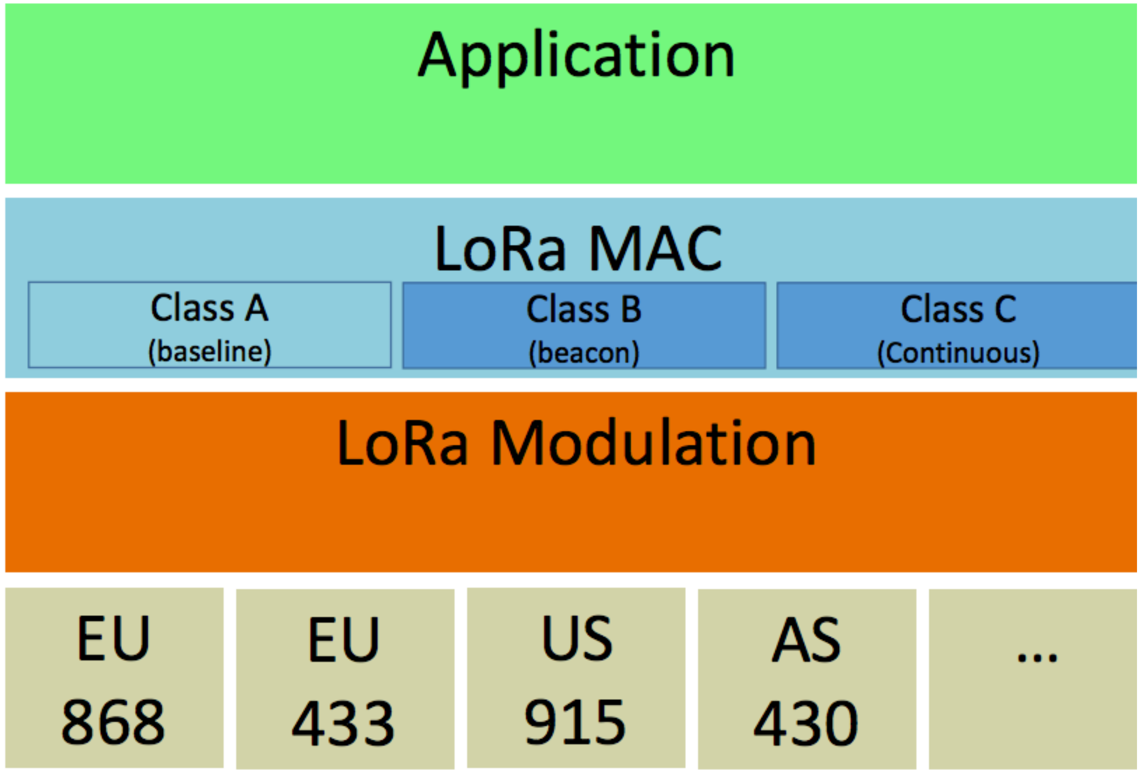
# 2. LoRaWAN for geolocation (I)

- Features
  - Long range -> 5 km urban / 15 km rural
  - Low power consumption
  - Low data rate -> From 250 bps to 50 kbps
  - Bandwidth bigger than other IoT technologies in LPWANs
  - Previous studies presented good results
  - Open source

# 2. LoRaWAN for geolocation (II)

- LoRa
  - Physical layer
  - Chirp Spread Spectrum (CSS)
  - Forward Error Correction (FEC)
- LoRaWAN
  - MAC protocol
  - Bidirectional
  - Standardized

LoRa® Alliance




**Source:** LoRaWAN Specification - LoRa Alliance

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- **3. System design**
  - **3.1 System structure**
  - **3.2 End-node**
  - **3.3 Gateways**
  - **3.4 Server**
  - **3.5 Application**
- 4. Multilateration in LoRaWAN networks
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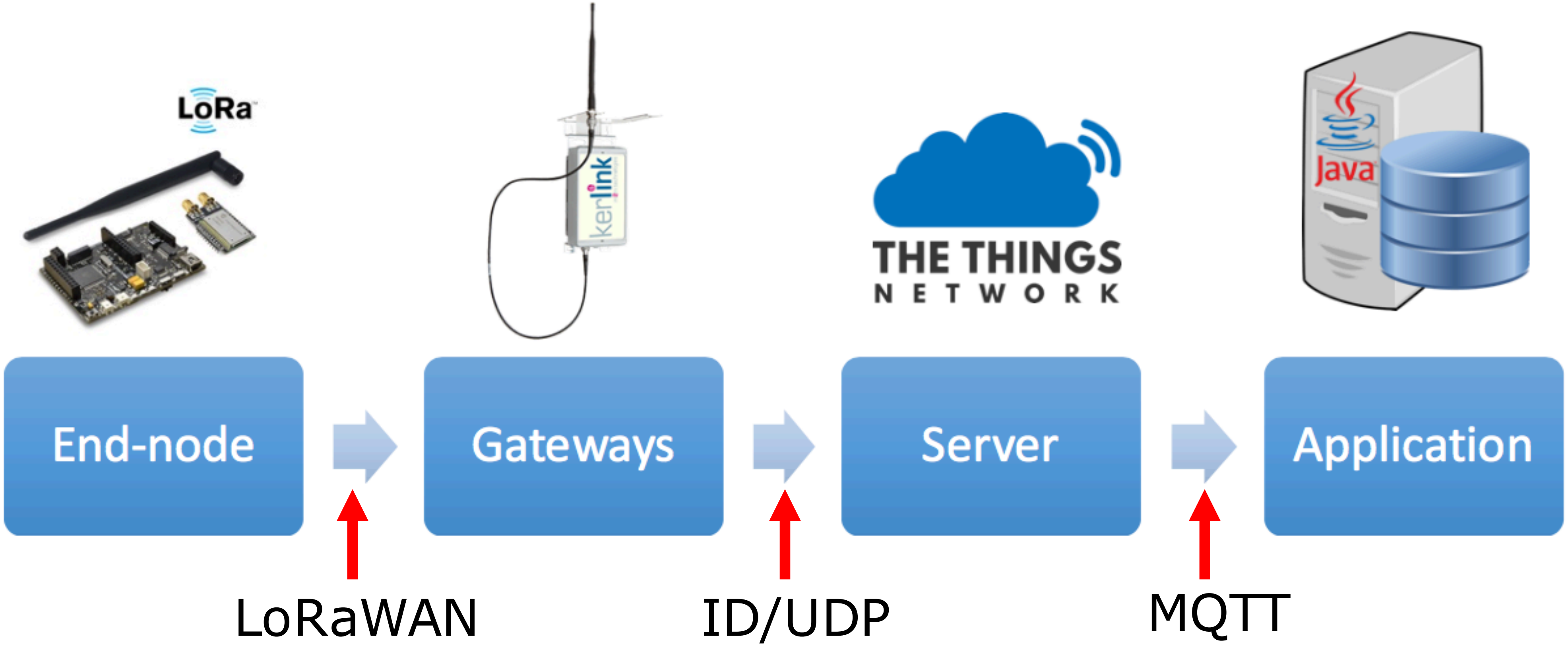
# 3.1 System structure




- Important information → Time each packet was received by each gateway to apply **multilateration**

# 3.2 End-node

End-node → Gateways → Server → Application

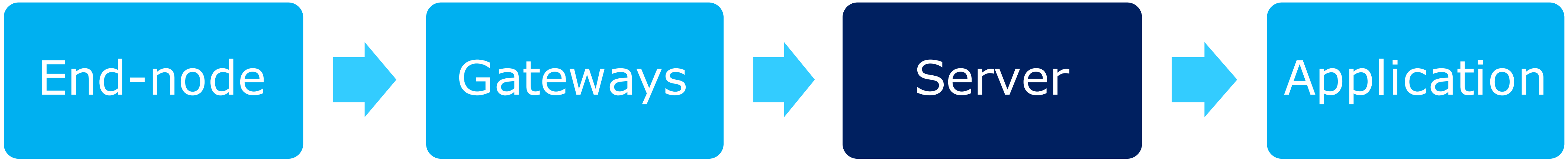
- Transmit GPS data through LoRaWAN module
- Elements
  - Waspmote
  - LoRaWAN module
  - GPS receiver


# 3.3 Gateways

End-node → **Gateways** → Server → Application

- Time received packet
- Forward data to server via UDP/IP
- 4 Kerlink gateways → Embedded GPS

# 3.4 Server




- Decode data from the gateways and transmit it to the application

- The Things Network (TTN)
  - Open Source
  - Third-party apps

| | counter | port | dev id | payload | fields |
|---|---|---|---|---|---|
| 09:40:30 | 8 | 1 | waspmote | 05 54 69 33 27 10 12 31 12 63 31 | |
| 09:40:24 | 7 | 1 | waspmote | 05 54 69 33 87 10 12 31 12 54 01 | |
| 09:40:18 | 6 | 1 | waspmote | 05 54 69 33 53 10 12 31 12 70 41 | |
| 09:40:12 | 5 | 1 | waspmote | 05 54 69 33 20 10 12 31 12 95 41 | |

# 3.5 Application

End-node → Gateways → Server → Application

- Parse and insert the information to a database
- Elements
  - Java Application + MQTT client
  - MySQL

| id | id_uplink | gtw_id | timestamp | time | ns_time | channel | rssi | snr | latitude | longitude | altitude |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 33281 | 22072 | eui-0000024b080e1039 | 1584438275 | Mon Dec 19 12:20:38 CET 2016 | 739825260 | 4 | -122 | -7.5 | 55.78188 | 12.51783 | 58 |
| 33282 | 22072 | eui-0000024b080e0ffc | 1649924371 | Mon Dec 19 12:20:38 CET 2016 | 739814260 | 4 | -83 | 10.8 | 55.76842 | 12.45721 | 19 |
| 33283 | 22072 | eui-0000024b080e0fdf | 4007757227 | Mon Dec 19 12:20:38 CET 2016 | 739818260 | 4 | -116 | 5 | 55.78203 | 12.48078 | 67 |
| 33284 | 22072 | eui-0000024b080e104c | 4212951715 | Mon Dec 19 12:20:38 CET 2016 | 739813260 | 4 | -116 | 6.5 | 55.76842 | 12.47625 | 21 |
| 33472 | 22167 | eui-0000024b080e1039 | 2749440603 | Mon Dec 19 12:40:03 CET 2016 | 741554258 | 4 | -123 | -2.5 | 55.78191 | 12.51781 | 58 |

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  - **4.3 Extraction of TDOAs**
  - **4.4 Detection of outliers**
  - **4.5 Non-iterative algorithm**
  - **4.6 Iterative algorithm**
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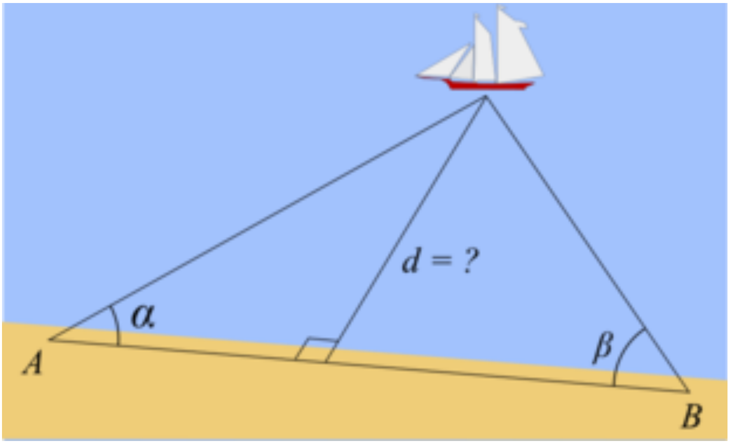
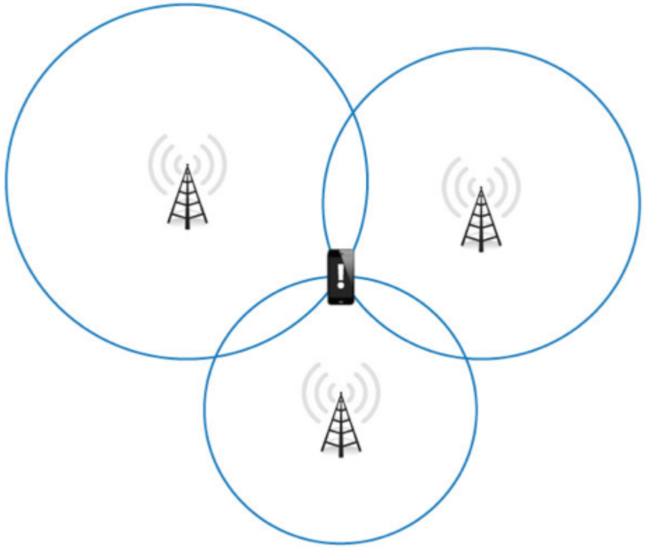
# 4.1 Geolocation techniques (I)

- Triangulation
  - Angles of incidence
  - Triangle defined with angles

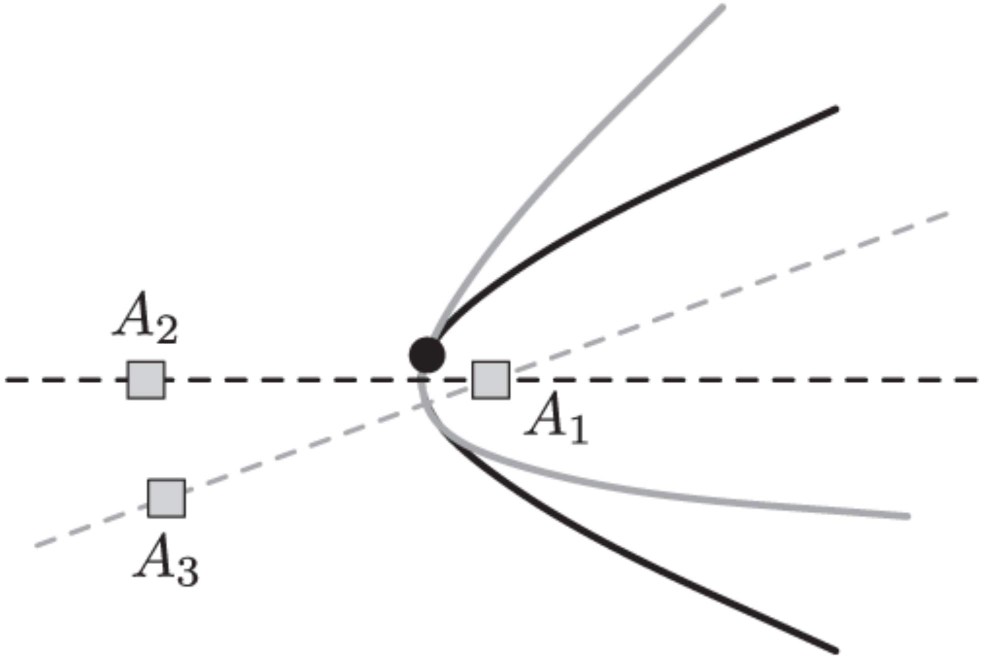



- Trilateration
  - Distance between transmitter and receiver → Time Of Flight (TOF) → Requires Synchronization
  - Intersection of three circles

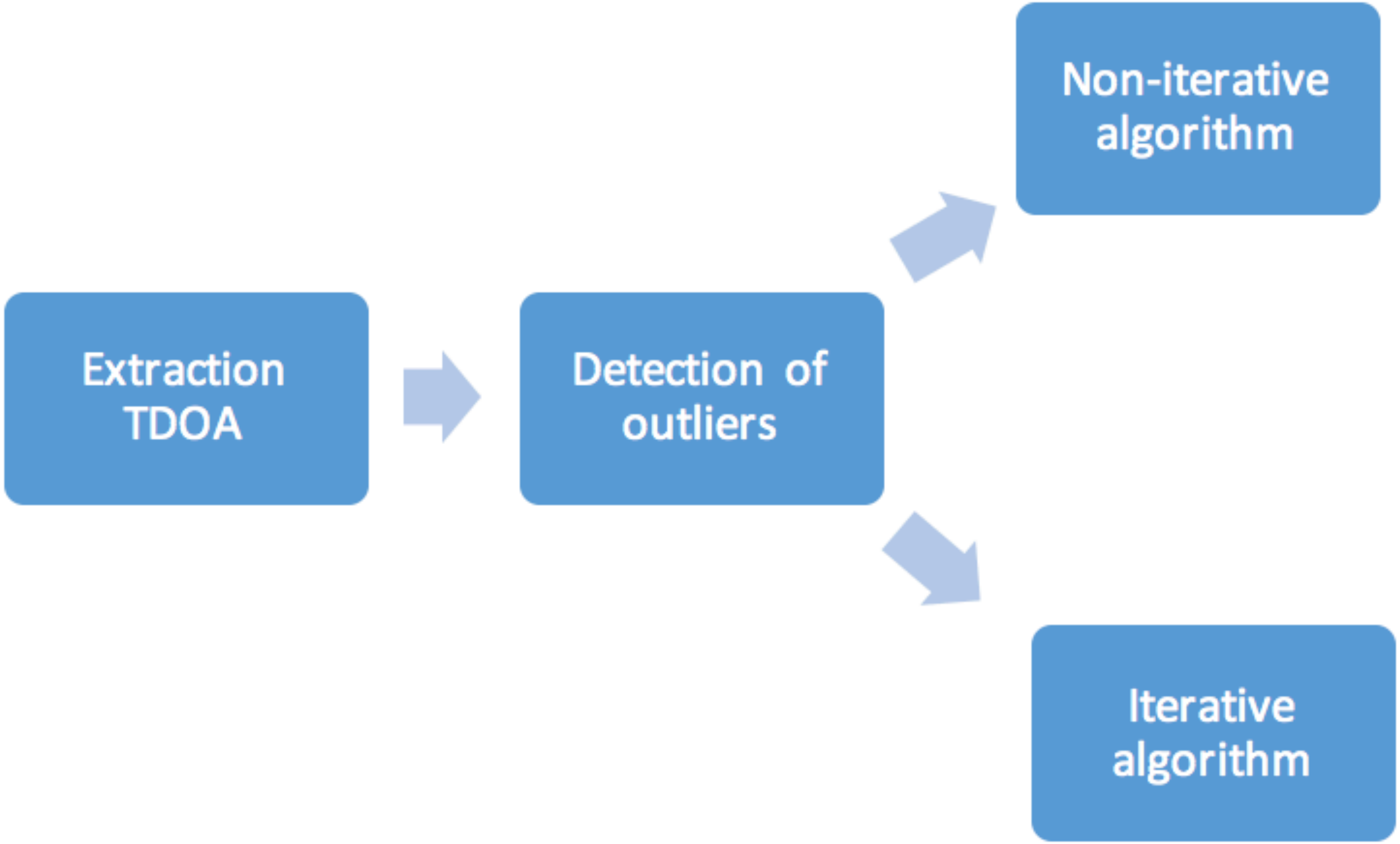


# 4.1 Geolocation techniques (II)

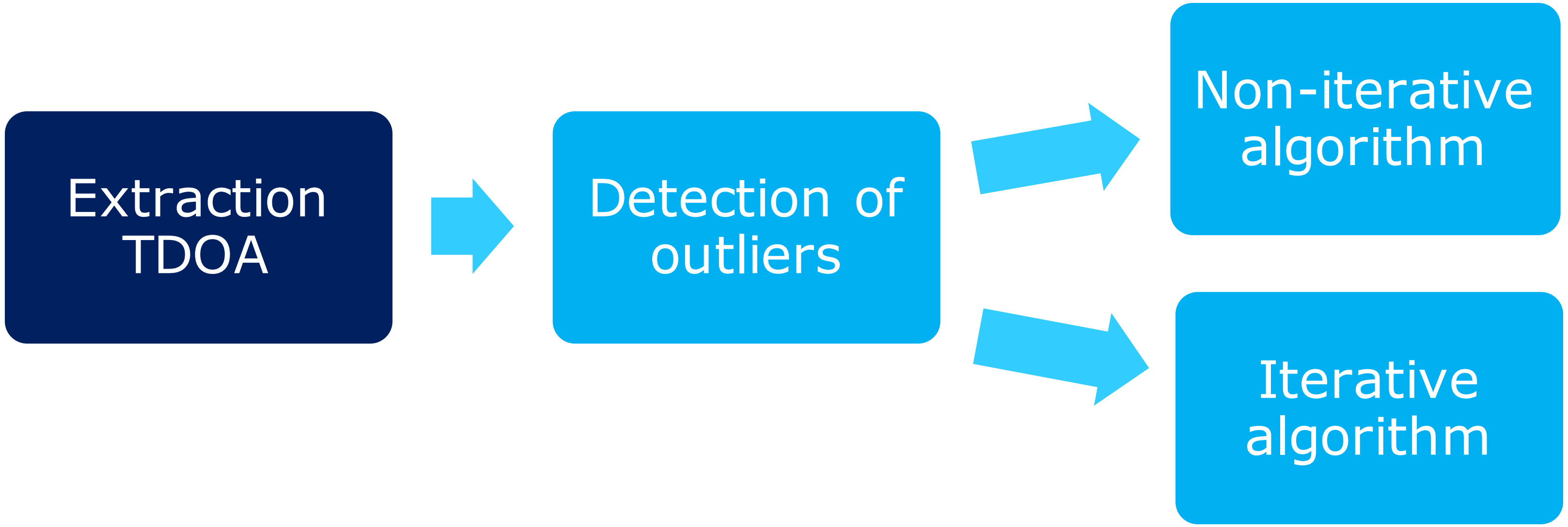
- **Multilateration**
  - No synchronization → Time Difference Of Arrival (TDOA)
  - Intersection of at least two hyperbolas (3 antennas required)



# 4.2 Algorithm structure



# 4.3 Extraction of TDOAs




- Compute TDOA based on a pair of UTC times per each packet

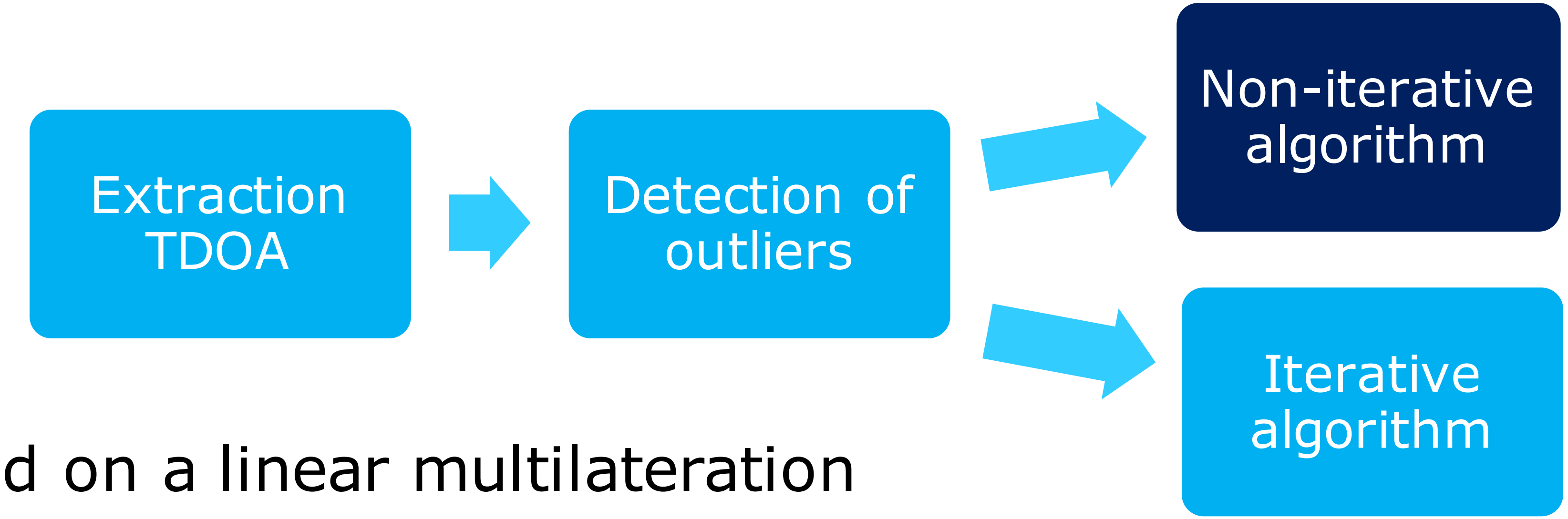
$$t_{ij} = t_i - t_j \qquad \forall\, i,j = 1:4 \quad j \neq i$$

$$\text{Where } t_i = \text{time packet was received by gateway i}$$

# 4.4 Detection of outliers

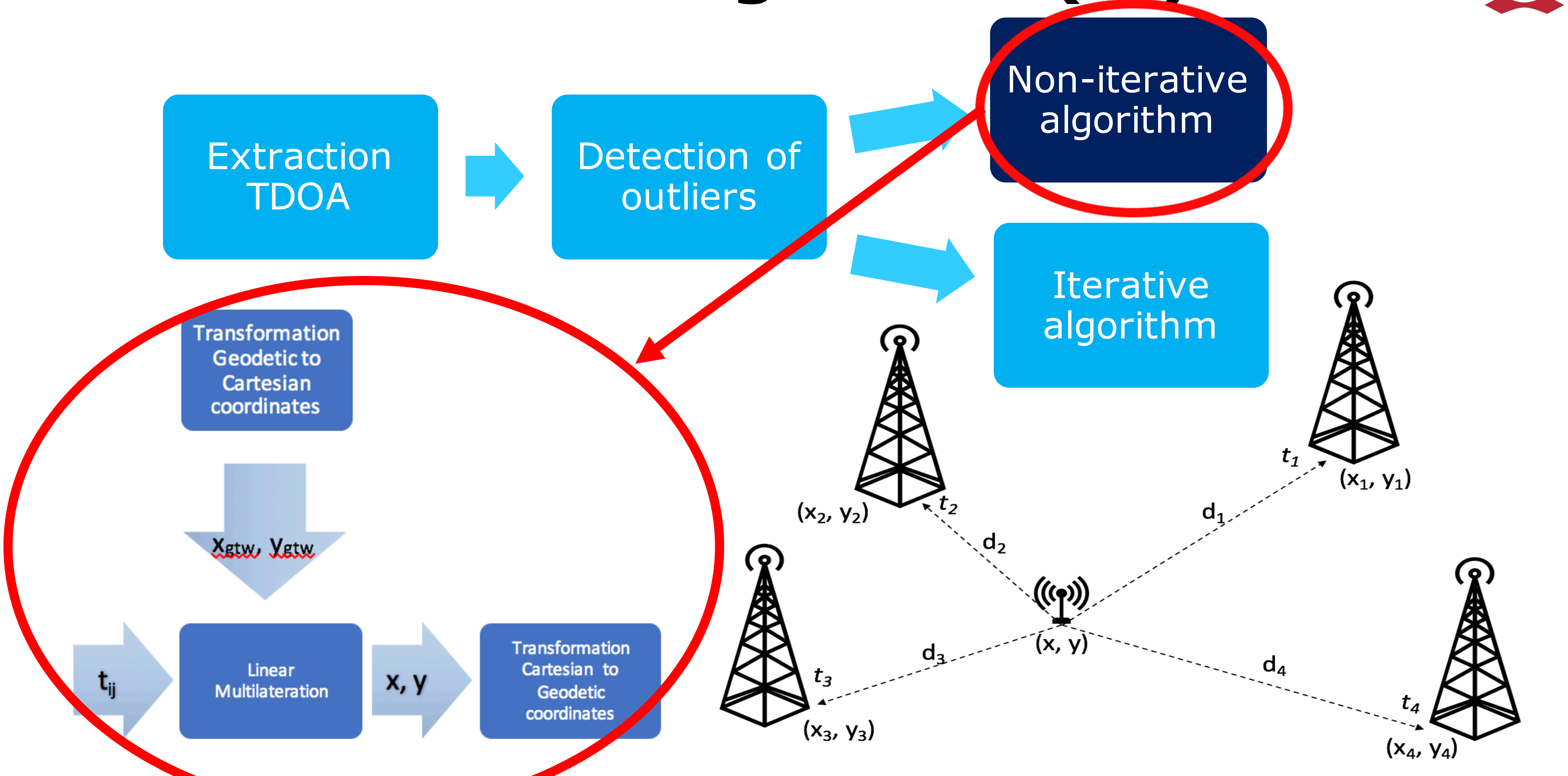

- Definition (Barnett and Lewis): "An observation which appears to be inconsistent with the remainder of that set of data"
- Methods to detect outliers
  - Grubb's test
  - Tietjen-Moore test
  - **Generalized Extreme Studentized Deviate (ESD) test**

# 4.5 Non-iterative algorithm (I)

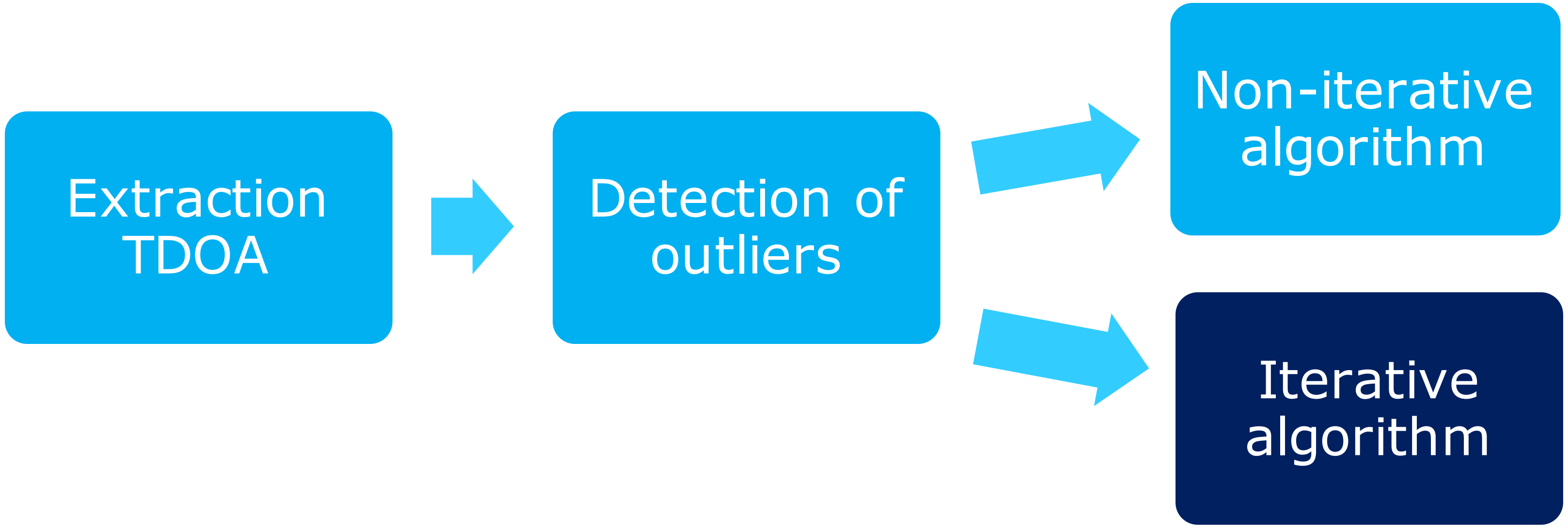



- Based on a linear multilateration
  - 4 gateways → TDOAs
  - Location of the 4 gateways
  - Coordinates conversion required
    - Geodetic (latitude, longitude) ←→ Cartesian (x, y)
    - Reference ellipsoid WGS-84 (GPS)

# 4.5 Non-iterative algorithm (II)

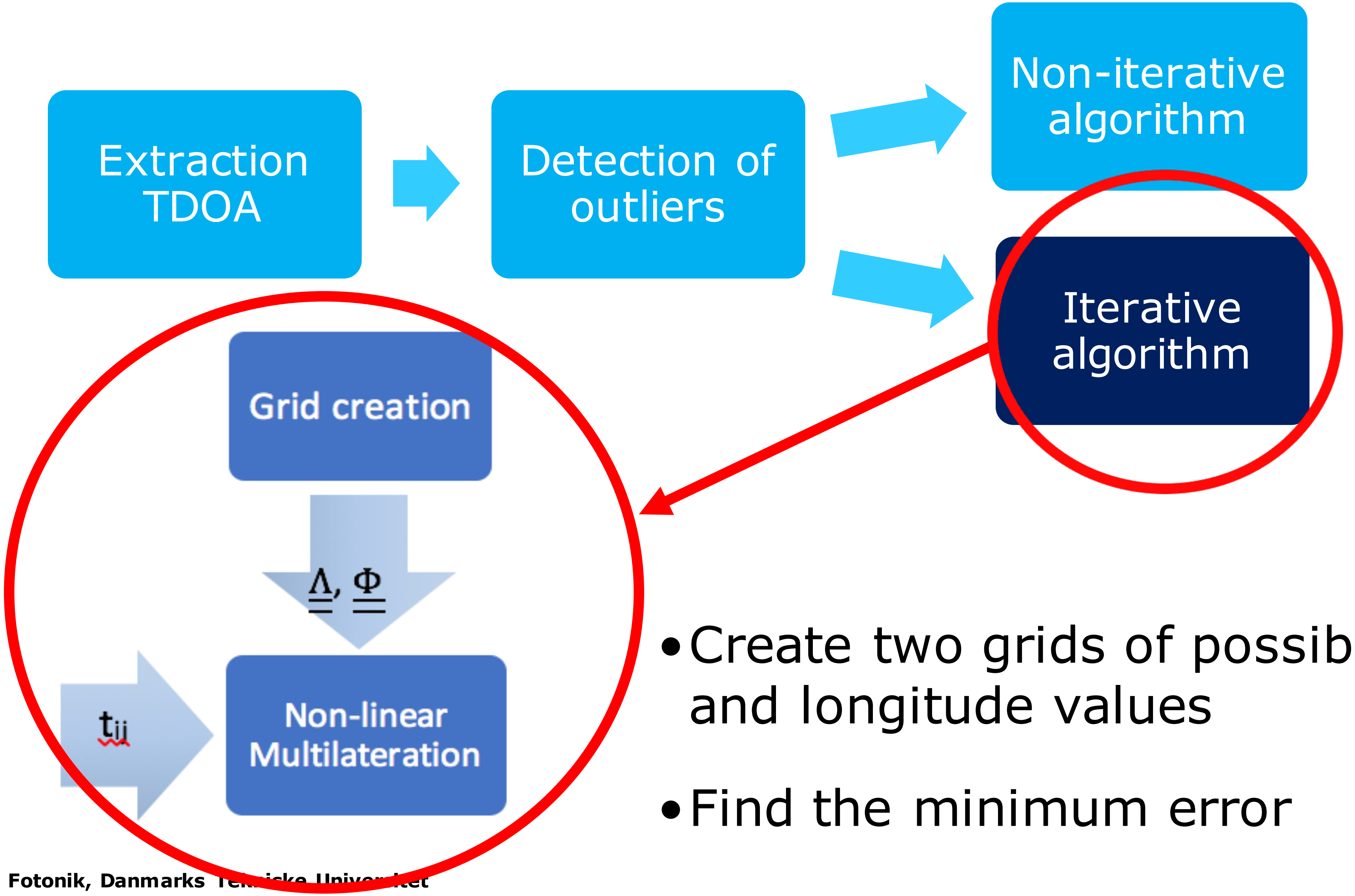


# 4.6 Iterative algorithm (I)




- Avoid coordinates transformation → Error propagation
- Solution → Iterative algorithm
  - Haversine formula → Compute the distance between two points over the globe

# 4.6 Iterative algorithm (II)




- Create two grids of possible latitude and longitude values
- Find the minimum error

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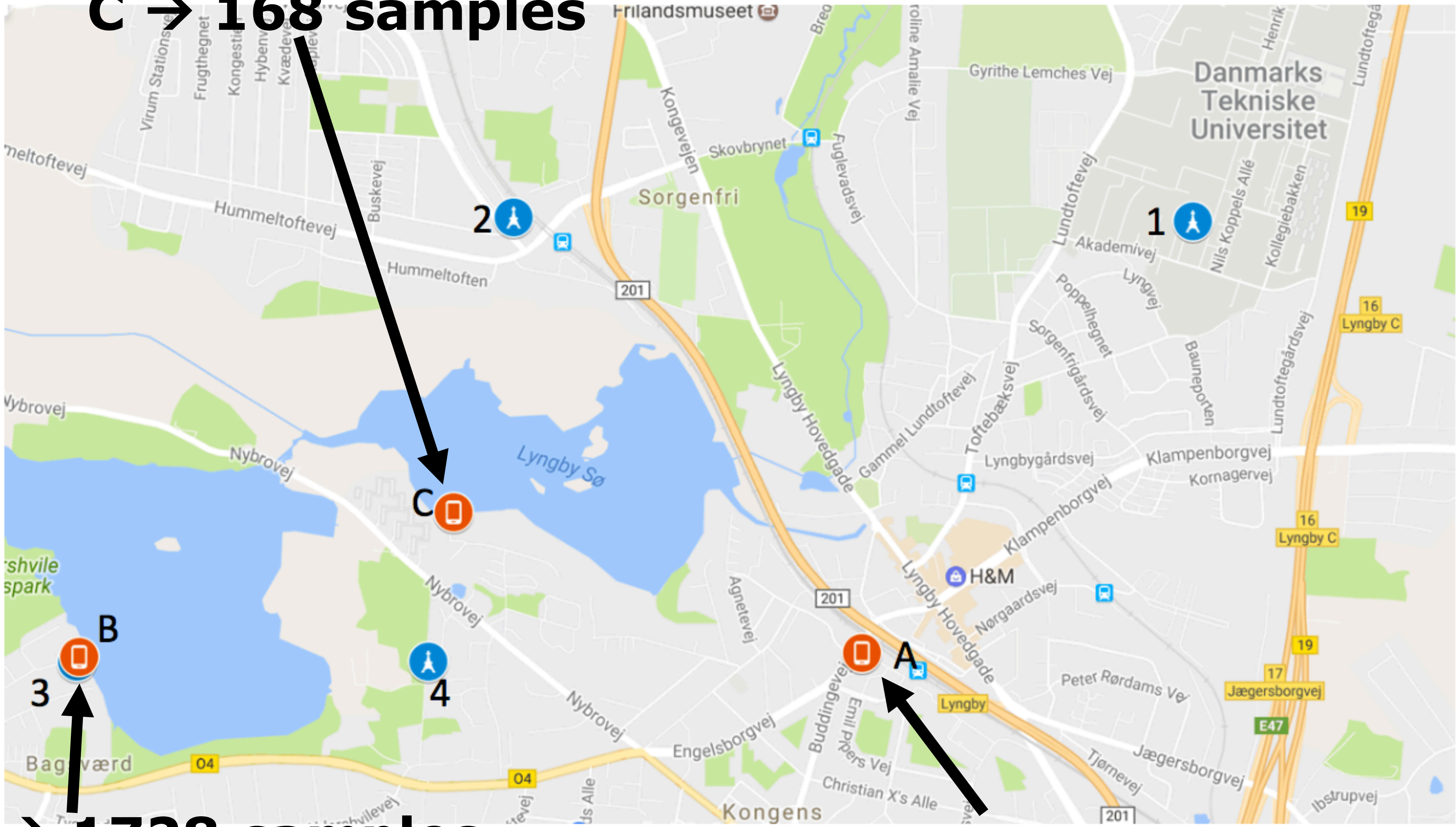
# 5.1 Test spots

**C → 168 samples**




**B → 1728 samples**

**A → 454 samples**

# 5.2 Non-iterative algorithm

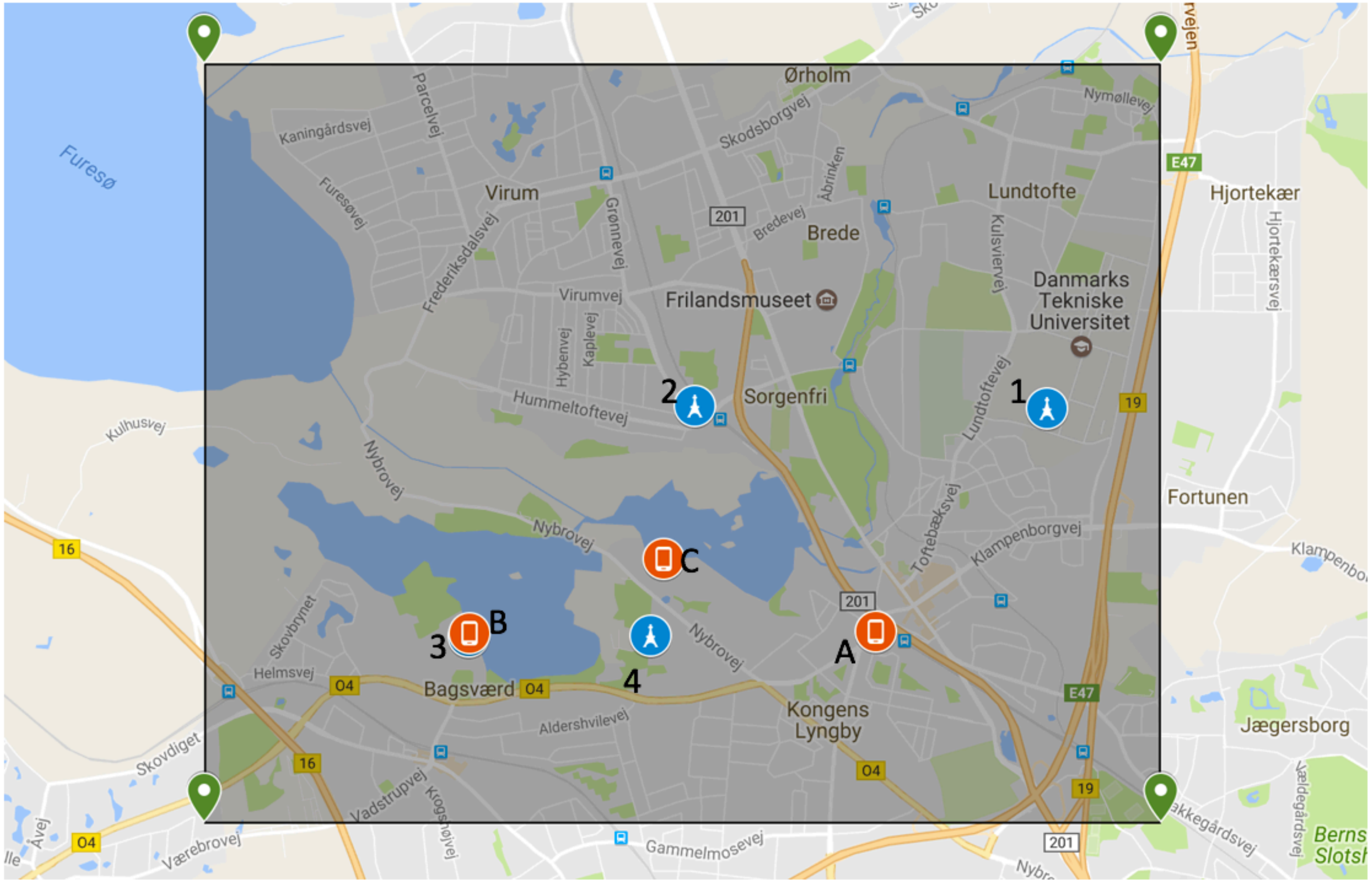
- Mean Absolute Localization Error (MALE)

| | All | Lyngby building (A) | Bagsværd (B) | Lyngby lake (C) |
|---|---|---|---|---|
| **MALE** | 9,58 km | 5,54 km | 10,72 km | 9,76 km |
| **MALE - No outliers TDOA** | - | 5,46 km | 10,71 km | 9,67 km |

- Mean estimator → $\bar{t}_{ij} = \frac{1}{N}\sum_{k=1}^{N} t_{ijk}$

| | Lyngby building (A) | Bagsværd (B) | Lyngby lake (C) |
|---|---|---|---|
| **ALE - Sample mean TDOA** | 167 m | 89 m | 427 m |
| **ALE - No outliers, Sample mean TDOA** | 116 m | 65 m | 206 m |

# 5.3 Iterative algorithm (I)



# 5.3 Iterative algorithm (II)

| | All | Lyngby building (A) | Bagsværd (B) | Lyngby lake (C) |
|---|---|---|---|---|
| **MALE** | 1,16 km | 1,39 km | 1,09 km | 1,15 km |
| **MALE - No outliers TDOA** | - | 1,38 km | 1,08 km | 1,12 km |

| | Lyngby building (A) | Bagsværd (B) | Lyngby lake (C) |
|---|---|---|---|
| **ALE - Sample mean TDOA** | 167 m | 175 m | 136 m |
| **ALE - No outliers, Sample mean TDOA** | 119 m | 127 m | 114 m |

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  - **6.1 Future work**

# 6. Conclusions

- IoT tracking system using LoRa
- LoRaWAN presents attractive features
  - Long range
  - Low power consumption
- Two designed algorithms → Accuracy 100 meters
- Real-time tracking application → Not usable
- Mean estimator improves accuracy

# 6.1 Future work

- Kerlink gateways
  - Clock
  - Increase amount
- Multipath
  - To resolve → Bandwidth signal
- Algorithm
  - Machine Learning to combine TDOAs with RSSI measurements
  - K-Nearest Neighbors to improve the accuracy in "real-time"