Implementation and Evaluation of mobile RSSI-based LoRa™ Localization

Bachelor Thesis for B.sc. Informatik

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Motivation

- Apple AirTag™

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- GPS is insufficient
  - Mountains
  - Underwater
  - Indoor

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- Chirp Spread Spectrum Modulation (CSS)
- Low-power (TX: $\sim 20\,\mathrm{mA}$, RX: $\sim 11\,\mathrm{mA}$) [2]

- LoRa™ EU $f_{\text{center}} = 433.05 - 434.79\,\text{MHz}$ and $863 - 870\,\text{MHz}$

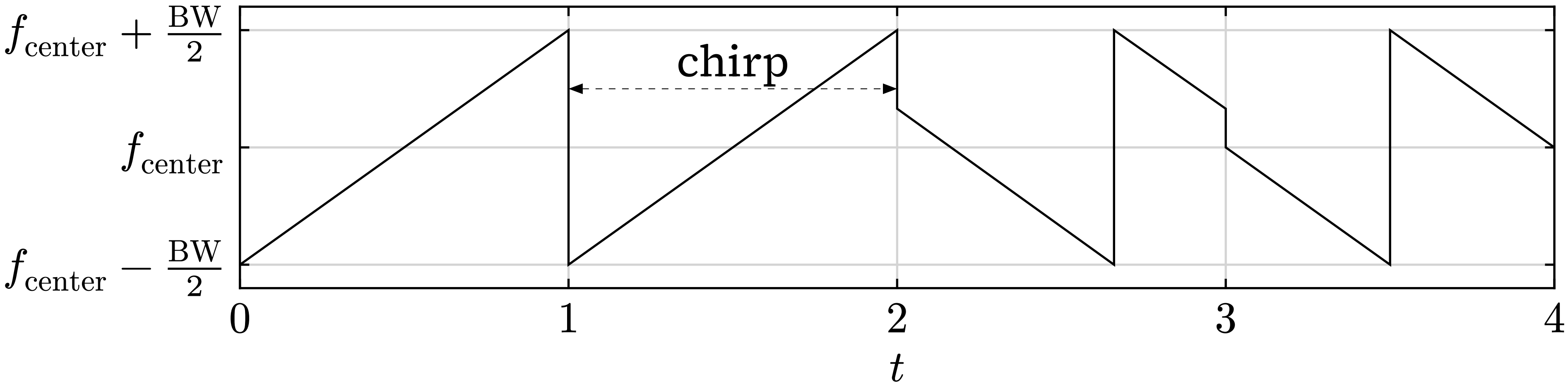
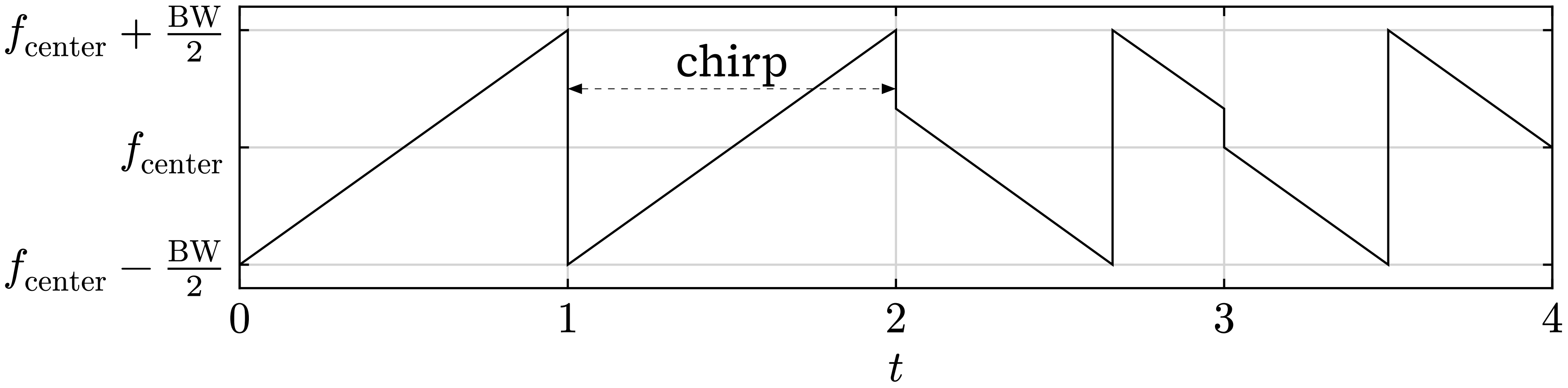


Figure 1: *Chirp Spread Spectrum Modulation*

- LoRa™ EU f_{center} = 433.05 - 434.79 MHz and 863 - 870 MHz



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- $2^{\text{Spreading Factor}}$ symbols per chirp (7-12) [3]

Goal of this Thesis

- Evaluate feasibility of a RSSI-based localization system with LoRa™

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- Implement a simple reference system for evaluation

Implementation

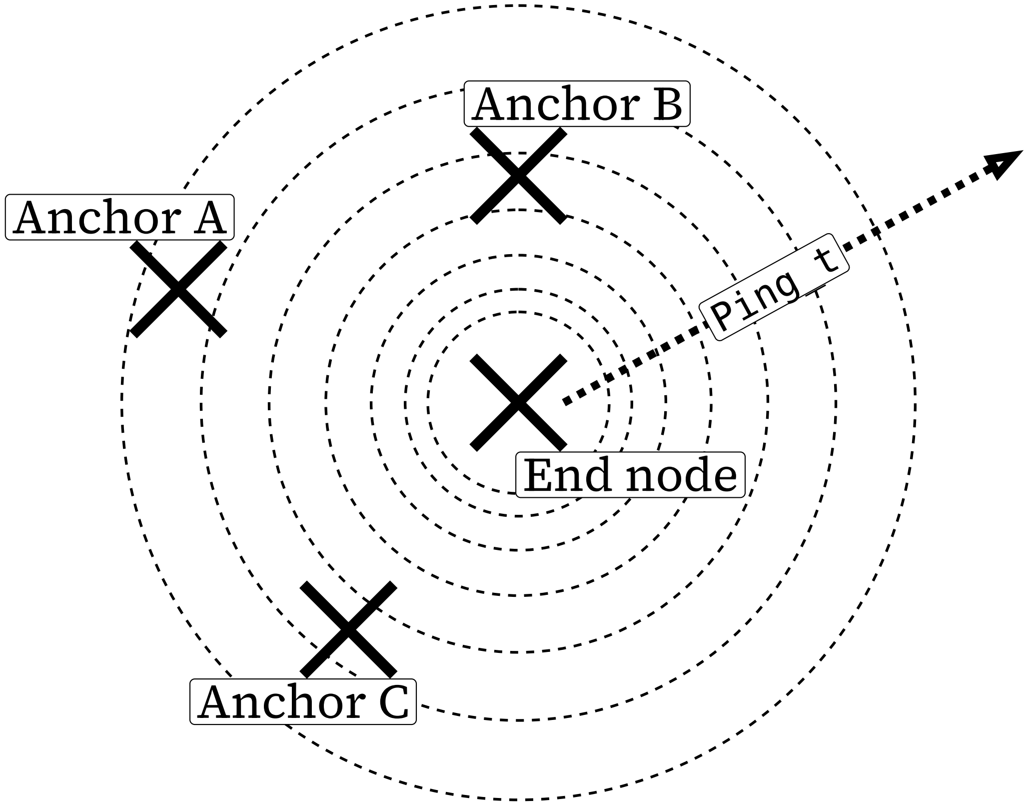

Figure 2: *Propagation of `Ping_t` message*

Hardware

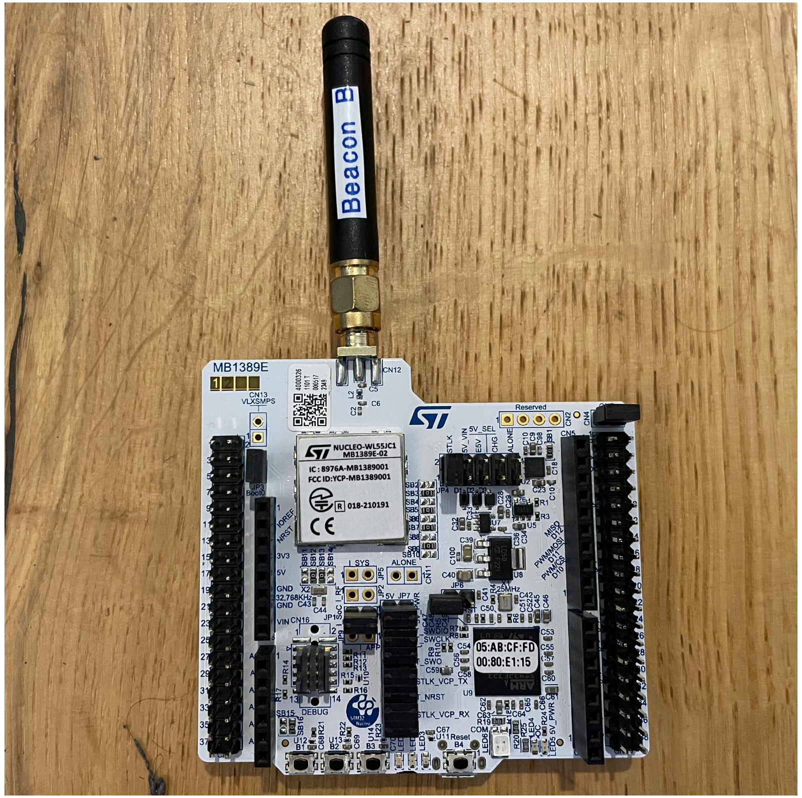

Figure 3: NUCLEO-WL55JC

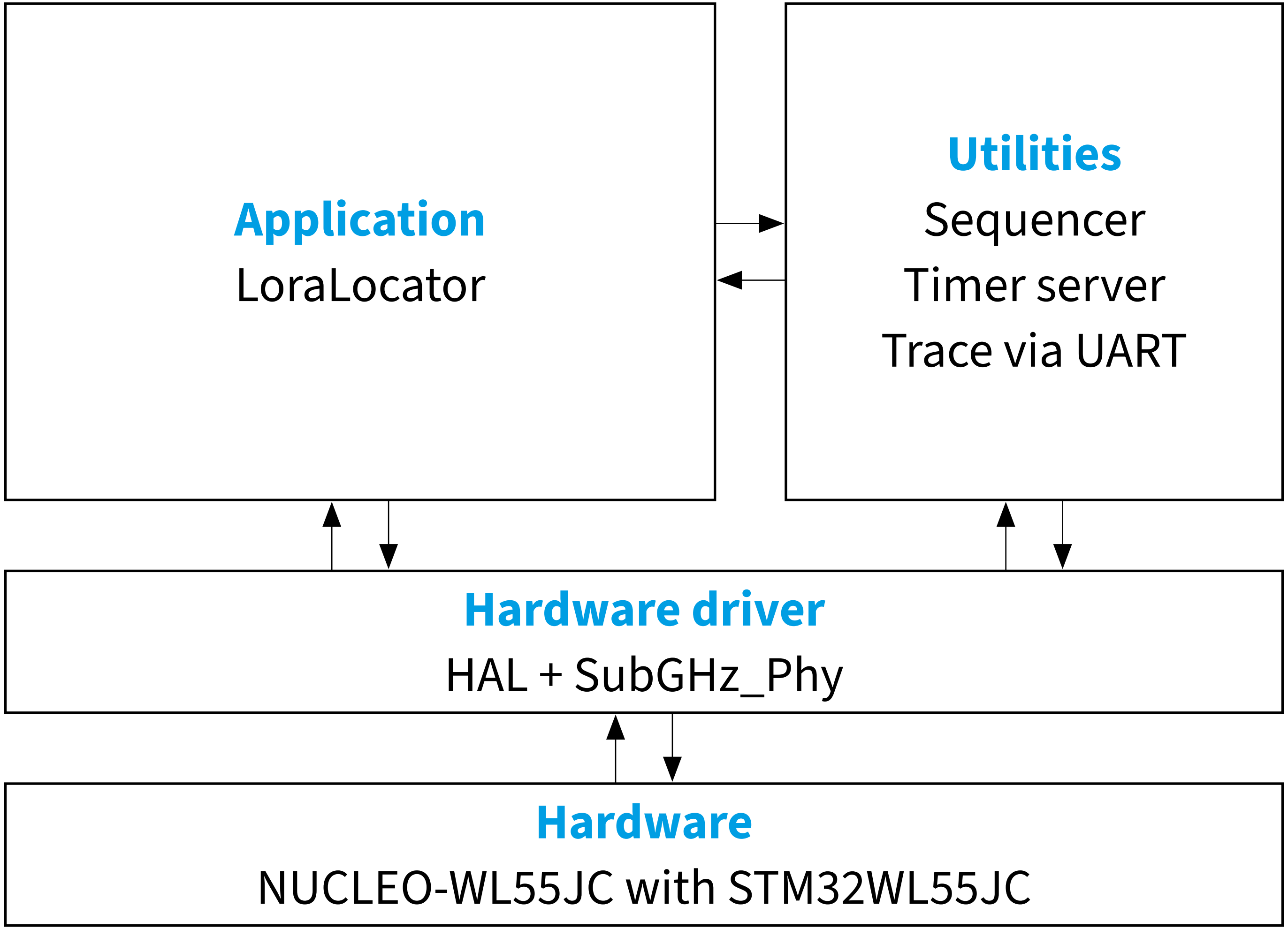

Figure 4: Firmware architecture

- Path-Loss Model [4]

$$\mathrm{RSSI}(d) = P_0 - 10n \cdot \log_{10}\left(\frac{d}{d_0}\right) \tag{1}$$

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- find coefficients with linear regression

$$y = ax + b \tag{3}$$

$$y = \mathrm{RSSI}(d),\ a = -10n,\ x = \log_{10}\left(\frac{d}{d_0}\right),\ b = P_0 \tag{4}$$

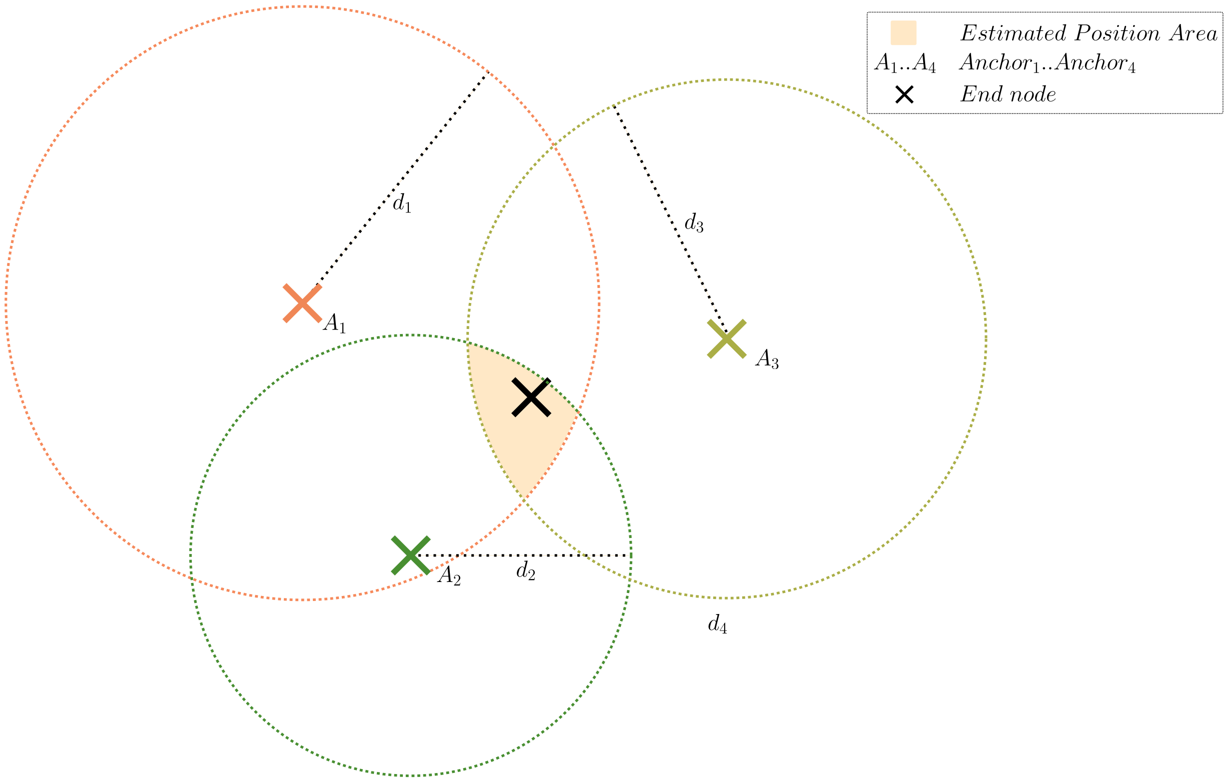

Figure 4: *Position estimation error with trilateration*

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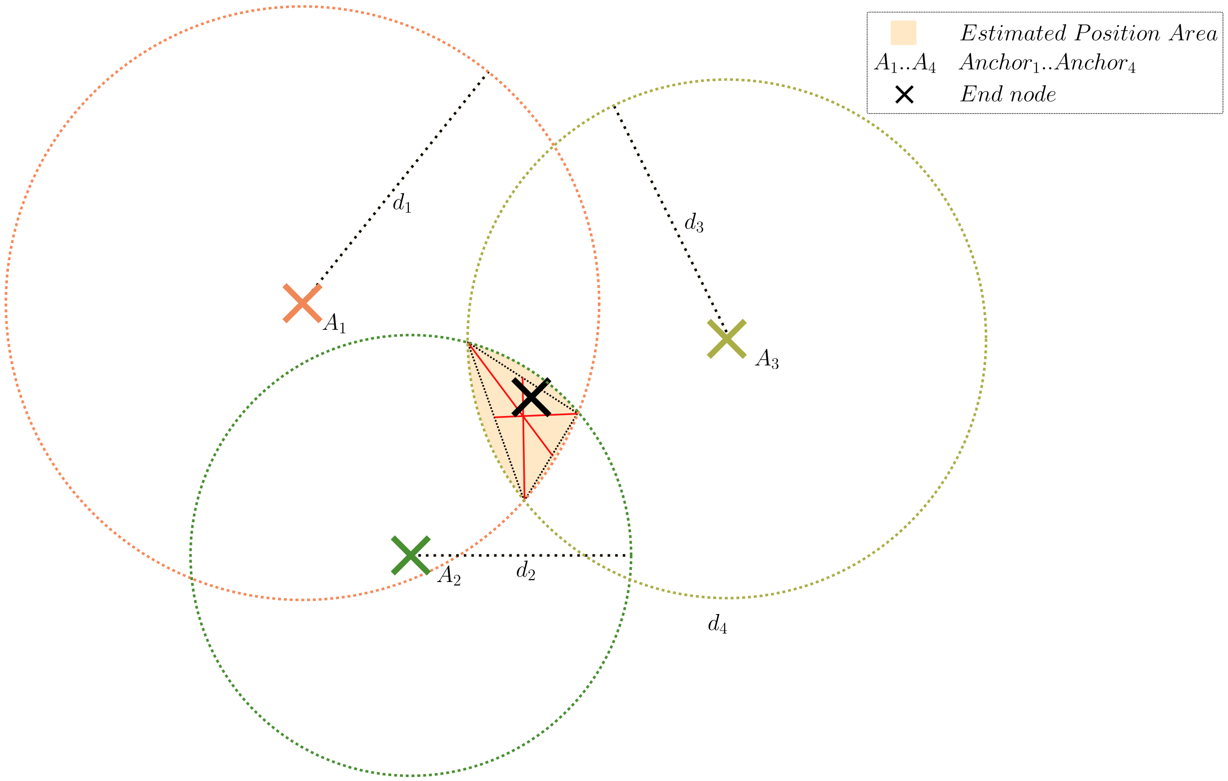

Figure 5: *Modified trilateration*

Evaluation

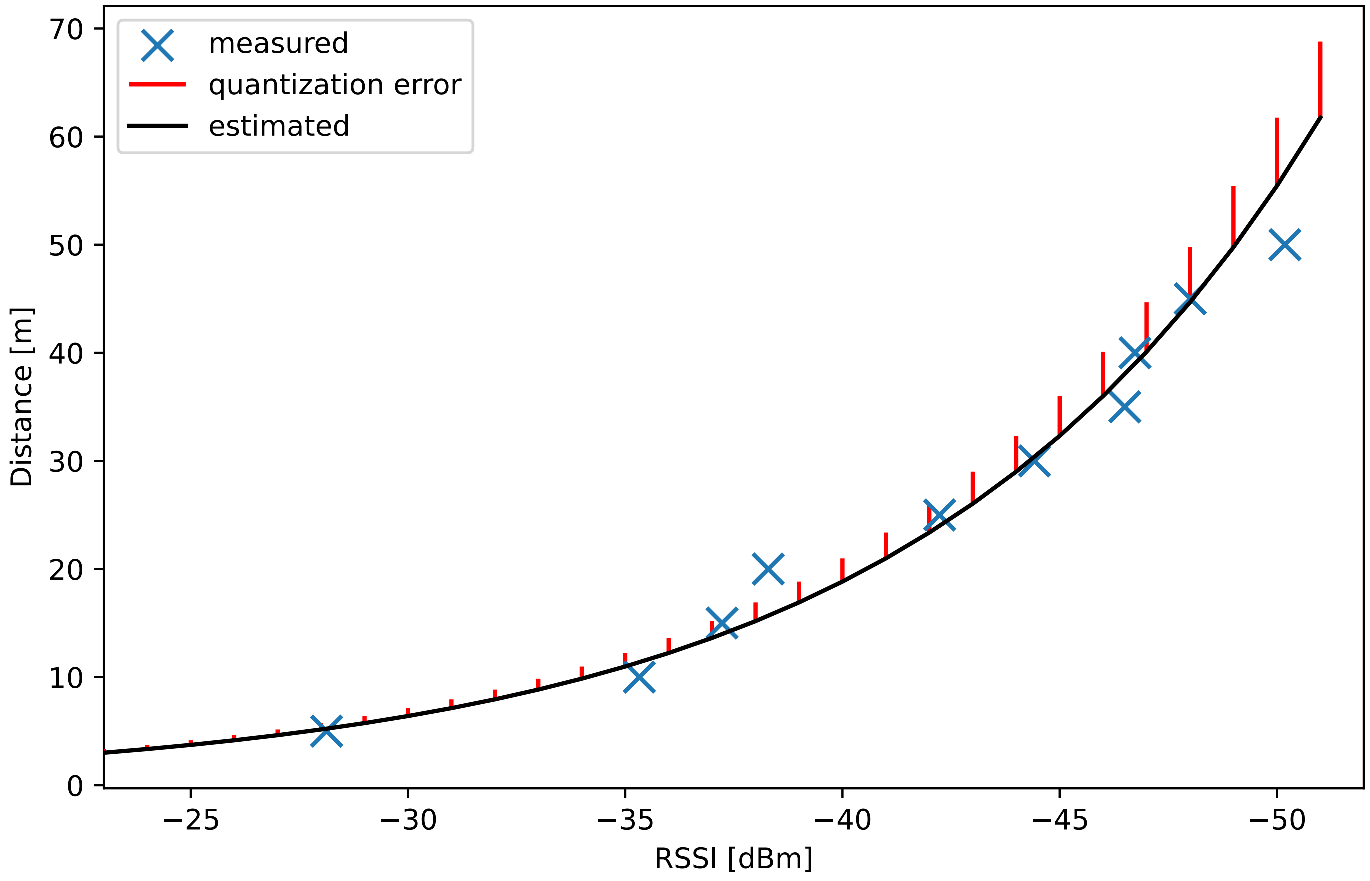

***Figure 6:* RSSI vs. Distance data from experiment 02_1**

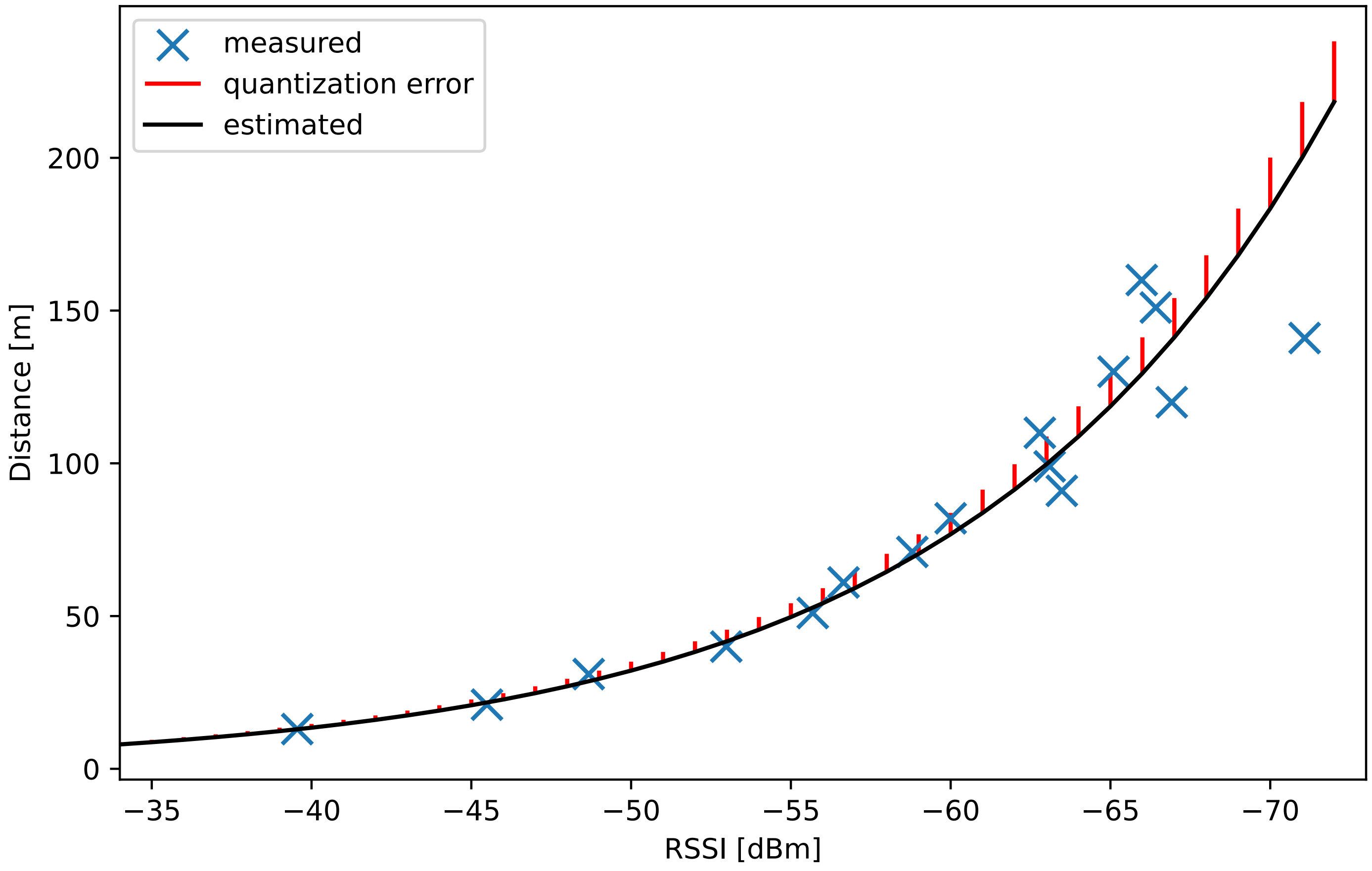

Figure 7: *RSSI vs. Distance data from experiment 07*

Distance Estimation (3/3)

ID	**Range**	n	P_0	$\mu(e_r)$	$\sigma(e_r)$	$e_{\max}$
01_2	5 m – 50 m	2.0873	-15.8050	0.0183	± 0.1967	$+11.0087$ m
02_1	5 m – 50 m	2.1331	-12.8029	0.0052	± 0.1051	$+6.5532$ m
02_2	5 m – 50 m	1.7558	-17.6398	0.0323	± 0.2710	$+19.4399$ m
07	10 m – 160 m	2.6444	-10.1465	0.0088	± 0.1454	$+60.4273$ m

Table 1: *Experiments for distance estimation evaluation*

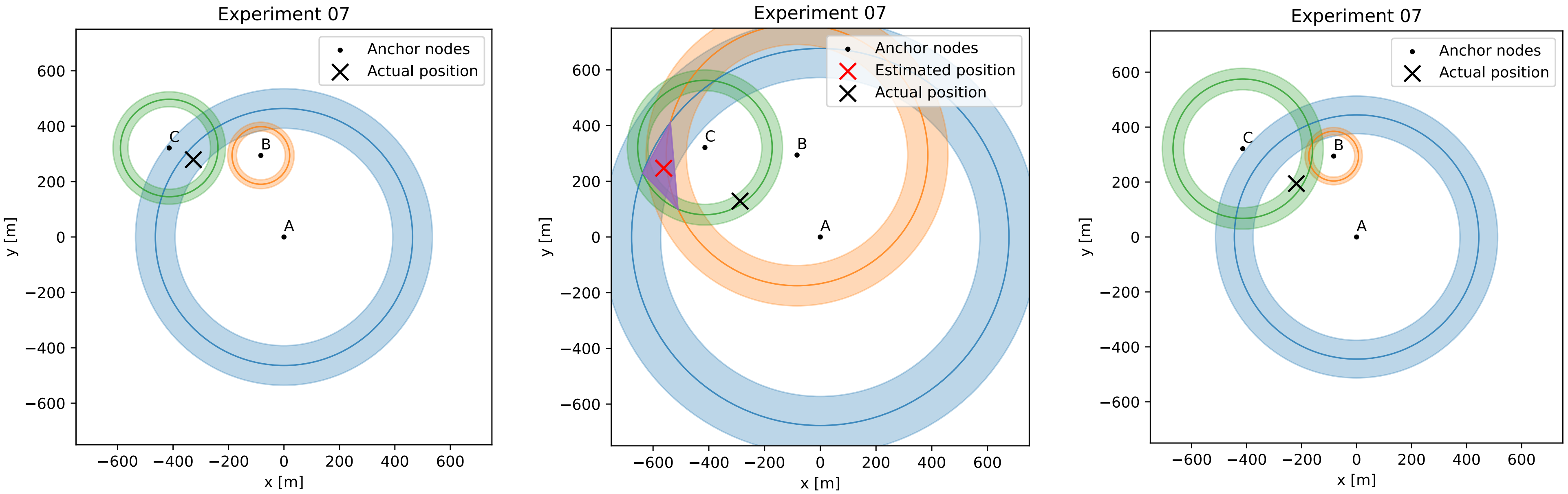

Figure 8: Localization – Experiment 07

Distance model	Position	Anchor ID	RSSI [dBm]	Distance [m]	Estimated Position	Actual Position
07	pos2	A	-85.0000	677.0604 ± 104.4287	x: -561.83 y: 246.99	x: -287.79 y: 128.70
		B	-80.7910	469.3139 ± 72.3862		
		C	-73.15	241.30 ± 37.22		

***Table 2:** Experiments for localization evaluation*

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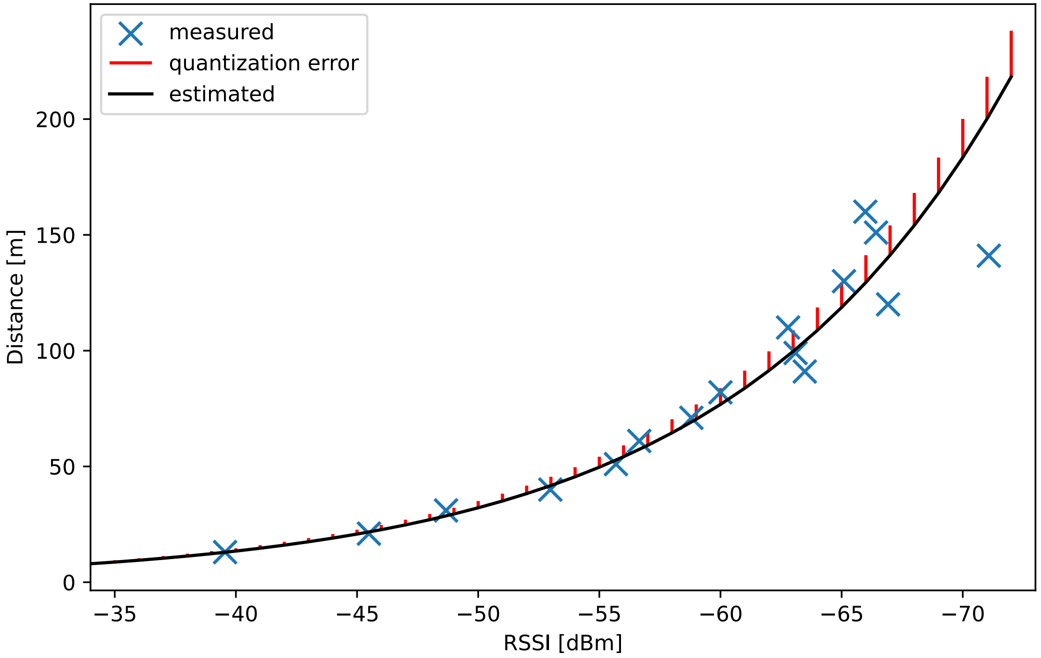

Figure 1: *RSSI vs. Distance data from experiment 07*

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- performance of the system was evaluated
- evaluation showed that the implemented system is not usable for localization in current state
  - big variations between different Path-Loss models
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→ potential for future improvements is visible

- different localization systems with LoRa™ already exist
  - RSSI-based [5], [6]
  - timing-based [7]

Future Work

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  - analyze the cause for the RSSI variation at higher distances
  - try different Path-Loss model
- try different localization algorithm
  - weighted least-mean-square method [5], [8]
  - DV-Hop [9]

Thank you

- firmware available on GitHub:
  https://github.com/moseschmiedel/lora-locator
- data available on GitHub:
  https://github.com/moseschmiedel/bachelor-thesis

[1] M. R. Seye, B. Ngom, B. Gueye, and M. Diallo, "A Study of LoRa™ Coverage: Range Evaluation and Channel Attenuation Model," in *2018 1st International Conference on Smart Cities and Communities (SCCIC)*, Jul. 2018, pp. 1–4. doi: 10.1109/SCCIC.2018.8584548.

[2] L. Casals, B. Mir, R. Vidal, and C. Gomez, "Modeling the Energy Performance of LoRa™ WAN," *Sensors*, vol. 17, no. 10, p. 2364–2365, Oct. 2017, doi: 10.3390/s17102364.

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[4] A. Zanella, "Best Practice in RSS Measurements and Ranging," *IEEE Communications Surveys & Tutorials*, vol. 18, no. 4, pp. 2662–2686, 2016, doi: 10.1109/COMST.2016.2553452.

[5] N. El Agroudy, N. Joram, and F. Ellinger, "Low power RSSI outdoor localization system," in *2016 12th Conference on Ph.D. Research in Microelectronics and Electronics (PRIME)*, Jun. 2016, pp. 1–4. doi: 10.1109/PRIME.2016.7519456.

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[7] B. C. Fargas and M. N. Petersen, "GPS-free geolocation using LoRa™ in low-power WANs," in *2017 Global Internet of Things Summit (GIoTS)*, Jun. 2017, pp. 1–6. doi: 10.1109/GIOTS.2017.8016251.

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[9] H. Safa, "A novel localization algorithm for large scale wireless sensor networks," *Computer Communications*, vol. 45, pp. 32–46, Jun. 2014, doi: 10.1016/j.comcom.2014.03.020.

List of Figures

```c
typedef struct {
    // attribute used to discriminate
    // between packet types
    PacketType_t packet_type;
    // ID of the device
    // sending the `Ping_t`
    uint8_t device_id;
    // ID of the `Ping_t`, `device_id`
    // combined with this should be unique
    uint8_t packet_id;
} Ping_t;
```

Listing 1: *Packet type `Ping_t`*

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```c
// Note that this packet does not need a `packet_type` discriminator because
// it is the only type that is 4 bytes long.
typedef struct {
    // ID of the anchor sending the `AnchorResponse_t`
    Device_t anchor_id;
    // ID of the `Ping_t` that triggered this `AnchorResponse_t`
    uint8_t packet_id;
    // RSSI of `Ping_t` measured by the anchor node
    int16_t recv_rssi;
} AnchorResponse_t;
```

Listing 2: *Packet type `AnchorResponse_t`*

Packet Types (3/3)


```c
typedef struct {
    // attribute used to discriminate between packet types
    PacketType_t packet_type;
    // ID of the anchor this `Ack_t` is addressed to
    Device_t receiver_id;
    // ID of the `Ping_t` that triggered the communication
    uint8_t packet_id;
} Ack_t;
```

Listing 3: *Packet type `Ack_t`*

Mode	Current [mA]	Power consumption [mW]
Transmitting	27	135
Receiving	8.5	42.5
Sleep	2.9	14.5

Table 1: *Power consumption*

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$$P_{\text{tx}} = \frac{2 \cdot T_{\text{tx}}}{1\,000\,\text{ms}} \cdot 135\,\text{mW} \tag{1}$$

$$P_{\text{rx}} = \frac{400\,\text{ms}}{1\,000\,\text{ms}} \cdot 42.5\,\text{mW} \tag{2}$$

$$P_{\text{tx}} = \frac{1000 - (2 \cdot T_{\text{tx}} + 400\,\text{ms})}{1\,000\,\text{ms}} \cdot 14.5\,\text{mW} \tag{3}$$

$$P_{\text{total}} = P_{\text{tx}} + P_{\text{rx}} + P_{\text{sleep}} = 30.7\,\text{mW} \tag{4}$$

$$P_{\text{total}} = P_{\text{tx}} + P_{\text{rx}} + P_{\text{sleep}} = 30.7\,\text{mW} \tag{5}$$

Low-Power (2/2)

$$P_{\text{total}} = P_{\text{tx}} + P_{\text{rx}} + P_{\text{sleep}} = 30.7\,\text{mW} \tag{5}$$

Figure 1: *LiPo Battery*

- lifetime of ~1303 h or 54.3 days with battery capacity of 40000 mWh

$$P_r^{[\mathrm{dB}]} = P_t^{[\mathrm{dB}]} + G_t^{[\mathrm{dBi}]} + G_r^{[\mathrm{dBi}]} + 20\log_{10}\left(\frac{\lambda}{4\Pi d}\right) \tag{6}$$