I. Abstract

II. Introduction

- something about importance of IoT and smart cities and fourth industrial revolution

[1]–[3]

- IoT with LoRa [4]
- importance of localization in IoT implementations [5]

LoRa provides excellent communication range at low power consumption but does this by only providing very slow data rates up to a theoretical limit of 11 kbps [3]. Due to this limitation many applications for which LoRa was evaluated in involve a low- or ultra-low-power sensor IoT device which has only small data packets which need to be transferred to a centralized control system or storage server. In [3] a proposal is made for utilizing LoRa and LoRaWAN technology for providing wireless local networks for communication of sensors and actuators in an Industry 4.0 scenario. Other work evaluates LoRa in concrete real-time scenarios. In [6] they evaluate LoRa as a communication technology for vehicle and asset tracking data at the harbor. In [7] they evaluate the achievable coverage in a smart campus setting. And in [8]

III. State of the Art

LoRa and LoRaWAN were released as a radio communication technology to the public in 2015 by Semtech. Very early on it already received coverage in scientific media as it was introduced as a promising long-range radio communication technology for IoT devices [4].

This section presents relevant literature correlating with mobile RSSI-based LoRa Localization.

A. LoRa Localization

There a multiple approaches for localization in RF based communication networks. The most commonly used all depend on one or more of four physical metrics of the received radio signal. These properties are the angle of arrival (AoA), time of arrival (ToA), Time delay of arrival (TDoA) and received signal strength (RSSI) [9].

Localization systems which are based on the angle of arrival use a directed antenna array to measure the angle at which the radio signal was received. When the exact distances between two anchor nodes are known, the position of a third node, further called end node, can be estimated simply on basis of the SAS congruence theorem. A slight variation of this method can be used when the distances between the anchor nodes is unknown. In this case the AoA of at least three anchor nodes must be known. The position of the end node can now be estimated by projecting lines from each anchor node with the measured AoA. The intersection of the lines represents the point or area in which the end node must be located. The projected lines only intersect in a single point when the AoA measurements are perfect i.e. the measurement has no error attached.

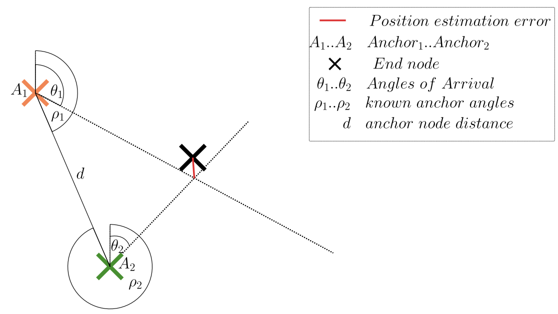

Figure 1: Angulation with two anchor nodes

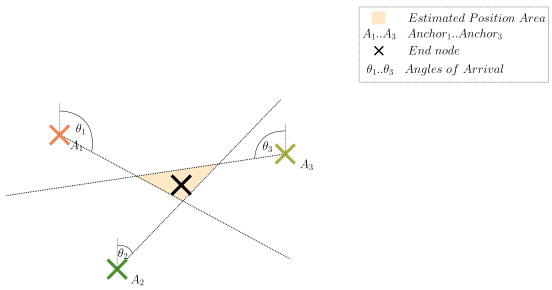

Figure 2: Angulation with three anchor nodes

Many different applications for LoRa/LoRaWAN were evaluated since its release. Because of the scope of this thesis this section only covers previous work which include some kind of localization with LoRa. The following section should not be regarded as a comprehensive list of all work including LoRa localization concepts but rather be used as a short overview of different applications for which LoRa localization was evaluated prior to this thesis.

Fargas et al. evaluate LoRa for use in an alternative GPS-free geolocation system [10]. Their proposed approach for localization with LoRa signals is based on precise measurements of the Time of Arrival (ToA) of one packet at multiple LoRa gateways (anchor node). They then calculate the time difference of the different ToA timestamps and estimate the distance between the end node and each gateway by using the propagation velocity of radio waves, which is the speed of light. These distance are then combined by a multilateration algorithm to estimate the position of the end node.

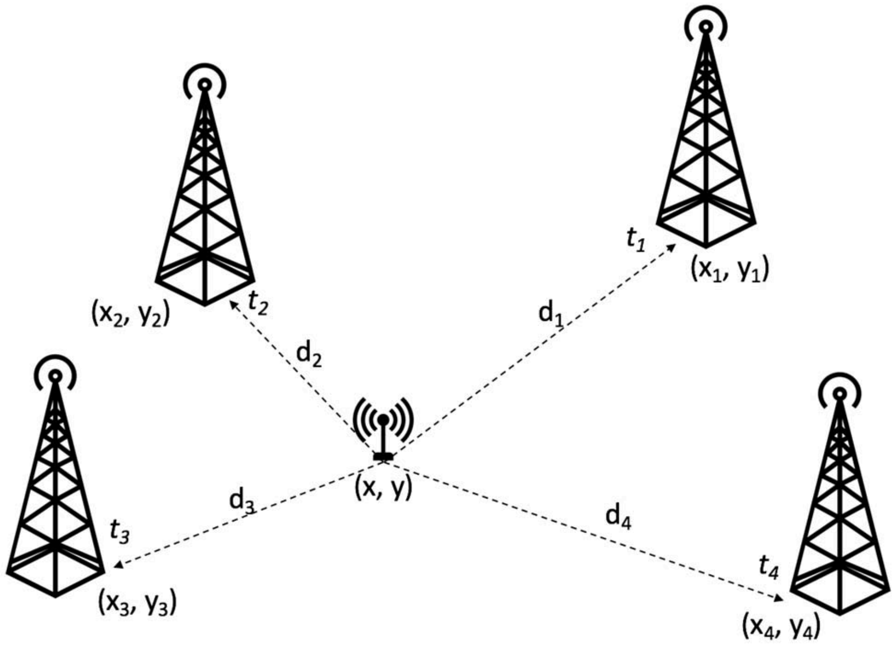

Figure 3: Position estimation with multilateration algorithm © 2017 IEEE

Fargas et al. also showed in their work, that by using the Generalized ESD test for detecting and eliminating outliers in the distance measurement data they could improve the accuracy of the position estimation.

At last they shortly compared the current consumption of their test system with a GPS + GSM based device and found that their device had significant lower current consumption and therefore could drastically decrease the power requirements for devices with localization systems.

This idea is further advanced in [11] where they evaluate LoRa as alternative localization system to GPS for Emergency Services.

They found that simple off-the-shelf LoRa hardware could be used for achieving a positioning error between $9 - 20\,\mathrm{m}$ in an area of $200\,\mathrm{m}$ x $120\,\mathrm{m}$.

They also estimated the expected battery-life both of the transmitter and the receiver node and found that the transmitter would possibly run up to 200 hours on a 5000 mAh battery but the receiver would only last about 90 hours with one battery charge.

Another point Fargas et al. highlight is the importance of a method for detecting and removing outliers in the RSSI measurement. They show the difference

In [12] they use RSSI-based LoRa Localization to track individual animals of a cattle herd to better deal with livestock theft. Their solution is based on a hybrid localization approach where they use both GPS and LoRa RSSI measurements to estimate the positions of the individual animals. They both deploy hybrid nodes, nodes equipped with both LoRa and GPS, and LoRa-only nodes. The hybrid nodes are used to continuously improve the RSSI-distance model over time by correlating their GPS position with the current distance estimated by the RSSI-distance model. Through this mechanism

In [13] they evaluate LoRa in carp

- RSSI-based LoRa localization for a low-cost car park localization implementation [13].
- LoRa evaluated for use as communication technology for Emergency Services in off-grid environments [11].
- Evaluation of LoRaHarbor [6]
- lightweight boat tracking using LoRa technology [14]
- LoRa-based mobile emergency management system (LOCATE) [8]

- tracking of patients in elderly care [15]
  - indoor and outdoor

B. Low Power

[16]

C. Deployment

- smart campus [7]
- coverage [3]

D. Challenges for LoRa Localization

[17]

- multiple approaches
  - ToA or TDoA => time-based approach
    - needs specialized hardware
    - insufficient accuracy for range of applications
    - often need pre-trained models
  - RSSI => signal-strength approach
    - multipath effect
    - high fluctuations in RSSI measurements at equal distance

E. Similar work

- RSSI-based LoRaWAN localization + evaluation of accuracy, impairments and prospects with SDR (software-defined radio) [18]
- low power rssi outdoor using 868 MHz ZigBee [16]
  - current consumption: 20mA in active mode, 6.7 uA in sleep-mode all at 3.3V -> receiver periodically wakes up to receive signals
- (indoor RSSI-based LoRa Localization in 2.4 GHz frequency band [19])
- evaluation of using AoA measurement for LoRa Localization in the cloud [20]
- AoA based (indoor?) LoRa Localization [21]
- LoRaWAPS: wide-area positioning system based on LoRa Mesh [22]
- public outdoor LoRa network used for TDoA-based tracking [23]

F. Contribution of this Thesis

- implementation and evaluation of mobile localization tag using RSSI-based LoRa localization with off-the-shelf (OTS) components
  - RSSI measurement is implemented in nearly all receivers -> no dedicated hardware
  - accuracy loss due to multipath effect should not play a huge role in outdoor localization because of higher LOS (line-of-sight) component of the signal
- evaluation of the feasibility of a LoRa based localization system
  - accuracy
  - power consumption
  - frequency band usage

IV. Principals

A. LoRa

B. RSSI-based distance estimation

C. Multilateration

Multilateration is a position estimation algorithm which uses three or more distances between the node which position should be estimated and nodes with known positions. The algorithm can be geometrically explained by drawing circles, each with the measured distance at the anchor as radius, around the positions of the anchors. The position of the end node is estimated by the point of intersection of all the circles. In a perfect scenario this single point of intersection would exist, but in a real-world scenario the distance measurement always includes an error. Due to this error the circles all intersect at different points. These points describe an area in which the real position of the end node must be located.

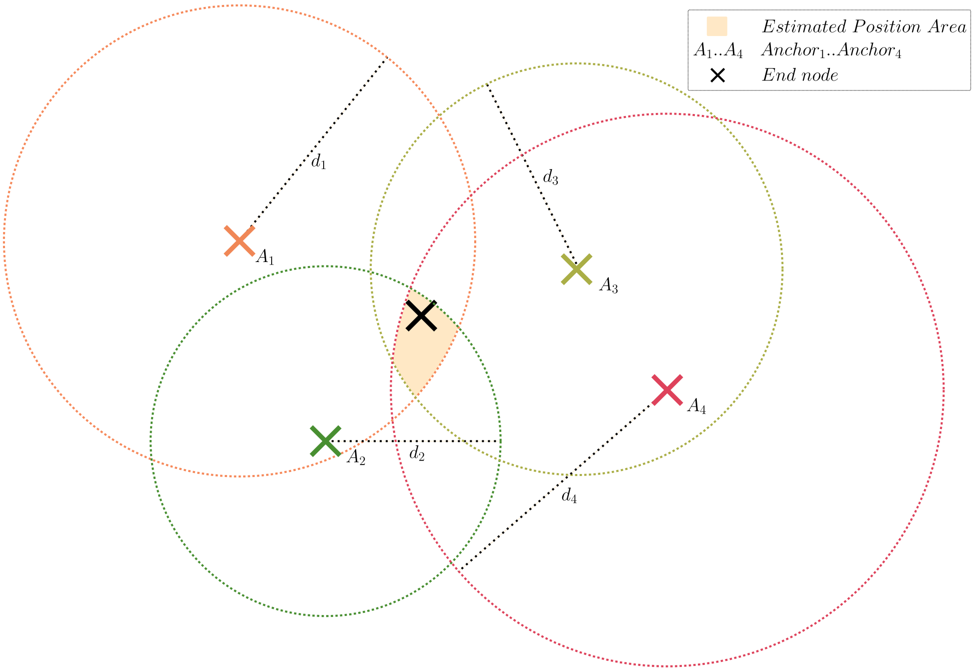

Figure 4: Position estimation error with multilateration

Figures

Bibliography

[1] H. Arasteh *et al.*, "Iot-based smart cities: A survey," in *2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC)*, Jun. 2016, pp. 1–6. doi: 10.1109/EEEIC.2016.7555867.

[2] M. Peña-Cabrera, V. Lomas, and G. Lefranc, "Fourth industrial revolution and its impact on society," in *2019 IEEE CHILEAN Conference on Electrical, Electronics Engineering, Information and Communication Technologies (CHILECON)*, Nov. 2019, pp. 1–6. doi: 10.1109/CHILECON47746.2019.8988083.

[3] M. Rizzi, P. Ferrari, A. Flammini, E. Sisinni, and M. Gidlund, "Using LoRa for industrial wireless networks," in *2017 IEEE 13th International Workshop on Factory Communication Systems (WFCS)*, May 2017, pp. 1–4. doi: 10.1109/WFCS.2017.7991972.

[4] L. Vangelista, A. Zanella, and M. Zorzi, "Long-Range IoT Technologies: The Dawn of LoRa™," in *Future Access Enablers for Ubiquitous and Intelligent Infrastructures*, V. Atanasovski and A. Leon-Garcia, Eds., Cham: Springer International Publishing, 2015, pp. 51–58. doi: 10.1007/978-3-319-27072-2_7.

[5] R. C. Shit, S. Sharma, D. Puthal, and A. Y. Zomaya, "Location of Things (LoT): A Review and Taxonomy of Sensors Localization in IoT Infrastructure," *IEEE Communications Surveys & Tutorials*, vol. 20, no. 3, pp. 2028–2061, 2018, doi: 10.1109/COMST.2018.2798591.

[6] I. F. Priyanta, F. Golatowski, T. Schulz, and D. Timmermann, "Evaluation of LoRa Technology for Vehicle and Asset Tracking in Smart Harbors," in *IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society*, Lisbon, Portugal: IEEE, Oct. 2019, pp. 4221–4228. doi: 10.1109/IECON.2019.8927566.

[7] H. B. M. Alves *et al.*, "Introducing a survey methodology for assessing LoRaWAN coverage in Smart Campus scenarios," in *2020 IEEE International Workshop on Metrology for Industry 4.0 & IoT*, Jun. 2020, pp. 708–712. doi: 10.1109/MetroInd4.0IoT48571.2020.9138300.

[8] L. Sciullo, A. Trotta, and M. D. Felice, "Design and performance evaluation of a LoRa-based mobile emergency management system (LOCATE)," *Ad Hoc Networks*, vol. 96, p. 101993–101994, Jan. 2020, doi: 10.1016/j.adhoc.2019.101993.

[9] L. E. Marquez and M. Calle, "Understanding LoRa-Based Localization: Foundations and Challenges," *IEEE Internet of Things Journal*, vol. 10, no. 13, pp. 11185–11198, Jul. 2023, doi: 10.1109/JIOT.2023.3248860.

[10] 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.

[11] A. Mackey and P. Spachos, "LoRa-based Localization System for Emergency Services in GPS-less Environments," in *IEEE INFOCOM 2019 - IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, Paris, France: IEEE, Apr. 2019, pp. 939–944. doi: 10.1109/INFCOMW.2019.8845189.

[12] O. Dieng, C. Pham, and O. Thiare, "Outdoor Localization and Distance Estimation Based on Dynamic RSSI Measurements in LoRa Networks: Application to Cattle Rustling Prevention," in *2019 International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, Barcelona, Spain: IEEE, Oct. 2019, pp. 1–6. doi: 10.1109/WiMOB.2019.8923542.

[13] P. Gotthard and T. Jankech, “Low-Cost Car Park Localization Using RSSI in Supervised LoRa Mesh Networks,” *2018 15th Workshop on Positioning, Navigation and Communications (WPNC)*, pp. 1–6, Oct. 2018, doi: 10.1109/WPNC.2018.8555792.

[14] R. Sanchez-Iborra, I. G. Liaño, C. Simoes, E. Couñago, and A. F. Skarmeta, “Tracking and Monitoring System Based on LoRa Technology for Lightweight Boats,” *Electronics*, vol. 8, no. 1, p. 15–16, Jan. 2019, doi: 10.3390/electronics8010015.

[15] C. D. Fernandes *et al.*, “Hybrid indoor and outdoor localization for elderly care applications with LoRaWAN,” in *2020 IEEE International Symposium on Medical Measurements and Applications (MeMeA)*, Jun. 2020, pp. 1–6. doi: 10.1109/MeMeA49120.2020.9137286.

[16] 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.

[17] C. Gu, L. Jiang, and R. Tan, “LoRa-Based Localization: Opportunities and Challenges.”

[18] H. Kwasme and S. Ekin, “RSSI-Based Localization Using LoRaWAN Technology,” *IEEE Access*, vol. 7, pp. 99856–99866, 2019, doi: 10.1109/ACCESS.2019.2929212.

[19] A. Vaishnav, “Design and Evaluation of an Indoor Localization System using 2.4 GHz LoRa,” 2022, Accessed: Aug. 17, 2024. [Online]. Available: https://www.ds.informatik.uni-kiel.de/en/teaching/bachelor-and-master-theses/completed-master-and-bachelor-theses/2022-master-ashok-vaishnav.pdf

[20] N. BniLam, S. Nasser, and M. Weyn, “Angle of Arrival Estimation System for LoRa Technology based on Phase Detectors,” in *2022 16th European Conference on Antennas and Propagation (EuCAP)*, Mar. 2022, pp. 1–5. doi: 10.23919/EuCAP53622.2022.9769059.

[21] J. Ge, D. Zhu, L. Sun, C. Han, and J. Guo, “A Long-Range Signal-Based Target Localization Algorithm,” *Electronics*, vol. 13, no. 6, p. 1069–1070, Jan. 2024, doi: 10.3390/electronics13061069.

[22] B. Li, Y. Xu, Y. Liu, and Z. Shi, “LoRaWAPS: A Wide-Area Positioning System Based on LoRa Mesh,” *Applied Sciences*, vol. 13, no. 17, p. 9501–9502, Jan. 2023, doi: 10.3390/app13179501.

[23] N. Podevijn *et al.*, “TDoA-Based Outdoor Positioning with Tracking Algorithm in a Public LoRa Network,” *Wireless Communications & Mobile Computing*, vol. 2018, Jan. 2018, doi: 10.1155/2018/1864209.