Master Thesis Proposal

Sensor-based Positioning for Vehicular Applications

Jan Matthias Nausner

Supervisors:
Prof. Christoph Mecklenbräuker
Univ.Ass. Mehdi Ashury

April 5, 2022

1 Motivation & Problem Statement

For several decades, various global navigation satellite systems (GNSS) have enabled vehicular positioning with an average accuracy between a few meters and up to 20 meters or above in worst case scenarios. With the advent of safety-critical vehicular applications like autonomous driving and advanced driver assistance systems (ADAS), new and more stringent requirements with regard to measures like positioning accuracy (decimeter-level), latency and reliability have emerged. In 2021 alone, 359 people have died due to road traffic accidents in Austria [1] and many more have been injured. Safe autonomous vehicles and ADAS will likely contribute to a continuous reduction of this number towards the goal of zero traffic deaths. One promising method to approach this goal would be to cooperatively build a map of the traffic environment by fusing the distributed sensor data of all road users in a certain range and in turn notify the users if a dangerous situation has been detected. However, this of course requires highly accurate position information for at least some of the participating road users.

One upcoming technology in particular, namely the 5th generation of broadband cellular networks (5G), promises to support positioning over radio signals with high accuracy, which could meet the requirements of state-of-the-art vehicular applications. The key enabling properties of 5G for positioning are: 1) High carrier frequencies in the millimeter wave band (mmWave) around 30 GHz, allowing for large antenna arrays with strong beamforming and signal estimation capabilities and a sparse channel with regard to multipath components. 2) Large bandwidths in the order of hundreds of MHz, reducing latency and increasing time measurement accuracy. 3) High-speed, low-latency data exchange not only between mobile users and the cellular base stations, but also directly between mobile devices, known as device-to-device (D2D) communication. Furthermore, it is expected that the roll-out of 5G comes with a densification of the cellular network, leading to an increased number of reference points and a higher probability for a line of sight (LOS) connection. This would be beneficial for positioning especially in urban areas, where conventional GNSS tends to struggle the most.

The purpose of this work is to evaluate in simulation whether 5G positioning can meet the requirements of state-of-the-art and future vehicular applications. If this is not the case, it shall be investigated how the positioning accuracy can be improved further by fusing 5G position data with data from other sensors such as an inertial measurement unit (IMU), automotive radar or GNSS receivers.

2 Aim of the Work

The aim of the work is to develop a positioning method which is able to meet the requirements of state-of-the-art and future vehicular applications. A proof-of-concept shall be implemented and evaluated by performing simulations of appropriate vehicular scenarios. At first, the positioning method should only rely on measurements within the 5G cellular network. Although very promising, it remains an open question if positioning with 5G signals can provide sufficient accuracy on its own. In a second step, it should be investigated how the position accuracy can be improved by fusing 5G position data with measurements from other sensors such as IMU, radar or GNSS. The overall performance of the position estimation and data fusion algorithms shall be evaluated by simulating realistic vehicular scenarios.

3 Methodological Approach

1. **Literature review.**
   An extensive literature study provides the necessary overview over existing approaches to the problem and their limitations. Furthermore, it is the basis for a good theoretical understanding of the problem.

2. **Study of statistical methods.**
   Methods for estimating signal delay and receiver position shall be studied and adapted to fit the problem at hand.

3. **Evaluation of 5G vehicular positioning.**
   Methods for obtaining vehicular positions over the 5G cellular network shall be implemented. The performance of the methods shall be evaluated by matters of simulation of realistic vehicular scenarios.

4. **Evaluation of data fusion for vehicular positioning.**
   Methods for sensor data fusion shall be implemented in order to increase vehicular positioning accuracy and reliability of the 5G-based method obtained in the previous step. The overall system performance shall be evaluated by simulating appropriate vehicular scenarios.

4 State of the Art

The 3rd Generation Partnership Project [2] Release 16 specifies several 5G New Radio (NR) positioning techniques. The following approaches are among the supported methods [3, 4]: Downlink Time Difference of Arrival (DL-TDoA), using positioning reference symbols (PRS) for time measurement; Uplink Time Difference of Arrival (UL-TDoA), relying on sounding reference signals (SRS) for time measurement; Uplink Angle of Arrival (UL-AoA), using for example the Multiple Signal Classification (MUSIC) Algorithm; Downlink Angle of Departure (DL-AoD), using several available reference signals. Further, even more accurate positioning techniques will be specified in Release 17, which is expected to be published in the first half of 2022. In the book [5] an in-depth summary of the signal processing techniques involved in the above stated positioning methods is given. The survey [6] provides an overview over various 5G multiple-input-multiple-output (MIMO) positioning techniques while in [7] promising methods for NLOS mitigation and sub-meter precise positioning are suggested. Recent studies have focused on the statistical analysis of 5G mmWave MIMO positioning, derived fundamental bounds on positioning and orientation errors [8, 9, 10]. The paper [11] presents a tensor-based channel estimator for 5G massive MIMO systems which is able to accurately determining delay and angles by exploiting the information available in mmWave multipath components. Based on this concept, [12] shows an end-to-end positioning system, achieving sub-meter positioning accuracy with the downside of high computational cost for the extensive signal processing methods in use.

State-of-the-art and future vehicular applications such as automated overtaking, collision detection or vulnerable road user detection require decimeter-level positioning accuracy, which is expected to be met by 5G based positioning methods [13]. In [14, 15] methods are shown which are able to locate and track vehicles in 5G networks with sub-meter accuracy by using information of multipath components in mmWave propagation. The paper [16] proposes a 5G vehicle position estimation algorithm using TDoA measurements with a non line of sight (NLOS) cancellation MUSIC implementation to improve accuracy in the presence of NLOS components. The prospected vehicle-to-everything (V2X) communication capabilities of 5G are outlined in [17] and the applicability to cooperative vehicular positioning is discussed.

The survey [18] lists state-of-the-art vehicular positioning techniques, compares their strengths and weaknesses and discusses their applicability to autonomous driving, hence giving a good overview of potential sensor candidates to be considered for a data fusion approach. In [19] a field measurement campaign for a hybrid 5G MIMO/GNSS/IMU positioning method has been conducted and the results are promising with sub-meter accuracy being achieved in certain scenarios. The work in [20] shows how TDoA in the long term evolution (LTE) cellular network improves positioning accuracy of GNSS by fusing data from both sensor types with an extended kalman filter (EKF). A method for cooperative position estimation by fusion of multiple radar sensors with the particle filter algorithm has been proposed in [21].

5 Relevance to the Curricula of Computer Engineering

In order to achieve the aim of this thesis, different statistical signal processing and parameter estimation methods need to be studied, evaluated and implemented for simulation purposes. Therefore, the research on the topic of this thesis requires knowledge acquired in the following courses of the Computer Engineering curriculum:

- 107.A04 Probability Theory and Stochastic Processes for Computer Science
- 182.763 Stochastic Foundations of Cyber Physical Systems
- 389.166 Signal Processing 1
- 389.170 Signal Processing 2
- 389.119 Parameter Estimation Methods
- 389.040 Signal Detection
- 389.163 Digital Communications 1
- 194.076 Modeling and Simulation

References

[1] “Verkehrsstatistik 2021, bundesministerium für inneres.” https://www.bmi.gv.at/202/Verkehrsangelegenheiten/unfallstatistik_vorjahr.aspx. Accessed: 05.04.2022.

[2] “3rd generation partnership project.” https://www.3gpp.org/. Accessed: 06.03.2022.

[3] R. Keating, M. Säily, J. Hulkkonen, and J. Karjalainen, "Overview of positioning in 5g new radio," in *2019 16th International Symposium on Wireless Communication Systems (ISWCS)*, pp. 320–324, IEEE, 2019.

[4] S. Dwivedi, R. Shreevastav, F. Munier, J. Nygren, I. Siomina, Y. Lyazidi, D. Shrestha, G. Lindmark, P. Ernström, E. Stare, *et al.*, "Positioning in 5g networks," *IEEE Communications Magazine*, vol. 59, no. 11, pp. 38–44, 2021.

[5] R. Zekavat and R. M. Buehrer, *Handbook of position location: Theory, practice and advances*, vol. 27. John Wiley & Sons, 2011.

[6] F. Wen, H. Wymeersch, B. Peng, W. P. Tay, H. C. So, and D. Yang, "A survey on 5g massive mimo localization," *Digital Signal Processing*, vol. 94, pp. 21–28, 2019.

[7] O. Kanhere and T. S. Rappaport, "Position location for futuristic cellular communications: 5g and beyond," *IEEE communications magazine*, vol. 59, no. 1, pp. 70–75, 2021.

[8] A. Shahmansoori, G. E. Garcia, G. Destino, G. Seco-Granados, and H. Wymeersch, "5g position and orientation estimation through millimeter wave mimo," in *2015 IEEE Globecom Workshops (GC Wkshps)*, pp. 1–6, IEEE, 2015.

[9] A. Shahmansoori, G. E. Garcia, G. Destino, G. Seco-Granados, and H. Wymeersch, "Position and orientation estimation through millimeter-wave mimo in 5g systems," *IEEE Transactions on Wireless Communications*, vol. 17, no. 3, pp. 1822–1835, 2017.

[10] Z. Abu-Shaban, X. Zhou, T. Abhayapala, G. Seco-Granados, and H. Wymeersch, "Error bounds for uplink and downlink 3d localization in 5g millimeter wave systems," *IEEE Transactions on Wireless Communications*, vol. 17, no. 8, pp. 4939–4954, 2018.

[11] F. Wen, J. Kulmer, K. Witrisal, and H. Wymeersch, "5g positioning and mapping with diffuse multipath," *IEEE Transactions on Wireless Communications*, vol. 20, no. 2, pp. 1164–1174, 2020.

[12] Y. Ge, F. Wen, H. Kim, M. Zhu, F. Jiang, S. Kim, L. Svensson, and H. Wymeersch, "5g slam using the clustering and assignment approach with diffuse multipath," *Sensors*, vol. 20, no. 16, p. 4656, 2020.

[13] H. Wymeersch, G. Seco-Granados, G. Destino, D. Dardari, and F. Tufvesson, "5g mmwave positioning for vehicular networks," *IEEE Wireless Communications*, vol. 24, no. 6, pp. 80–86, 2017.

[14] H. Kim, H. Wymeersch, N. Garcia, G. Seco-Granados, and S. Kim, "5g mmwave vehicular tracking," in *2018 52nd Asilomar Conference on Signals, Systems, and Computers*, pp. 541–547, IEEE, 2018.

[15] H. Kim, K. Granström, L. Gao, G. Battistelli, S. Kim, and H. Wymeersch, "5g mmwave cooperative positioning and mapping using multi-model phd filter and map fusion," *IEEE Transactions on Wireless Communications*, vol. 19, no. 6, pp. 3782–3795, 2020.

[16] Z. Deng, X. Zheng, H. Wang, X. Fu, L. Yin, and W. Liu, "A novel time delay estimation algorithm for 5g vehicle positioning in urban canyon environments," *Sensors*, vol. 20, no. 18, p. 5190, 2020.

[17] H. Bagheri, M. Noor-A-Rahim, Z. Liu, H. Lee, D. Pesch, K. Moessner, and P. Xiao, "5g nr-v2x: Toward connected and cooperative autonomous driving," *IEEE Communications Standards Magazine*, vol. 5, no. 1, pp. 48–54, 2021.

[18] S. Kuutti, S. Fallah, K. Katsaros, M. Dianati, F. Mccullough, and A. Mouzakitis, "A survey of the state-of-the-art localization techniques and their potentials for autonomous vehicle applications," *IEEE Internet of Things Journal*, vol. 5, no. 2, pp. 829–846, 2018.

[19] F. Mata, F. Grec, M. Azaola, F. Blázquez, A. Fernández, E. Dominguez, G. Cueto-Felgueroso, G. Seco-Granados, J. del Peral-Rosado, E. Staudinger, *et al.*, "Preliminary field trials and simulations results on performance of hybrid positioning based on gnss and 5g signals," in *Proceedings of the 33rd International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2020)*, pp. 387–401, 2020.

[20] C. Mensing, S. Sand, and A. Dammann, "Hybrid data fusion and tracking for positioning with gnss and 3gpp-lte.," *International Journal of Navigation & Observation*, 2010.

[21] M. Ashury, C. Eliasch, T. Blazek, and C. F. Mecklenbräuker, "Accuracy requirements for cooperative radar with sensor fusion," in *2020 14th European Conference on Antennas and Propagation (EuCAP)*, pp. 1–5, IEEE, 2020.