21.09.2021

Master Thesis

Design and Evaluation of a 5G NR mmWave Cellular Outdoor Positioning System

Motivation and Problem Statement

Basic positioning capabilities have first been introduced with LTE release 9 for *regulatory services* such as emergency calls and lawful interception, and been extended steadily since [1]. Recently, it was enhanced significantly by release 16 of 5G New Radio (NR) and it is now set to be evolved further by releases 17 and 18, cf. Fig. 1. The aim of 5G NR rel. 16 and beyond positioning services is to offer enhanced capabilities enabling *commercial* and *industrial use cases* such as localization and tracking of pedestrians, vehicles and assets in challenging environments, e.g. indoor industrial facilities or busy urban outdoor environments [2]. Moreover, there is also interest for *network-internal usage*, e.g. for location-aware handover [3]. As of now, standardization has defined seven service levels with the strongest requirements for example demanding for cm-level horizontal accuracy compared to LTE's accuracy in the tens of meters [4; Sec. 6.27 & 7.3]. To meet such ambitious requirements, wider bands, higher carriers, and large-scale antenna arrays will be used as these offer the necessary degrees of freedom enabling more accurate positioning.

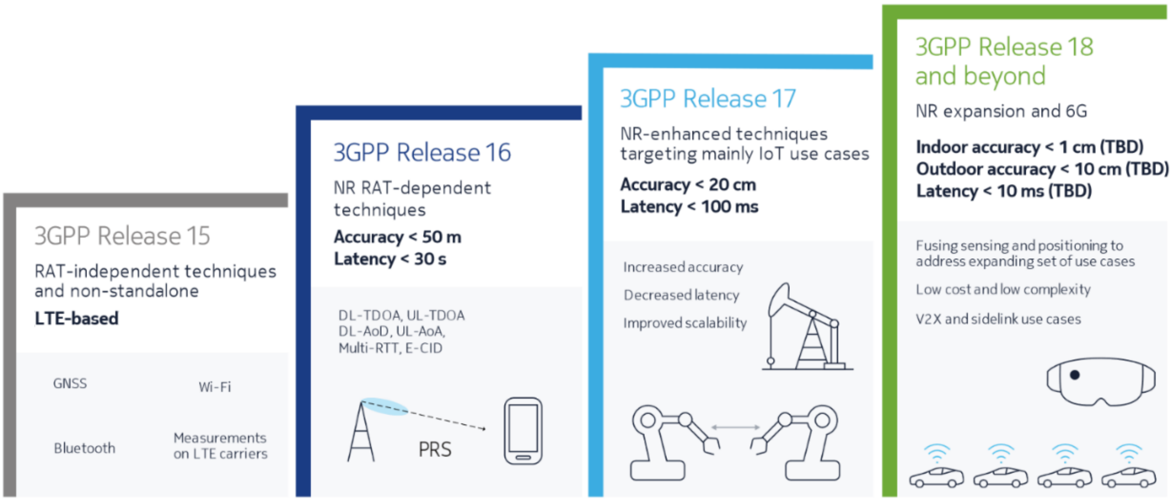

Figure 1: Positioning features for 3GPP rel. 15 to rel. 18 and beyond (adapted from [5]).

Requirements-compliant deployment of 5G NR positioning services with minimal physical resource needs, minimal energy consumption and high scalability to large numbers of mobile users, might be seen as a first step towards future perceptive mobile networks (PMNs). This envisioned 6G concept aims to provide radar-like sensing (and imaging) services for internal and external usage, in particular including positioning services. Realization of this concept will be enabled by use of millimeter-wave (mmWave) carriers (> 24 GHz) which have recently been introduced to cellular networks by 5G [6]. However, communication at such high frequencies is very different due to novel propagation characteristics which necessitate beamforming and -steering using large antenna arrays. As a result, mmWave communication becomes directional, which is a huge challenge on the one hand, but also an exciting opportunity for both communication and sensing on the other hand [7].

Considering the overlap of 5G positioning services and 5G mmWave with the design goals for 6G, we are interested in analyzing 5G NR positioning services employed at mmWave carriers. This allows us to evaluate the benefits 5G location services (LCS) may offer and, more interestingly, which impact providing LCS has on primary network operation, i.e. communications, in terms of network capacity.

Potential Goals

This master thesis brings together several interesting topics such as the ever-evolving 5G standard, positioning techniques, IIoT/Industry 4.0 use cases, and - in particular - mmWave propagation and beam management. Expect to dive into standardization documents and positioning literature to become an expert on your topic. Afterwards you will build up your own 5G-conformal positioning system flavors which are evaluated analytically and based on ray-tracing simulation data.

Potential topics your master thesis will address:

- *Survey:* Research applicable positioning algorithms and relevant channel parameters; competing technologies (Wi-Fi, BLE, UWB, GNSS etc.); application requirements.
- *Analysis of sub-6 GHz 5G NR positioning (rel. 16)*: What is new or has been adapted compared to baseline 5G NR (rel. 15) which relies upon LTE positioning? What are the inherent design trade-offs (bandwidth, delay, accuracy, velocity etc.)?
- *Analysis of 5G mmWave for positioning services*: What changes when moving the system to mmWave? Is this concept feasible in practice considering beam management overhead? How is the performance vs. sub-6 GHz positioning?
- *Ray-tracing data-based evaluation*: Implement LOS/NLOS timing- and angle-based positioning techniques to be used to evaluate the achievable positioning accuracy in sample scenarios considering beamforming characteristics and larger bandwidths.

Requirements

- Interest in 5G standard, mmWave systems, and positioning techniques
- Participation in *MFN* lecture (Grade: *excellent/good*); other CNI lectures are a plus
- Excellent English skills; highly desirable: Willingness to write thesis in English
- Basic MATLAB/Python and LaTeX/TikZ skills

References

[1] S. M. Razavi *et al*., "Positioning in cellular networks: Past, present, future," *2018 IEEE Wireless Communications and Networking Conference (WCNC)*, June 2018.

[2] S. Dwivedi *et al.*, "Positioning in 5G networks," *arXiv cs.NI e-prints*, February 2021, available: https://arxiv.org/pdf/2102.03361.pdf.

[3] R. Keating *et al.*, "Overview of Positioning in 5G New Radio," *2019 16th International Symposium on Wireless Communication Systems (ISWCS)*, October 2019.

[4] 3GPP TS 22.261, "Service requirements for the 5G system (Rel. 18)," v18.2.0, March 2021, available: https://www.3gpp.org/ftp//Specs/archive/22_series/22.261/22261-i20.zip.

[5] A. Ghosh *et al.*, "The Evolution of 5G New Radio Positioning Technologies," Nokia Bell Labs, White Paper, February 2021, available: https://www.bell-labs.com/institute/white-papers/evolution-5g-new-radio-positioning-technologies/ [last visited: September 21, 2021].

[6] J. A. Zhang *et al.*, "Perceptive mobile networks: Cellular networks with radio vision via joint communication and radar sensing," in *IEEE Vehicular Technology Magazine*, June 2021.

[7] M. Giordani *et al.*, "A Tutorial on Beam Management for 3GPP NR at mmWave Frequencies," in *IEEE Communications Surveys & Tutorials,* September 2018.