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 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.

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 (PMMs). 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].

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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 skills

**References**


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