technische universität
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Faculty EE/IT
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Bachelor Thesis

Design and Performance Evaluation of Mobile mmWave Initial Access Protocols

Motivation and Problem Statement

The extension of 5G networks towards the millimeter-wave (mmWave) spectrum is a reaction to the exponential growth of wireless data traffic and the need for significantly higher data rates [1]. This move has been mirrored with Wi-Fi amendments IEEE 802.11ad/aj/ay, and there is already speculation whether 6G will use even higher frequencies than 5G. However, the drastic change of carrier frequency comes with new challenges, primarily due to the hostile propagation characteristics of mmWaves [2]. To overcome these, antenna arrays and analog/hybrid beamforming transceiver ought to be used [3]. MmWave communication thereby becomes directional such that even detecting an available network becomes cumbersome. Therefore, base station (BS) and user equipment (UE) side pencil beams have to be aligned precisely by means of *beam management* (a.k.a. *beamsteering*), in particular, *beam training* protocols aim to establish the mmWave link in the first place. Naturally, when taking user mobility into account, the beams need to be realigned continuously by means of *beam tracking and switching* protocols to ensure consistent multi-Gbps connectivity [4, 5].

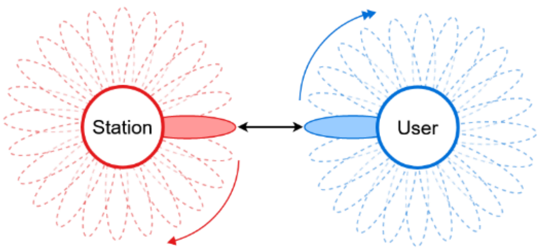

Figure 1: Illustration of exhaustive beam search in azimuth plane using pencil beams.

Figure 3: Iterative search: Two-stage hierarchical beam training illustrated in azimuth plane. (*Left:* Exhaustive sector beam sweeping. *Right:* Ensuing pencil beam refinement.)

As of now, research has investigated and designed numerous beamsteering algorithms for initial access (beam training). For example, as shown in Figure 1, the *Exhaustive Search* protocol sweeps the pencil beams on both sides. By testing all possible combinations, the UE finds the BS and the subsequently established link will leverage the optimal beam pair (if the user is stationary). While this maximizes the *data rate* upon network registration, excessive control signaling *delay* (and energy consumption) is incurred. In contrast, the *Iterative Search* protocol shown in Figure 2 has a lower delay as the sector beams (lower antenna gain, broader beamwidth), which are used in the first stage, allow for quicker scanning of the whole angular domain. However, the *cell radius* shrinks due to reduced antenna gains [6].

Beyond these well-known protocols aiming to establish the optimal beam pair, there are greedy algorithms with the explicit aim of minimizing the initial signaling overhead, e.g. [7] and [8]. While one might think that the other beam management protocols, which set in after the user device has successfully registered in the network, will equalize the initial severe losses in data rate in no time, it may occur that there may indeed be no time for these to set in if the beam training protocol's selected beam pair is not robust to user mobility such that the link is lost before the selected beam pair is updated. We therefore find that there might be another trade-off for beam training protocol design beneath delay, data rate, and coverage: Depending on the used protocol, how much may the user move before the link is lost? In other words, what is the time cap for subsequent beam management protocols to come up with an updated beam pair? This bachelor thesis shall therefore investigate the achieved *spatial robustness* of several beam training protocols. In particular, this also pertains to assessing the performance of state-of-the-art protocols when the user is moving during beam training as measurements may become stale. As this has not yet been covered thoroughly by research, this could be a work of great interest to the mmWave community.

Goals of this Bachelor Thesis

This bachelor thesis brings together several interesting topics, namely the 5G standard and, in particular, mmWave propagation and beam management. In your thesis you will implement and evaluate well-known beam training protocols, and derived greedy flavors, on the CNI's ray-tracing based *urban mmWave dataset*. Your evaluation will focus on the arising trade-offs, in particular pertaining to mobility.

Your bachelor thesis will address:

- Initial access in cellular networks and how it deviates for mmWave communications.
- MmWave channel characteristics and state-of-the-art beam training algorithms.
- *Beam training with stationary user:* Implementation of beam training algorithms. Evaluation of well-known performance trade-offs "delay, data rate, coverage" by considering varying transmit power levels and the angular search spaces. Special focus will be on post-training user mobility (including device rotation).
- *Beam training for mobile users:* Extend the setup such that user mobility during beam training (along pre-selected trajectories) can be studied. Are the state-of-the-art protocols still capable of establishing links? By the previous established metrics, what are the implications of mobility during initial access?

Requirements

- Interest in mmWave communication and the 5G standard
- Excellent English skills and willingness to write thesis in English
- Basic MATLAB/Python skills; LaTeX/TikZ skills are a plus

References

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[4] M. Giordani, M. Mezzavilla, and M. Zorzi, "Initial access in 5G mmWave cellular networks," in *IEEE Communications Magazine*, vol. 54, no. 11, Nov. 2016.
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