Master Thesis

Design of a mmWave Beam Training Protocol for Ultra-Dense mmWave Deployments

Motivation and Problem Statement

The recent move of 5G towards the millimeter-wave (mmWave) spectrum (> 24 GHz) is a reaction to the exponential growth of wireless mobile data consumption and the need for significantly higher data rates for emerging applications such as VR and 8K video [1]. A similar move has also already occurred with Wi-Fi amendments IEEE 802.11ad/aj/ay, and there is already speculation whether 6G could even use THz frequencies. This drastic change of carrier frequency comes with new challenges due to the rather hostile propagation characteristics at the mmWave domain [2]. To overcome these, large planar antenna arrays and novel beamforming transceiver architectures are facilitated [3]. As a result, mmWave communication becomes directional such that base station (BS) and user equipment (UE) side pencil beams have to be aligned precisely by means of *beam management* (a.k.a. *beamsteering*) to establish the mmWave link. Afterwards, the beams have to be realigned continuously to enable robust communication at multi-Gigabit/s data rates in mobile environments as shown in Fig. 1 [4].

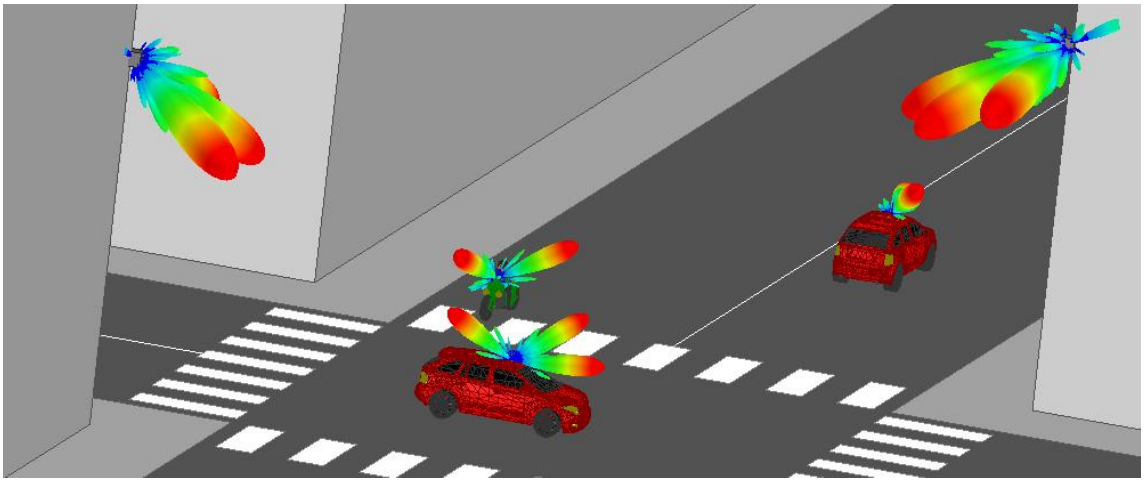

Figure 1: Pencil beams have to be aligned precisely such that communication may occur. In dense networks UEs may be able to detect more than one BS at a time.

So far, research has focused almost exclusively on beamsteering algorithms for initial access in scenarios where there is just one mmWave BS, cf. Figs. 2-3. In this context, it was found that there is a *trade-off* between *delay* (and energy consumption) for initial access, achieved *link quality* (signal strength/SNR/data rate) at time of the network access grant, and the *coverage* region in which UEs can access the network using a specific beamsteering algorithm [5]. However, due to the hostile propagation characteristics, mmWave BSs will be deployed very densely within hotspot regions (e.g. city centers, business districts, near tourist attractions) such that the cellular network can serve as many customers with high data rate demands as possible in these areas. This further means that the user may have the choice to select between several cells to connect to the network [6], hence beamsteering should consider such scenarios. Therefore, we want to find out how a network operator has to coordinate beam management of nearby mmWave BSs such that the user can access the network with low delay and high data rate at once. We want you to find the sweet spot for this problem based on available ray-tracing data for an urban Manhattan grid scenario.

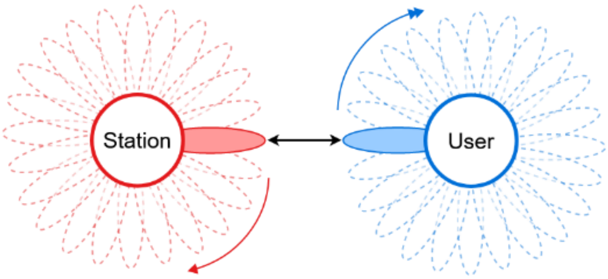

Figure 2: Illustration of exhaustive beam search in azimuth plane using pencil beams.

Figure 3: Illustration of a two-stage hierarchical beam search algorithm in azimuth plane. (*Left:* Exhaustive sector beam search. *Right:* Ensuing beam refinement using pencil beams.)

Goals of this Master Thesis

This master thesis brings together several interesting topics such as the ever-evolving mobile communication standards and - in particular - mmWave propagation and beam management. Expect to dive deeply into state-of-the-art mmWave beamsteering literature to become an expert on your topic. Afterwards you will implement several beamsteering flavors and evaluate the achievable performance based on ray-tracing simulation data.

Potential topics your master thesis will address:

- Surveying of applicable beam training algorithms and mmWave channel characteristics before subsequent *conceptualization of your own algorithms.*
- *Ray-tracing data-based evaluation*: Implement several different beamsteering algorithms and evaluate the achievable performance. Address the trade-off between the different schemes.

Requirements

- Interest in 5G/6G mmWave communications
- Participation in MRN 1+2 lectures (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] P. Jonsson *et al.*, “Ericsson Mobility Report June 2022,” Ericsson, Stockholm, Sweden, Tech. Rep., Jun. 2022.

[2] T. S. Rappaport *et al.*, "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!," in *IEEE Access*, vol. 1, May 2013.

[3] W. Roh *et al.*, "Millimeter-wave beamforming as an enabling technology for 5G cellular communications: Theoretical feasibility and prototype results," in *IEEE Communications Mag.*, vol. 52, no. 2, Feb. 2014.

[4] M. Giordani, M. Polese, A. Roy, D. Castor and M. Zorzi, "A tutorial on beam management for 3GPP NR at mmWave frequencies," in *IEEE Communications Surveys & Tutorials*, vol. 21, no. 1, Sep. 2018.

[5] L. Wei, Q. Li and G. Wu, "Exhaustive, iterative and hybrid initial access techniques in mmWave communications," *IEEE Wireless Communications and Networking Conf. (WCNC)*, Mar. 2017.

[6] R. Hersyandika, Q. Wand, and S. Pollin, “Association in dense cell-free mmWave networks,” in *IEEE Int. Conf. on Communications (ICC)*, Jun. 2021.

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