technische universität dortmund

Communication Networks Institute

Master Thesis

Development and Evaluation of a Network Planning Scheme for Metasurface-assisted mmWave Indoor Communications

Motivation

Millimeter wave (mmWave) networks have emerged as a promising solution to meet the demand for higher data rates and improved connectivity in current 5G and future 6G networks. However, challenging propagation characteristics limit the coverage and increase the risk of poorly connected shadow areas, making it crucial to plan such networks carefully. One of the key considerations in mmWave network design is the trade-off between active and passive elements. Active components, such as antenna arrays, are essential for signal generation and processing, but often have significant power requirements. In contrast, passive elements such as reflecting metasurfaces, also known as intelligent reflecting surfaces (IRSs), offer a smart way to improve signal propagation in 6G radio environments without incurring considerable power costs.

The Communication Networks Institute presents a *k-means* based network planning strategy for sub-6 GHz (FR1) 5G outdoor environments in [1]. Accurate and fast channel modelling plays a key role in successful network planning. Against this background, the CNI has shown the potential of machine learning (ML) based propagation modelling for 5G indoor environments with the so-called *IndoorDRaGon* method in [2]. The unique characteristics of mmWave (FR2, 24.2 GHz – 72.0 GHz) signals require adapted modelling techniques that consider various environmental factors. This includes reflections of metasurfaces such as the CNI's so-called *HELIOS* reflectors [3]. The topic of ML-assisted mmWave network planning leveraging active and passive network infrastructure component is therefore a challenging but very timely topic to be explored in the scope of this master thesis.

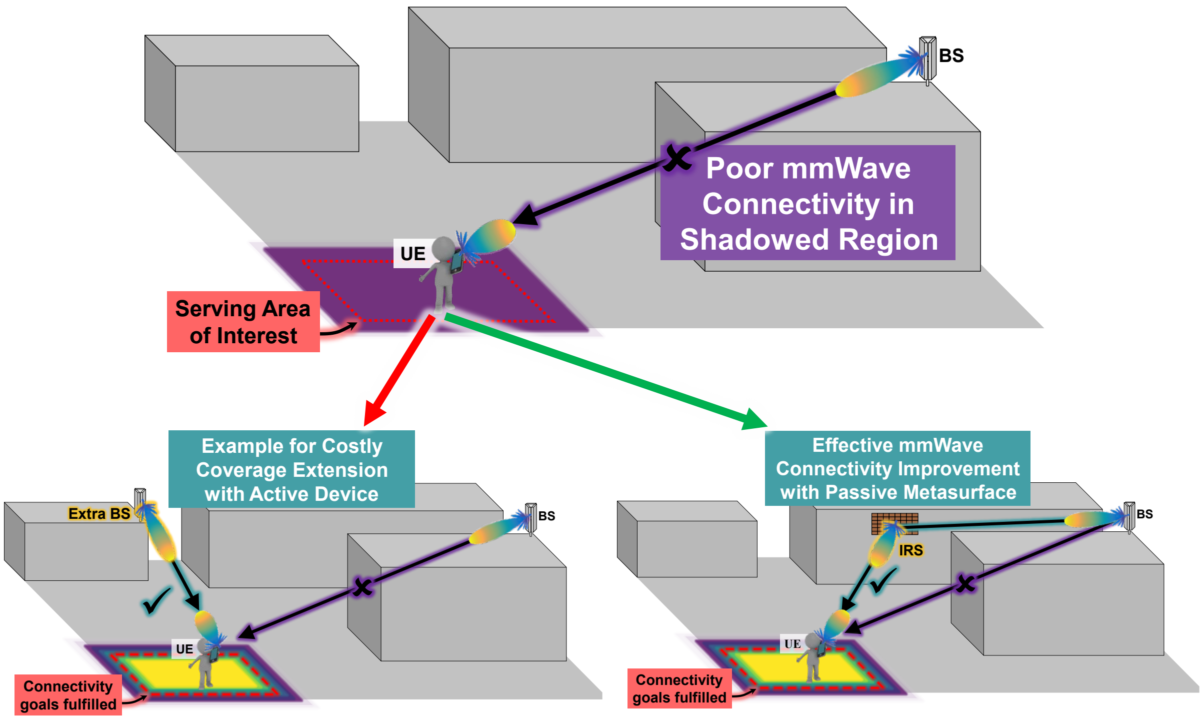

Fig. 1: Non-Line-of-Sight mmWave connectivity situation (cf. top) is traditionally solved by deploying extra BSs (cf. bottom left). 6G networks are expected to employ IRSs for a cost and energy efficient network design where possible (cf. bottom right). However, determination of the optimal number and positions of BSs and IRSs for given connectivity goals is a complex task.

{melina.geis, simon.haeger}@tu-dortmund.de

Potential Goals

A master thesis in this area brings together several interesting topics such as the 5G standard, mmWave communications, reflecting surfaces, machine learning, network planning/optimization, and propagation modeling. The CNI provides you the opportunity for interesting insights into these topics which align closely with our research goal of realizing an efficient hybrid mmWave network planning for 6G:

Your master thesis may address some but not all of the following topics:

- Deriving a “mmWave-IndoorDRaGon” propagation model: The goal is to extend the existing 5G indoor path-loss method to the mmWave spectrum.
    - Familiarization with ray-tracing software: mmWave training samples need to be generated. As comprehensive measurement campaigns are not feasible at this point, synthetic data generated with the help of ray-tracing simulations will be the key enabler.
    - Application of Transfer Learning: With the help of these samples, transfer learning shall be applied to adapt the IndoorDRaGon model to higher frequencies.
    - Illustrate your solution by realization of mmWave indoor network planning for Greenfield scenarios.
- Explore IRS extension of path loss model: Deriving a ML-assisted path loss modeling scheme for artificial reflection paths:
    - Understanding the physical principles of reflection and propagation effects on metasurfaces [4].
    - Couple mmWave-IndoorDRaGon model with metasurface context information (position, size, configuration) for reflection path loss prediction, e.g., specifically for HELIOS IRS.
    - Optimizing metasurface placement in Brownfield Scenarios: Create a process chain to optimize the reflector position for a given scenario and given transmitter position and configuration with the help of the derived path loss modeling scheme for reflected paths and mmWave-IndoorDRaGon.
- Conduct potential and sensititvity analyses for your solution approach:
    - Increasing the degree of freedom in network planning: Allow for greater flexibility by allowing more reflector positions, supporting multi-reflector deployment, optimizing reflector configurations, and facilitating greenfield planning, including active antenna elements.
    - Conducting a trade-off analysis between active and passive elements in order to evaluate factors such as energy requirements, performance efficiency, deployment complexity, and overall impact on network optimization.
    - Increase complexity of planning scenarios (e.g. obstacles, antenna characteristics, diverse materials, …).
    - *… and according to your interests!*

Requirements

- Interest in 5G/6G communications, particularly in network planning, mmWave and IRSs
- Basic knowledge on Machine Learning
- Good Python, LaTeX and presentation skills
- Participation in MRN I+II lectures (Grade: *excellent*); successful participation in other CNI courses is beneficial
- Good English skills; highly desirable: Willingness to write thesis in English

References

[1] M. Geis, C. Bektas, S. Böcker, and C. Wietfeld, "AI-driven Planning of Private Networks for Shared Operator Models," in *IEEE International Symposium on Local and Metropolitan Area Networks (LANMAN)*, Boston, USA, July 2024. [pdf]

[2] M. Geis, H. Schippers, M. Danger, C. Krieger, S. Böcker, J. Freytag, I. Priyanta, M. Roidl, and C. Wietfeld, "IndoorDRaGon: Data-Driven 3D Radio Propagation Modeling for Highly Dynamic 6G Environments", in *European Wireless 2023*, Rome, Italy, October 2023. IEEE. [pdf]

[3] S. Häger, K. Heimann, S. Böcker, and C. Wietfeld, "Holistic Enlightening of Blackspots with Passive Tailorable Reflecting Surfaces for Efficient Urban mmWave Networks," in *IEEE Access*, vol. 11, pp. 39318-39332, April 2023. [pdf]

[4] S. Häger, S. Böcker, and C. Wietfeld, "Reflection Modeling of Modular Passive IRS Geometries," in *IEEE Wireless Communications Letters*, February 2025. [pdf]

– References to external related works can be made available to interested students upon contact. –

{melina.geis, simon.haeger}@tu-dortmund.de www.cni.tu-dortmund.de