technische universität dortmund

Faculty EE/IT
Communication Networks Institute (CNI)
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Multiple Master Thesis Topics

Design and Validation of Metasurface-enabled Programmable Radio Environments for 6G

Motivation

With the recent move of 5G networks to incorporate millimeter-wave (mmWave) spectrum, scalability of both network capacity and peak data rate is achieved. However, more hostile propagation characteristics reduce the coverage while also making it prone to shadow regions within. Despite the switch to directional communications by using antenna arrays, network operators will perceive *(a)* regions with insufficient signal strength in the intended coverage area of the mmWave network, and *(b)* regions in which there is insufficient multipath in the sense that blockages due to ambient mobility cannot be recovered anymore.

Against this background, 6G mmWave research focuses heavily on so-called metasurfaces which, for example, allow for tuning of both the reflection angle and width of impinging electro-magnetic (EM) waves. Hence, radio environments become programmable when mounting such metasurfaces, for example, on a wall in order to increase the cell size or connectivity within the cell. The Communication Networks Institute recently proposed the so-called *HELIOS reflectors* [1], as shown in Fig. 1, that exploit custom reflecting surface geometries that are 3D-printed and subsequently conductively coated. We showed in our study that these can be mounted in urban regions in order to extend mmWave network coverage around corners into other street canyons. With our experimental 6G mmWave platform we have also shown this in practice [2]. There, we employed two different HELIOS reflectors with one providing a broad reflection with lower power gain and the other providing a narrow reflection with high gain. Thus, a programmable radio environment was realized using multiple HELIOS reflectors with individually customized reflection characteristics such that connectivity in the cell's area is realized according to the network operators planning targets.

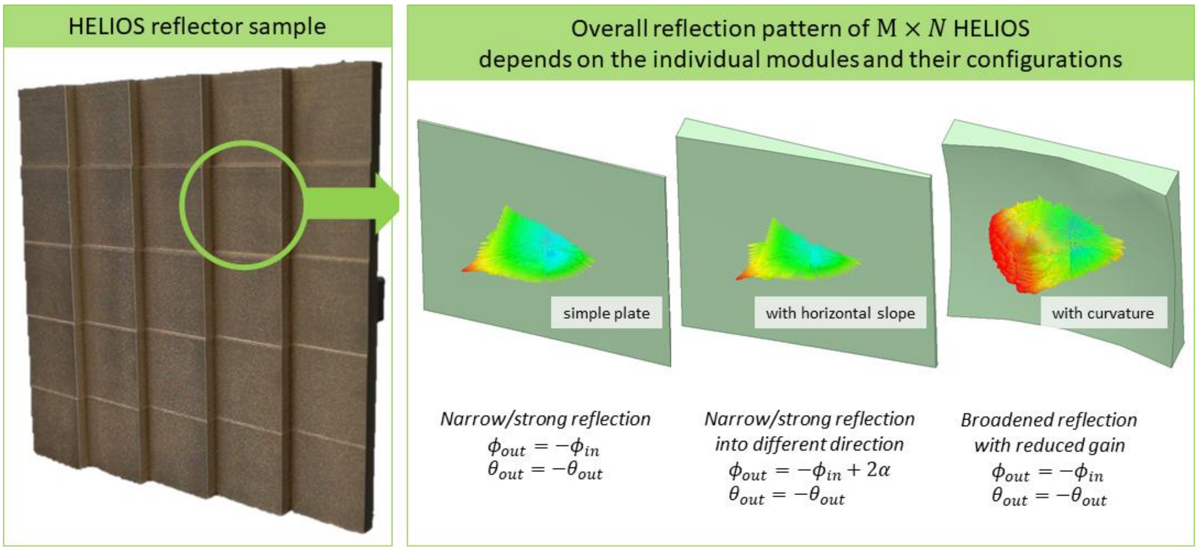

Figure 1: Our modular HELIOS reflector approach consists of $\boldsymbol{M} \times \boldsymbol{N}$ elements with each having multiple degrees of freedom, for example in terms of element footprint size $(\boldsymbol{a} \times \boldsymbol{b})$, horizontal and vertical slopes $(\boldsymbol{\alpha}, \boldsymbol{\beta})$, and the curvature radius $(\boldsymbol{r})$. These parameters affect the realized reflection pattern for the given incident electromagnetic wave from direction $(\boldsymbol{\phi_{in}}, \boldsymbol{\theta_{in}})$.

Potential Goals

A master thesis in this area brings together several interesting topics such as the 5G standard, mmWave communications, reflecting surfaces, and network planning/optimization which are closely tied to our on-going 6G research. The CNI gives you the chance for interesting insights into these topics with master theses investigating some aspects down the road towards our research goal of realizing efficient HELIOS-enabled mmWave networks:

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

- *HELIOS Design Process:* The goal is to identify a suitable HELIOS geometry that fulfills the desired reflection direction, reflection gain, and reflection width parameters. This optimization process shall identify a suitable algorithm and cost function in order to be as quick as possible. The starting point for this work is our existing simulation-based design process, but analytical reflection models may also be leveraged. Testing of schemes from literature, e.g., [3], is also recommended.
- *Hybrid Network Planning:* After the deployment of several base stations in a given scenario a network operator may still identify regions in which the connectivity needs to be improved. Here, suitable reflector mounting positions and target reflection characteristics need to be identified for the subsequent HELIOS design process. Even more interesting is the case when a network operator aims to build up an entirely new network for which the number of base stations needs to be minimized, too. For this purpose, channel models such as [4] shall be integrated into a novel network planning scheme. In addition, a ray-tracing tool may be used, too.
- *Experimental Validation:* The above topics can be shaped to include a measurements-based validation by incorporating commercial mmWave UEs and our 5G mmWave network. Detailed channel characterizations may naturally also be conducted with our experimental 6G mmWave platform.

Requirements

- Interest in 5G/6G communications, particularly at mmWave frequencies
- Participation in MRN I+II lectures (Grade: *excellent/good*) with other CNI courses being considered as a plus
- Good MATLAB/Python and LaTeX/TikZ skills
- Good English skills; highly desirable: Willingness to write thesis in English

References

[1] S. Häger, K. Heimann, S. Böcker, 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.

[2] K. Heimann, S. Häger, C. Wietfeld, "Demo Abstract: Experimental 6G Research Platform for Digital Twin-enabled Beam Management," in *ACM Symposium on Mobility Management and Wireless Access (MobiWac),* October 2023. Demo video: https://tiny.cc/HeliosDemonstrator.

[3] M. Al Hajj, K. Tahkoubit, H. Shaiek, V. Guillet, D. L. Ruyet, "On Beam Widening for RIS-Assisted Communications Using Genetic Algorithms," *Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*, June 2023.

[4] Ö. Özdogan, E. Björnson, E. G. Larsson, "Intelligent Reflecting Surfaces: Physics, Propagation, and Pathloss Modeling," in *IEEE Wireless Communications Letters*, vol. 9, no. 5, pp. 581-585, May 2020.

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More references can be made available to interested students upon contact, depending on the specific topic of interest.

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