



Codebook-Based Downlink Beamforming with Imperfect CSI Using Model-Driven Deep Learning



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Abstract: In this talk, we address the challenge of energy-efficient codebook-based downlink beamforming in multi-user multiple-input single-output wireless systems under imperfect channel state information (CSI). While existing model-based optimization algorithms typically assume perfect or mean CSI, leading to performance degradation and quality-of-service violations under channel estimation errors or quantized CSI feedback, conventional deep learning approaches with generic neural architectures suffer from poor data efficiency and lack of explainability. To overcome these limitations, we propose a novel model-aided deep learning approach that unrolls an optimal iterative algorithm for codebook-based beamforming, incorporating adaptive outage probability constraints through learnable parametric functions. Our architecture leverages uplink-downlink duality and employs

a graph neural network to predict unforeseen interference patterns caused by CSI imperfections. The framework includes a differentiable approximation of outage probability constraints and a novel adaptive approximation scheme to maintain targeted quality of service levels. Extensive numerical results demonstrate that our approach achieves the target outage probability while adapting to varying CSI quality, outperforming both conventional model-based methods and generic deep neural networks in terms of power efficiency and computational cost. The proposed architecture exhibits strong generalization capabilities across different user configurations and CSI degradation scenarios, making it particularly suitable for practical deployment in systems with codebook-based hybrid beamforming structures.

Lecturer bio: Marius Pesavento received the Dipl.-Ing. degrees from Ruhr-Universität Bochum, Germany, in 1999, the M.Eng. degree from McMaster University, Hamilton, ON, Canada, in 2000, and the Ph.D. degree from Ruhr-Universität Bochum in 2005. From 2005 to 2008, he was a Research Engineer with two start-up companies. He became an Assistant Professor in 2010 and a Full Professor (W3) of Communication Systems in 2013 with the Department of Electrical Engineering and Information Technology, Technical University of Darmstadt, Germany. His research interests include statistical and sensor array signal processing, MIMO communications, optimization, and model-assisted deep learning. He has been a member of the “Signal Processing Theory and Methods” Technical Committee (since 2021). He is also a member of the IEEE Signal Processing Society Board of Governors and the Regional Director-at-Large for Region 8 (2025–2027). He has served as the Vice-Chair for the IEEE SPS “Sensor Array and Multichannel Signal Processing” Technical Committee in 2025 (member, 2012–2017), and is the Past Chair of the EURASIP “Signal Processing for Multisensor Systems” Technical Area Committee. He was an Associate Editor of IEEE Transactions on Signal Processing (2012–2016) and a Subject Editor of EURASIP Journal on Signal Processing (2024–2025; Handling Editor, 2011–2023). He is the Editor-in-Chief (2026–2028) of IEEE Open Journal of Signal Processing (Deputy Editor-in-Chief, in 2025, and Senior Area Editor, 2019–2024).

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