UCLA Samueli Electrical & Computer Engineering

Ph.D. Defense

Low-Complexity Decoding of Low-Density Parity Check Codes and Optimal Modulation and Coding for Short Block-Length Transmissions

Linfang Wang

Advisor: Professor Richard Wesel

Friday, May 26, 2023 – 10:00 AM to 12:00 PM

Engineering Bldg. IV – Elliott Room #53-135

Abstract This dissertation investigates two topics in channel coding theory: low-complexity decoder design for low-density parity-check (LDPC) codes and reliable communication in the short blocklength regime. For the first topic, we propose a finite-precision decoding method that features the three steps of Reconstruction, Computation, and Quantization (RCQ). The parameters of the RCQ decoder, for both the flooding-scheduled and the layered-scheduled, can be designed efficiently using discrete density evolution featuring hierarchical dynamic quantization (HDQ). To further reduce the hardware usage of the RCQ decoder, we propose a second RCQ framework called weighted RCQ (W-RCQ). Unlike the RCQ decoder, whose quantization and reconstruction parameters change in each layer and iteration, the W-RCQ decoder limits the number of quantization and reconstruction functions to a very small number during the decoding process, for example, three or four. However, the W-RCQ decoder weights check-to-variable node messages using dynamic parameters optimized by a quantized neural network. The proposed W-RCQ decoder uses fewer parameters than the RCQ decoder, thus requiring much fewer resources such as lookup tables. For the second topic, we apply probabilistic amplitude shaping (PAS) to cyclic redundancy check (CRC)-aided tail-biting trellis-coded modulation (TCM). CRC-TCM-PAS produces practical codes for short block lengths on the additive white Gaussian noise (AWGN) channel. In the transmitter, equally likely message bits are encoded by a distribution matcher (DM), generating amplitude symbols with a desired distribution. A CRC is appended to the sequence of amplitude symbols, and this sequence is then encoded and modulated by TCM to produce real-valued channel input signals. We prove that the sign values produced by the TCM are asymptotically equally likely to be positive or negative. The CRC-TCM-PAS scheme can thus generate channel input symbols with a symmetric capacity-approaching probability mass function. We also provide an analytical upper bound on the frame error rate of the CRC-TCM-PAS system over the AWGN channel. This FER upper bound is the objective function used for jointly optimizing the CRC and convolutional code. Additionally, this paper proposes a multi-composition DM, which is a collection of multiple constant-composition DMs. The optimized CRC-TCM-PAS systems achieve frame error rates below the random coding union (RCU) bound in AWGN and outperform the short-blocklength PAS systems with various other forward error correction codes.

Biography Linfang Wang received an M.Sc. degree in information and communication engineering from the Harbin Institute of Technology, Harbin, China, in 2018. He is currently pursuing a Ph.D. degree with the University of California at Los Angeles, Los Angeles. His current research interest lies in coding theory, especially on LDPC code, trellis code, and the application of deep learning/ machine learning on channel coding. Linfang Wang was a recipient of 2022 UCLA Dissertation Year Fellowship.

For more information, contact Prof. Richard Wesel at wesel@ee.ucla.edu