Research Summary

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Topic 1. Channel Estimation in Millimeter Wave Communications

[1] (Deterministic Hybrid Beamformer Design) In many compressed sensing (CS) algorithms for narrowband millimeter wave channel estimation, the hybrid beamformers are randomly configured which does not always yield the low-coherence sensing matrices desirable for those CS algorithms whose recovery guarantees rely on coherence. We propose a deterministic sensing matrix design for CS algorithms with coherence-based recovery guarantees to enhance channel estimation accuracy. The codebooks obtained for deterministic beamformers are shown in simulations to outperform random configurations in terms of both channel estimation error and spectral efficiency using orthogonal matching pursuit and basis pursuit denoising.

[2] (One-Bit Channel Estimation) A hybrid beamforming architecture and one-bit resolution ADCs have been proposed to reduce power consumption in millimeter wave communication systems. However, analog beamforming and one-bit quantization make channel estimation more challenging. We propose a narrowband channel estimation algorithm for millimeter wave communication systems with one-bit ADCs and hybrid beamforming based on generalized approximate message passing (GAMP). We show through simulation that the proposed one-bit GAMP algorithm achieves the lowest estimation error among the GAMP variants and least-squares estimator.

Topic 2. Receiver Design in Millimeter Wave Communications

[3, 4] (Two-Stage Analog Combining) We propose a two-stage analog combining architecture for millimeter wave (mmWave) communications with hybrid analog/digital beamforming and low-resolution analog-to-digital converters (ADCs). We first derive a two-stage combining solution by solving an mutual information (MI) maximization problem without a constant modulus constraint on analog combiners. With the derived solution, the proposed receiver architecture splits the analog combining into a channel gain aggregation stage followed by a spreading stage to maximize the MI by effectively managing quantization error. We show that the derived two-stage combiner achieves the optimal scaling law with respect to the number of radio frequency (RF) chains and maximizes the MI for homogeneous singular values of a MIMO channel. Then, we develop a two-stage analog combining algorithm to implement the derived solution under a constant modulus constraint for mmWave channels.

[5] (Learning-Based One-Bit Detection) we investigate learning-based maximum likelihood (ML) detection for uplink massive multiple-input and multiple-output (MIMO) systems with one-bit ADCs. To resolve large dependency of learning-base detection on the training length, we propose two learning-based one-bit ML detection methods: a biased-learning method and a dithering-and-learning method. The biased-learning method keeps likelihood functions with zero probability from wiping out the obtained information through learning, thereby providing more robust detection performance. Extending the biased method to the system with the knowledge of signal-to-noise ratio, the dithering-and-learning method estimates more likelihood functions by adding dithering noise to the quantization input to draw non-zero transition probability within limited training length.

[6, 7] (Antenna Selection) We investigate antenna selection for large-scale MIMO communications with low-resolution ADCs, thereby providing more flexibility in resolution and number of ADCs. For uplink, to incorporate quantization effects, we generalize an existing objective function for a greedy capacity-maximization antenna selection approach. The derived objective function offers an opportunity to select an antenna with the best tradeoff between the additional channel gain and increase in quantization error. For downlink, we analyze the gain of using a single transmit antenna selection method in the low-resolution ADC systems. We derive the approximated ergodic rate of the system with single transmit antenna selection and the derived expressions characterize the gain of using a single transmit antenna selection method.

[8, 9] (Resolution-Adaptive ADC) We propose a hybrid analog-digital beamforming architecture with resolution-adaptive ADCs for millimeter wave (mmWave) receivers with large antenna arrays. We adopt array response vectors for the analog combiners and derive ADC bit-allocation (BA) solutions in closed form. The BA solutions reveal that the optimal number of ADC bits is logarithmically proportional to the RF chain's signal-to-noise ratio raised to the 1/3 power. Using the solutions, two proposed BA algorithms minimize the mean square quantization error of received analog signals under a total ADC power constraint. We further extend the bit-allocation problem to a total receiver power constraint case to improve the receiver performance by optimizing both the number of RF chains and ADC bits. A binary search-based joint RF chain-and-bit optimizing algorithm is developed to solve the extended problem.

Topic 3. Uplink User Scheduling in Millimeter Wave Communications

[10, 11] (User Scheduling) We investigate uplink user scheduling for millimeter wave (mmWave) hybrid analog/digital beamforming systems with low-resolution analog-to-digital converters (ADCs). Deriving new scheduling criteria for the mmWave systems, we show that the channel structure in the beamspace, in addition to the channel magnitude and orthogonality, plays a key role in maximizing the achievable rates of scheduled users due to quantization error. The criteria show that to maximize the achievable rate for a given channel gain, the channels of the scheduled users need to have (1) as many propagation paths as possible with unique angle-of-arrivals (AoAs) and (2) even power distribution in the beamspace. Leveraging the derived criteria, we propose an efficient scheduling algorithm for mmWave zero-forcing receivers with low-resolution ADCs. We further propose a chordal distance-based scheduling algorithm that exploits only the AoA. Based on the derived rates, we show that the beamspace channel leakage resulting from phase offsets between AoAs and quantized angles of analog combiners can lead to sum rate gain by reducing quantization error compared to the channel without leakage.

Topic 4. Powerline Communications

[12] (Real-Time Testbed for Powerline and Wireless Communications) Utilizing both powerline communication and wireless communication technologies can potentially enhance communication reliability, and many diversity combining schemes have been proposed. In this paper, we propose a flexible real-time testbed that can be used to evaluate diversity schemes over physical channels. As initial results, we show that performance of MRC from measurements obtained on the testbed over physical channels is very close to that in simulations in various test cases under a controlled laboratory environment.

Related Publications

[1] Junmo Sung and Brian L. Evans, "Deterministic Hybrid Beamformer Design to Improve Compressed Sensing Narrowband mmWave Channel Estimation Algorithm Performance," *IEEE Trans. Wireless Comm*. (submitted)

[2] Junmo Sung, Jinseok Choi, and Brian L. Evans, "Narrowband Channel Estimation for Hybrid Beamforming Millimeter Wave Communication Systems with One-bit Quantization," *IEEE ICASSP* 2018

[3] Jinseok Choi, Gilwon Lee, and Brian L. Evans, "Two-Stage Analog Combining in Hybrid Beamforming Systems with Low-Resolution ADCs", *IEEE Trans. Commun.* (under revision)

[4] Jinseok Choi, Gilwon Lee, and Brian L. Evans, "A Hybrid Combining Receiver with Two-Stage Analog Combiner and Low-Resolution ADCs", *IEEE ICC* 2019, (submitted)

[5] Jinseok Choi, Yunseong Cho, Brian L. Evans, and Alan Gatherer, "Robust Learning-Based ML Detection for Massive MIMO Systems with One-Bit Quantized Signals", *IEEE ICC* 2019, (submitted)

[6] Jinseok Choi and Brian L. Evans, "Analysis of Ergodic Rate for Transmit Antenna Selection in Low-Resolution ADC Systems", *IEEE Trans. Veh. Techonol.*

[7] Jinseok Choi, Brian L. Evans, and Alan Gatherer "Antenna Selection for Large-Scale MIMO Systems with Low-Resolution ADCs", *IEEE ICASSP* 2018

[8] Jinseok Choi, Brian L. Evans, and Alan Gatherer, "Resolution-Adaptive Hybrid MIMO Architecture for Millimeter Wave Communications", *IEEE Trans. Signal Process.*

[9] Jinseok Choi, Junmo Sung, Brian L. Evans, and Alan Gatherer, "ADC Bit Optimization for Spectrum- and Energy-Efficient Millimeter Wave Communications", *IEEE GLOBCOM* 2017

[10] Jinseok Choi, Gilwon Lee, and Brian L Evans, "User Scheduling for Millimeter Wave Hybrid Beamforming Systems with Low-Resolution ADCs", *IEEE Trans. Wireless Commun.* (under revision)

[11] Jinseok Choi and Brian L. Evans, "User Scheduling for Millimeter Wave MIMO Communications with Low-Resolution ADCs", *IEEE ICC* 2018

[12] Junmo Sung and Brian L. Evans, "Real-Time Testbed for Diversity in Powerline and Wireless Smart Grid Communications," *IEEE ICC Workshops* 2018