Data-Driven C-RAN Optimization Exploiting Traffic and Mobility Dynamics of Mobile Users

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Cellular operators are facing fast growing mobile subscribers and surging traffic demand. More base stations and more powerful processing units are deployed to increase the network capacity. However, the operational costs and service quality can be affected. Cloud-radio access network (C-RAN) provides a viable solution by handling traffic and mobility in a centralized manner. C-RAN separates a traditional base station into a remote radio head (RRH) and a baseband unit (BBU). The RRH is responsible for radio communication with mobile devices. The BBU is responsible for signal and data processing. The C-RAN supports dynamic BBU allocation and mapping to RRHs. However, due to dynamic traffic and mobility in real world, it is challenging to optimize such processes. In this work, the authors proposed a data-driven framework for C-RAN optimization. The core of the data processing is a deep-learning based multivariate long short term memory model that captures and predicts the spatiotemporal patterns and mobility. The RRH-BBU mapping issue was formulated as a set partitioning problem with cost and quality objectives. The authors proposed a greedy approach to solve the set partitioning problem. Evaluations were conducted based on real world datasets from Ivory Coast and Senegal. The results demonstrated that the framework proposed in this work can achieve a BBU utilization above 85.2%, where over 82.3% of mobility events being high quality services.

RIS Enhanced Massive Non-Orthogonal Multiple Access Networks: Deployment and Passive Beamforming Design

Xiao Liu, Yuanwei Liu, Yue Chen, and H. Vincent Poor, *IEEE Journal on Selected Areas in Communications*, vol. 39, no. 4, April 2021.

Reconfigurable intelligent surfaces (RISs) can modify the wireless communication environment proactively. Therefore, RISs have been recently studied to enhance wireless networks, such as compensating the power loss over long distances, and forming virtual line-of-sight links. In this work, the authors studied a RIS-enhanced wireless system by considering joint deployment, phase shift design, power allocation, and dynamic decoding order determination. Moreover, non-orthogonal multiple access (NOMA) technology was invoked to further improve the spectrum efficiency of the RIS-enhanced wireless network. The core of the proposed solution is a long short-term memory (LSTM) based echo state network (ESN) algorithm that predicts tele-traffic demand of users. The joint problem of deployment and design of the RIS are approached by a decaying double deep Q-network based position-acquisition and phase-control algorithm. The authors proved that the proposed deployment and design algorithm can converge within mild conditions. Evaluation results demonstrated that the LSTM-based ESN algorithm could strike a tradeoff between prediction accuracy and computational complexity. The results also demonstrated that the proposed decaying double deep Q-network algorithm could outperform the default Q-learning and deep Q-learning approaches. Moreover, the NOMA-enhanced RIS system was demonstrated with higher energy efficiency than orthogonal multiple access enabled RIS system.

RISMA: Reconfigurable Intelligent Surfaces Enabling Beamforming for IoT Massive Access

Placido Mursia, Vincenzo Sciancalepore, Andres Garcia-Saavedra, Laura Cottatellucci, Xavier Costa Pérez, and David Gesbert, *IEEE Journal on Selected Areas in Communications*, vol. 39, no. 4, April 2021.

In this work, the authors proposed reconfigurable intelligent surface (RIS) aided beamforming solutions for challenges of massive Internet-of-Things (IoT) access challenges in beyond 5G networks. Massive access for IoT in beyond 5G networks can be challenging due to bandwidth-limited technologies. On the one hand, millimeter-wave technologies (mmWave) can provide a large amount of bandwidth for massive IoT access. However, on the other hand, the cost and power requirements make it hard to implement mmWave in practice. RIS can provide a solution to cope with non-line-of-sight paths that address the challenge of deploying mmWave. The authors built a mathematical framework to jointly optimize the precoding strategy of the base station and the RIS parameters for the minimum system sum mean squared error (SMSE). The chosen SMSE revealed a convex structure in the precoding strategy at the transmitter and the RIS parameters. Thus, the chosen objective led to a mechanism of two algorithms that can provide solutions with good efficiency and scalability. Moreover, the authors proposed to decouple the optimization of the binary activation coefficients and the quantized phase shifts to accommodate meta-surfaces that only support phase shift values from a discrete set. Evaluation results demonstrated 20% to 120% performance gain in sum rate compared to a zero-forcing precoder; and 40% performance gain compared to a precoder based on minimum mean squared error.

Cooperative Multi-Point Vehicular Positioning Using Millimeter-Wave Surface Reflection

Zezhong Zhang, Seung-Woo Ko, Rui Wang, and Kaibin Huang, *IEEE Transactions on Wireless Communications*, vol. 20, no. 4, April 2021.

Vehicular positioning is an important and challenging issue in autonomous driving. Medium to short-range positioning such as within tens to several meters cannot rely on GPS location since it abstracts a vehicle as a single point. The current technologies for medium to short-range positioning are radio-detection-and-ranging (RADAR) and light-detection-and-ranging (LIDAR). These technologies usually require complex signal processing and computer vision that can introduce computation latency and inefficiency in non-line-of-sight scenarios. In this work, the authors proposed a cooperative multi-point positioning approach for vehicular positioning. With line-of-sight, the proposed approach establishes cooperation between a target vehicle and a sensing vehicle that removes the scanning and target recognizing processes to achieve lower latencies. In non-line-of-sight scenarios, nearby vehicles are incorporated in the proposed cooperation to generate mirror-like reflections over the vehicle's metal surfaces that can be detected as in the line-of-sight scenarios. In this way, the target vehicle can be positioned. The evaluation results demonstrated the concepts proposed in this work. Success of this work could introduce new solutions to enhance autonomous driving in the future.

Convolutional Neural Network-Based Multiple-Rate Compressive Sensing for Massive MIMO CSI Feedback: Design, Simulation, and Analysis

Jiajia Guo, Chao-Kai Wen, Shi Jin, Geoffrey Ye Li, *IEEE Transactions on Wireless Communications*, vol. 19, no. 4, April 2020

Massive multiple-input multiple-output (MIMO) is widely considered a viable solution for higher date rate and energy efficiency in the 5-th generation (5G) and beyond wireless communication systems. A massive MIMO system in 5G and beyond normally consists of a base station that is equipped with many antennas, and many user equipments (UEs) with either single or multiple antennas. An efficient operation of massive MIMO requires instantaneous channel state information (CSI). However, it is challenging to get the downlink CSI, especially in frequency-division systems that are widely deployed in cellular networks. As a solution, the base station relies on the CSI feedback from UE to estimate the downlink channels. In this paper, the authors proposed a multiple-rate compressive sensing neural network framework to compress and quantize the CSI so that the CSI matrix can be efficiently compressed in the feedback process. In specific, the authors established two network design principles for CSI feedback, and proposed a new network architecture named CsiNet+ with a novel quantization framework and training strategy. Comparing to some other quantization strategies, the proposed approach requires no parameter update at the UE, and only fine-tunes the parameters in the decoder at the base station. Furthermore, the authors introduced two different variable-rate approaches that decreased the parameter number at the UE by 38.0% and 46.7%, respectively. Experimental results demonstrated the better performance in CSI reconstruction comparing to the original CsiNet.

An Efficient Deep Learning Framework for Low Rate Massive MIMO CSI Reporting

Zhenyu Liu, Lin Zhang, and Zhi Ding, *IEEE Transactions on Communications*, vol. 68, no. 8, Aug. 2020

Massive MIMO enables high downlink throughput for gNodeB in 5G communication systems. In practice, gNodeB requires accurate downlink CSI to utilize the spatial diversity and multiplexing gains and take full advantage of the massive MIMO system. In this paper, the authors explored low rate CSI feedback to conserve feedback bandwidth and improve downlink CSI reconstruction accuracy for massive MIMO downlink in FDD systems. A deep-learning compression framework CQNet was developed to jointly tackle CSI compression, codeword quantization, and recovery under the bandwidth constraint. The proposed framework in this work could be compatible with existing CSI feedback solutions by replacing the quantizer module, which was customized in the radial coordinate with a magnitude-adaptive phase quantization framework. The evaluation results demonstrated that the proposed quantizer module can achieve lower quantization error compared to some existing approaches. The authors demonstrated the proposed CQNet by integrating it into two of the existing deep learning-based solutions for CSI compression and feedback. Furthermore, the authors exploited bi-directional channel correlation where magnitude and phase are processed separately to improve flexibility to manage the trade-off between CSI reconstruction accuracy and feedback bandwidth.

Massive MIMO CSI Feedback Based on Generative Adversarial Network

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In this work, the authors introduced generative adversarial network (GAN) into a deep learning-based framework to compress and recover CSI feedback in massive MIMO downlinks. In comparing to the existing deep learning approaches, this work proposed a similar encoder that compressed the original CSI matrix, while the decoder was developed based on GAN to decompress the codeword at the receiving base station. GAN is a neural network that consists of a generator and a discriminator. The generator produces synthesized output based on an input, i.e., compressed CSI signals from the encoder, while the discriminator estimates the probability that the output is identified as synthesized. A well-developed GAN could produce synthesized outputs that cannot be identified by the discriminator. In other words, the output of the GAN is comparable to the actual input to the encoder, i.e., the original CSI signals. A loss function is specified as a weighted combination of different loss components to better fit the proposed neural network. To train the proposed neural network, one can apply end-to-end training, or train the GAN as the decoder only using an existing encoder. Evaluation results demonstrated low normalized mean square errors in reconstructing the compressed CSI signals for massive MIMO downlink CSI feedback.

Downlink CSI Feedback Algorithm with Deep Transfer Learning for FDD Massive MIMO Systems

Jun Zeng, Jinlong Sun, Guan Gui, Bamidele Adebisi, Tomoaki Ohtsuki, Haris Gacanin, and Hikmet Sari, *IEEE Transactions on Cognitive Communications and Networking*, doi: 10.1109/TCCN.2021.3084409.

Deep learning has attracted much attention in developing downlink CSI feedback methods for massive MIMO in 5G and beyond wireless communications. Compared with the traditional compressive sensing techniques, deep learning can achieve high accuracy in reconstruction of the CSI matrix and effectively reduce the overhead in feedback. However, a deep learning model is usually developed based on a relatively stable environment, thus may not work in different communication networks. In this paper, the authors proposed to integrate transfer learning and reduce the training cost of CSI feedback neural networks. The advantage of using transfer learning is that the process only requires a relatively small amount of training samples to fine tune a pre-trained model. In comparison, the fine-tuning process is much more efficient than a retraining process. To further address the issue of developing a pre-trained model with a large number of samples, the authors proposed a model agnostic meta-learning method. This approach employs samples from multiple wireless channel environments for model initialization so that the pre-trained can be quickly tuned to fit a specific scenario. Evaluation results demonstrate that the proposed pre-training and fine-tuning procedure can achieve comparable accuracy comparing to some existing deep learning approaches.