Abstract

Interference is a fundamental issue in wireless communication systems, in which multiple transmissions occur at the same time over a common medium. Due to the tremendous increase of number of wireless communication devices in the recent years, this issue has now become more crucial than ever. Conventionally, in the design of a wireless communication system, interference is usually avoided because it may substantially limit the reliability and the throughput of the system. However, with massive number of wireless communication devices and limited wireless communication resources, avoiding interference becomes almost impossible. Compute-and-forward is a new technique that deals with this issue elegantly. Rather than avoiding interference or treating it as noise, compute-and-forward embraces and exploits it by computing linear functions of the transmitted messages directly from interfering signal. Thus, it allows simultaneous transmissions, which consequently results in an increase of network throughput.

Owing to its promising advantages, compute-and-forward has found many applications in various wireless communication scenarios such as multi-source multi-relay channels, two-way relay channels, multiple-access relay channels, multiple-input multiple-output (MIMO) systems, etc. In this dissertation, we study applications of compute-and-forward methods in wireless communication systems, investigate the issues that arise in the existing work, and then propose some solutions to solve them such that the system performance, e.g., network throughput and outage probability, is improved. In particular, this dissertation focuses on two different wireless communication scenarios: multiple-access relay channels and precoded MIMO systems.

In the multiple-access relay channels with compute-and-forward, the destination and the relay compute linear functions of the transmitted messages which are then used by the destination to recover the transmitted messages. The main issue in this system is that the final linear functions obtained by the destination must be linearly independent, and hence, cooperation between the destination and the relay must be carefully designed. To cope with this issue, we propose two cooperation strategies. In the first strategy, the relay helps the destination by forwarding its ``local best" linear functions without taking into account whether it is linearly independent of that of the destination. While in the second strategy, the relay forwards its optimal linear function ensuring the linear functions obtained by the destination are linearly independent. We show that both of the strategies outperform existing strategies available in the literature. It is also shown that the second strategy achieves better error performance compared to the first one with the cost of additional overhead for feedback.

For precoded MIMO systems, we are particularly interested in the unitary precoded integer-forcing (UPIF) MIMO where a unitary matrix is used as the precoder matrix for MIMO systems employing integer-forcing linear receivers. Integer-forcing is essentially another form of compute-and-forward. It has been shown that UPIF achieves full diversity gain while allowing full transmission rate. However, it is not easy to find the optimal unitary precoder matrix. No efficient algorithm is available for this problem. Instead of unitary precoder matrices, we propose orthogonal precoder matrices for the same systems. We show that not only has lower complexity, the proposed orthogonal precoder has performance advantage in terms of achievable rate and error rate. Further, we propose an efficient algorithm based on the steepest gradient algorithm that exploits the geometrical properties of orthogonal matrices as a Lie group. The proposed algorithm has low complexity and can be easily applied to an arbitrary MIMO configuration. We also show that the proposed orthogonal precoder outperforms the X-precoder, a precoder designed specifically for quadrature amplitude modulation (QAM), in high-order QAM schemes, e.g., 64- and 256-QAM.

Keywords:
Lattice network coding, multiple-access relay channel, compute-and-forward, integer-forcing, MIMO