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論　文　題　目	Finite Dimensional Lattice Code Design for Wireless Communications
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論文の内容の要旨

Lattice code is a coded-modulation scheme defined over real numbers, considered as a candidate for next generation wireless communication. Lattice codes provide error correction ability. It is also shown that lattice codes can achieve lower transmission power compared to conventional QAM modulation. Besides, lattice codes preserve the linearity of codewords, therefore can be applied for physical layer network coding. It has been shown that lattice codes achieve the capacity of the Gaussian channel if lattice decoding is performed using optimal decoding coefficient(s).

This research studies finite dimensional lattice codes for practical systems. Single user transmission and multiple access relay using compute-forward (CF) are considered as communication scenarios. The following three challenges are addressed. 1) Even with optimal coefficients, finite dimensional systems have a non-zero error rate, which gives a room on improving error rate. 2) Traditional CF relaying does not have error detection ability, potentially forwarding erroneous packets into network, for which a error detection scheme is required. 3) A lattice design is considered to achieve lower error rate than classic designs.

In this work, a retry decoding scheme is proposed for both single user scenario and CF relaying, which allows additional decoding attempts at receiver to improve error rate by adjusting value(s) of decoding coefficient(s), when errors are detected. A lower bound and an estimate on error probability are derived for single user scenario. The CRC-embedded lattice/lattice code are proposed having error detection ability for enabling retry decoding. The CRC-embedded lattices/lattice codes rely on CRC codes, with modest complexity on error detection. Besides, the error detection is applicable for CF relaying, which was not feasible in conventional systems. For a 2-user CF relay, numerical results show gains of 1.29dB, 1.31dB and 1.08dB at equal error rate 10^{-5} are achieved by n= 64, 128, 256 polar lattice codes at code rate R ≈ 1.6406, 1.7422, 1.8438, respectively, where only one additional decoding attempt is required. At last, a lattice design approach is provided using construction A and binary codes with known minimum Hamming distance and codeword multiplicity, the number of minimum weight codewords. Design examples consider extended BCH codes and polar codes, where lower error rates are achieved than that by classic design rules.

Keywords: Lattices, lattice codes, finite dimensional transmission, CRC codes, compute-forward relaying, construction A.

論文審査の結果の要旨

This dissertation makes an important contribution to the development of wireless communication systems by advancing the design and analysis of finite-dimensional lattice codes. It demonstrates that lattice-based methods can provide reliable communications with reduced latency, offering a practical alternative to conventional coding schemes. The research addresses fundamental challenges in single-user transmission and compute-forward (CF) relaying, where decoding errors and lack of error detection can reduce performance.

A central innovation of this dissertation is a retry decoding scheme, which improves error rates by allowing the decoder to adjust decoding coefficients and attempt recovery without requiring retransmission. This approach is broadly applicable since it does not alter the underlying lattice decoder, and numerical results show substantial coding gains for both single-user and CF relaying scenarios. The work also introduces CRC-embedded lattice codes, enabling low-complexity error detection within the lattice framework. This construction allows detection of erroneous decoding in CF relaying—something conventional schemes lack—thus preventing propagation of errors through the network. Optimization of CRC design further strengthens error detection and enhances the benefits of retry decoding. In addition, the dissertation proposes a new Construction A lattice design suitable for medium-dimensional scenarios requiring low latency. By leveraging properties of binary codes, the design identifies lattices that achieve significantly lower error rates than classical approaches, with validated performance using BCH and polar codes.

Overall, this dissertation represents a comprehensive study of finite-dimensional lattice code design, with novel algorithms and constructions that enhance reliability, reduce latency, and extend the applicability of lattice-based coding in modern wireless systems.

The committee recognizes the originality, technical depth, and significance of this work, and agrees that this dissertation is of excellent quality. The committee approves awarding the doctoral degree to Xue Jiajie.