AP19679505 Studying and developing multithreshold decoding algorithms for convolutional codes and their software and hardware implementation for high-speed radio channels with fading, p.m. Saylaukyzy Zh.

The relevance of the research is linked to the implementation of the objectives set by the state program "Digital Kazakhstan", the Law of the Republic of Kazakhstan "On National Security", and the State Cybersecurity Concept "Cyber Shield of Kazakhstan", which aim to ensure the information security of the national information and communication infrastructure and to maintain and develop an effective system for protecting information resources and communication infrastructure.The development of a national radio communication system is a crucial component of national and information security, as it ensures connectivity between special government agencies, the Armed Forces, law enforcement bodies, emergency medical services, fire brigades, and search and rescue teams.

Currently, high-speed and reliable radio communication systems are implemented using orthogonal frequency-division multiplexing (OFDM) technology, which ensures the required spectral efficiency and high data capacity. However, in broadband wireless communication over long distances, a large number of errors occur, making it necessary to apply forward error correction (FEC) methods. The main idea of the project is to develop and implement effective software-hardware error correction schemes for use in fading radio communication networks, especially under conditions of Doppler shift and inter-symbol interference.

The aim of the project is to investigate and develop error correction methods and tools that enable operation close to the channel capacity when applied in rapidly changing digital radio communication systems. This includes integration with technologies such as orthogonal frequency-division multiplexing (OFDM), high-order modulation schemes, space-time coding, and precoding.

Expected and Achieved Results

1. A comprehensive study was conducted on the specific features of digital radio communication systems for mobile radio communication with fading channels, including radiomodems and systems for video and audio transmission. The requirements for selecting error correction coding methods were defined based on the criterion of the maximum energy-per-bit-to-noise-power-density ratio (Eb/N0), processing speed, and the complexity of software and hardware implementations of encoders and decoders.
The basic principles of implementing an LDPC encoder were explored. Software and hardware implementations of encoding and decoding with hard-decision bit-flipping algorithms were developed based on mathematical models and algorithms. Modeling results were used to analyze the error correction performance of LDPC codes using Tanner graphs in radio channels. One publication based on these results was presented at the VIII International Scientific Conference “Informatics and Applied Mathematics” (October 26–27, 2023, Almaty, Kazakhstan).
2. An analysis was conducted on the susceptibility of self-orthogonal codes to error propagation using multidimensional generating functions and Tanner graphs. The findings were used to construct and select codes suitable for multi-threshold decoders (MTDs) under noise levels only a few tenths of a dB below channel capacity.
A method was proposed to reduce decoding error propagation by constructing self-orthogonal codes with low overlap between control error sets for different information symbols. A custom simulation tool was developed for convolutional encoders, supporting both manual and automatic tuning of code parameters, error injection in the channel, and optimization of iterative threshold decoding parameters. The simulation showed that optimizing threshold values and weights for all threshold elements reduces error propagation and improves correction efficiency.
The results were published and indexed in Scopus within the proceedings of the 7th International Symposium on Innovative Approaches in Smart Technologies (November 23–25, 2023, Istanbul, Turkey).

3. The performance of multi-threshold decoding (MTD) algorithms for convolutional codes in fading channels was investigated. Modifications of error correction schemes were proposed and justified by optimizing MTD parameters, improving functional unit algorithms, and using cascaded architectures based on MTD blocks.
A parameter optimization algorithm for symbol-based self-orthogonal codes in MTD was proposed, allowing a significant reduction in the number of decoding permutations and a more than 100x reduction in decoding error probability.
A new concatenated coding scheme was examined, consisting of two MTDs with varied encoding parameters in a Gaussian channel. Decoding error probabilities and execution speed of the concatenated MTD schemes were assessed.
One publication based on this research was accepted in a domestic journal recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan.

4. Theoretical and simulation-based modeling of MTD application in digital radio systems using orthogonal frequency division multiplexing (OFDM) and multi-level modulation was conducted. Theoretical estimates and experimental results were obtained for the decoding error probability of MTD for convolutional codes under fading, Doppler shift, and inter-symbol interference.
The results confirm the efficiency of MTD in complex radio channel conditions. Modeling showed that MTD combined with OFDM and multi-level modulation significantly reduces decoding error probability and provides resilience to inter-symbol interference and Doppler effects. Experimental data demonstrated MTD's ability to decode long codes with low computational complexity, making it suitable for high-speed data transmission systems. Compared to traditional methods, MTD offers reliable error correction and high adaptability.
One article was published in the international journal *Journal of Electrical Systems (JES)*, ranked in the top 20% CiteScore percentile on Scopus. Another publication was presented at the XXVI International Conference on Digital Signal Processing and Its Applications (DSPA–2024).

5. Methodologies for applying MTD in systems with multiple transmit and receive antennas (MIMO) were developed, along with channel assessment criteria using MTD. The results confirmed MTD's high efficiency in MIMO systems with fading, ensuring reliable data transmission even in complex multipath environments using OFDM. The developed methodologies allow adaptive decoding based on channel fading characteristics while maintaining low computational complexity.
These approaches highlight MTD's advantages for modern systems where data rates reach tens or hundreds of Gbit/s. Unlike other codes that lose effectiveness in multipath conditions, MTD provides nearly optimal decoding of long codes at low complexity.
Results were presented in the *Proceedings of the XVI Sagindin Readings: Integration of Education, Science and Production*, 2024, and indexed in Scopus within the 8th International Symposium on Innovative Approaches in Smart Technologies (December 6–7, 2024, Istanbul, Turkey).

6. Methods for joint iterative demodulation and decoding were implemented to enhance energy efficiency in digital radio systems using MTD. Experimental characteristics of error correction schemes with iterative demodulation and decoding were obtained via simulation. The study showed that the proposed joint methods significantly improved energy efficiency and noise resistance in fading channels while maintaining high data reliability. These techniques also reduce power consumption and are suitable for adaptive high-speed digital radio systems.
One article was published in the domestic journal *Bulletin of EKSTU named after D. Serikbayev* (Issue No. 4, 2024), recommended by the Committee for Quality Assurance in Science and Higher Education. A certificate of software registration was obtained (No. 46161, May 21, 2024).

7. High-speed software versions of multi-threshold decoders for radio systems were developed using parallel processing and heterogeneous systems based on the OpenCL standard. A software copyright certificate was obtained (No. 56400, April 3, 2025).

8. High-speed MTDs were designed and implemented as embedded systems on FPGAs using the OpenCL compiler for reconfigurable systems. Research results were presented with an oral report at the 29th IEEE/ACIS International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing (SNPD2025-Summer I) (June 25–27, 2025).

9. Test programs and validation methodologies are being developed for both software and hardware implementations of MTD in radio systems. Experimental performance metrics will be obtained. One publication was accepted for the domestic journal *Bulletin of KazATC*, recommended by the Committee for Quality Assurance in Science and Higher Education.

10. Preparation of technical and design documentation for the developed software and hardware, submission of patent and software registration applications, and preparation of a textbook for integrating project outcomes into the educational process are planned.

Figure 1 – **Scientific Internship:** at Ryazan State Radio Engineering University (RSREU) under the supervision of Professor Gennady Vladimirovich Ovechkin.
Project Supervisor: Zhuldyz Sailaukyzy

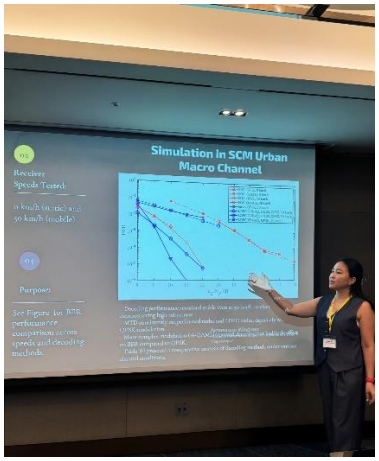

Figure 2 – **Participation:** 29th IEEE/ACIS International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing (SNPD2025-Summer I), June 25–27, 2025, Busan, South Korea.
Project Supervisor: Zhuldyz Sailaukyzy
Project Researcher: M.G. Kozhanov

Research Team

1. **Zhuldyz Sailaukyzy** – Project Supervisor, PhD, Acting Associate Professor, Department of Information Technology and Security, Abylkas Saginov Karaganda Technical University (KarTU)
ORCID: 0000-0001-7605-7634
Scopus Author ID: 57440117200

2. **Gulmira Tulendievna Danenova** – Senior Researcher, Candidate of Technical Sciences, Associate Professor, Department of Information Technology and Security, KarTU
H-index: 1
ORCID: 0000-0003-3301-7282
Scopus Author ID: 57140638000

3. **Zarina Toleubekovna Khasenova** – Senior Researcher, PhD, Dean of the School of Computer Science, D. Serikbayev East Kazakhstan Technical University (EKTU)
H-index: 2 (Scopus), 1 (WoS)
Scopus Author ID: 57205141835

4. **Makhabbat Meiramkyzy Kokkhoz** – Senior Researcher, Candidate of Pedagogical Sciences, Associate Professor, Department of Information Technology and Security, KarTU
H-index: 3
Researcher ID: P-6669-2017
Scopus Author ID: 56646533000
ORCID: 0000-0002-6232-1868

5. **Dina Zhagiparovna Satybaldina** – Senior Researcher, Candidate of Physical and Mathematical Sciences, Associate Professor, Department of Information Security, L.N. Gumilyov Eurasian National University (ENU)
Researcher ID: P-1120-2014
Scopus Author ID: 57193740669
ORCID: 0000-0003-0291-4685

6. **Murat Galiaskarovich Kozhanov** – Researcher, Master of Technical Sciences, Head of the Department of Information Technology and Security, KarTU
ORCID: 0000-0002-5310-9953
Researcher ID: P-1134-2014
Scopus Author ID: 55946377700
7. **Eldor Ulugbekovich Egamberdiev** – Researcher, Director of LLP “Adal Damu”
Researcher ID: K-5417-2013
ORCID: 0000-0001-5289-6580
Scopus Author ID: 57196402736
8. **Madina Maulenkyzy Zhakina** – Junior Researcher, Master's Student, Group VTM-23-1, Department of Information Technology and Security, KarTU
9. **Aidos Nurlanovich Amanov** – Junior Researcher, Master's Student, Group VTM-23-1, Department of Information Technology and Security, KarTU

List of Publications

1. Sailaukyzy Zh. *Development of an Algorithm for Optimizing the Parameters of Majority-Threshold Decoding of Convolutional Codes* // University Proceedings. – 2023. – No. 3(92). – pp. 474–480.
https://doi.org/10.52209/1609-1825_2023_3_474
http://tu.kstu.kz/publication/publication/download/634
2. Sailaukyzy Zh., Satybaldina D., Amanov A.N., Zhakina M.M. *Analysis of LDPC Codes Error Correction Efficiency Using Tanner Graphs for Radio Channels* // International Scientific Conference "Computer Science and Applied Mathematics", October 26–27, 2023, Kazakhstan, Almaty. pp. 274–280. https://conf.iict.kz/wp-content/uploads/2023/10/collection_CSAM_VIII_2023_1.pdf
3. Zhuldyz Sailaukyzy, Dina Satybaldina, Gulmira Danenova, Makhabbat Kokkoz, Nurlan Tashatov. *Design of Majority Decoded Codes and Decoding Algorithm Based on Error Propagation Analysis* // 7th International Symposium on Innovative Approaches in Smart Technologies (November 23–25, 2023, Istanbul, Türkiye). http://www.isassymposium.org/isas2023/ISAS2023_Symposium_Information.pdf
4. Sailaukyzy Zh., Khassenova Z.T., Zhakina M.M., Amanov A.N. *Simulation Model Development for Digital Radio Systems with Error-Correcting Coding* // XXVI International Conference on Digital Signal Processing and Its Applications (DSPA – 2024), March 27–29. http://dspa-conf.org/storage/Proceedings/DSPA2024_RNTORES_proceedings.pdf
5. Sailaukyzy Zh., Ibragimov U.M. *Methods and Criteria for Evaluating Radio Channels Using Noise-Resistant Codes* // Proceedings of the International Scientific and Practical Conference "XVI Saginov Readings. Integration of Education, Science and Production", 2024. https://www.kstu.kz/wp-content/uploads/2024/07/2-chast.pdf
6. Dina Satybaldina, Valery Zolotarev, Gennady Ovechkin, Zhuldyz Sailaukyzy, Zarina Khassenova, Eldor Egamberdiyev. *Specifics of Applying Multi-Threshold Decoding Methods to Correct Errors in Fading Communication Channels* // Journal of Electrical Systems (JES) 20-10s (2024): 4003–4012. https://journal.esrgroups.org/jes/article/view/5966
7. Sailaukyzy Zh., Danenova G.T., Kuanysh A.K., Kutzhan S.D. *Software Implementation for Evaluating Radio Channels Using Noise-Resistant Codes* // Certificate of State Registration of Copyright No. 46161 dated May 21, 2024 (Software for PC).
8. Z. Sailaukyzy, G.T. Danenova, M.M. Kokkoz. *Development of Methods for Improving Energy Efficiency of Digital Radio Systems Using Majority-Threshold Decoding* // Bulletin "D. Serikbayev EKSTU" – 2024, No. 4.
9. Gennady Ovechkin, Dina Satybaldina, Zhuldyz Sailaukyzy, Gulmira Danenova. *Methods of Multi-Threshold Decoders Use in MIMO Systems and Methods of Assessing Their Performance*

// 8th International Symposium on Innovative Approaches in Smart Technologies (December 6–7, 2024, Istanbul, Türkiye).

10. Eldor Ulugbekovich Egamberdiyev, Dina Zhagiparovna Satybaldina, Zhuldyz Sailaukyzy. *Parallel Implementation of Error Correction Systems for Radio Channels Using PyOpenCL* // Certificate of State Registration of Copyright No. 56400 dated April 3, 2025 (Software for PC).

Information for Potential Users

The implementation of this project on the development of error correction tools for radio channels contributes to the advancement of next-generation wireless networks and the application of adaptive telecommunication systems that ensure high reliability in data transmission over variable-parameter radio channels.

Application Area

Applicability and/or commercialization potential of the obtained scientific results: The expected scientific outcomes can be used to modernize communication systems in organizations responsible for national security and defense of the Republic of Kazakhstan, improving the reliability of information transmission.

Date of information update: 01.07.2025