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ABSTRACT

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Efficient error correction coding for Internet of Things transmission systems.

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1 Abstract

The role of the Internet of Things (IoT) in current social and economic life is extremely significant and is likely to continue growing in the future. Research on transmission protocols, including error correction coding, is crucial for the efficient operation of the Internet of Things. IoT devices operate in diverse environmental conditions and communicate through various types of networks, using different protocols, especially in links to end nodes of the network, e.g., Wireless Sensor Networks (WSNs). Effective transmission protocols, along with error correction mechanisms, are essential to ensure reliable communication, minimize delays, and optimize energy consumption.

The research conducted as part of the dissertation focused on the analysis and evaluation of the performance of advanced error correction coding, particularly several variants of Low-Density Parity-Check (LDPC) coding, in the context of their application in communication protocols dedicated to Internet of Things systems. LDPC coding, due to its error correction capabilities, is considered one of the most efficient methods known and used. The studies encompassed the structure and parameters of these codes, methods of construction, encoding, and implementation in systems forming the basis of typical embedded IoT devices.

As part of the research activities, energy-efficient solutions for LDPC encoding and decoding algorithms were developed, optimized for implementation in microcontrollers. An important aspect was to consider the limited computational and memory resources characteristic of hardware in devices, especially those associated with the Internet of Things. The obtained results indicate that LDPC codes, typically used in advanced systems with hardware implementation in dedicated digital circuits, can also be applied in devices with severely constrained resources, especially in the uplink direction of transmission. They can bring significant benefits in terms of energy efficiency and error correction effectiveness compared to traditional block codes.

Next, efforts were made to identify opportunities for further increasing energy efficiency by proposing and implementing an adaptive coding scheme. The application of adaptive encoding strategies for QC-LDPC codes was analyzed. Raptor-like (RL) codes emerged as a promising direction. The research included the development of a system architecture with a flexible design of RL QC-LDPC codes

and implementation in an IoT device. Experiments evaluated the transmission performance from the IoT device to the gateway, with a particular focus on the energy efficiency of adaptive coding with incremental redundancy. It was demonstrated that short blocks of QC-RL-LDPC codes can achieve higher energy efficiency than fixed-length LDPC codes.

Subsequent research efforts were directed towards the applications of non-binary (NB) codes. An analysis of the potential use of NB-LDPC codes was conducted, implementations of encoders were carried out, original decoding methods for Raptor-like codes were proposed, and an algorithm for creating check matrix of NB QC-RL-LDPC codes was developed. The importance of implementation efficiency of the encoding algorithm was emphasized, suggesting that effective deployment of non-binary codes could bring additional benefits, and the encoder could be efficiently implemented in a microcontroller circuit. The conclusions drawn from the conducted research indicate promising prospects for the application of NB-LDPC codes, both in terms of energy efficiency and overall performance of communication systems. Time dependencies for different codes over Galois fields (GF) were compared in experiments, allowing for the assessment of the impact of code selection on potential energy consumption. Correction capabilities were determined, and it was shown that the developed codes, along with the decoding algorithm, provide better opportunities than binary 5G standard codes, while still allowing for an efficient implementation of the encoder, which can be effectively utilized in uplink transmission.