A Performance Comparison of Reduced-Complexity LDPC Decoding Algorithm for Future Wireless Networks

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Abstract

In this paper, we present a comparative analysis of two LDPC decoding algorithms: Sum-Product (SP) and Offset Min-Sum (OMS). While the SP algorithm generally provides superior decoding accuracy and bit error rate (BER) performance, it is computationally more demanding than the Min-Sum (MS) algorithm. Similarly, for applications requiring low latency and low power consumption, SP is not an ideal candidate. Therefore, the presented research explores the performance of OMS, a modified version of the MS decoding algorithm that reduces computational complexity compared to SP and meanwhile maintaining good decoding accuracy. To assess practical viability, we also evaluate the effects of varying channel conditions. Simulation results demonstrate that the reduced-complexity OMS algorithm achieves favorable error rate performance, making it a suitable option for next-generation wireless communication networks.

Ⅰ. Introduction

Error control coding is widely used in a variety of communication systems to improve the data reliability and reducing the transmit power at the cost of bandwidth expansion. Low-density parity-check (LDPC) codes have recently been adopted in various communication standards, as they can achieve good error rate performance approaching Shannon limit. For 5G and beyond networks, in contrast to the other error correcting codes like turbo and convolutional, LDPC has shown better performance [1, 2]. As LDPC codes are already deployed in many communication systems and many application scenarios including IOTs require low power. So, the need to design algorithms which involve less computational complexity is much important.

The LDPC Min-Sum (MS) decoding algorithm simplifies check-node computation and reduces computational complexity compared to the Sum-Product (SP) algorithm [3]. However, this simplification comes at the cost of significantly degraded BER performance. Efforts to improve the MS algorithm have led to the development of the Normalized Min-Sum (NMS) and Offset Min-Sum (OMS) algorithms, which enhance decoding accuracy. Notably, OMS has demonstrated superior BER performance over NMS [3, 4]. This research presents a comparative analysis of the SP and OMS LDPC decoding algorithms, with a particular focus on their performance over a Rayleigh fading channel—a scenario not previously addressed in the literature. By measuring the performance of the reduced-complexity OMS decoder alongside the SP decoder as a reference, this work aims to evaluate their applicability in real-world wireless communication channels. The results provide valuable insights into the viability of OMS in practical Rayleigh fading environments for next-generation wireless networks.

Ⅱ. Proposed Methodology

At the transmitter side, the bits are LDPC encoded using the parity check matrix (1008, 2016) and then the codeword is converted to symbols using BPSK modulation. In addition to AWGN, the data is also assessed over the Rayleigh channel. Before the decoding is performed, the offset factor for OMS is determined (beta = 0.5), and adjusted with the assistance of the check-node computation outputs of the Min-Sum algorithm. In the decoding side, the algorithms SP and OMS are implemented. They utilize message passing between variable nodes and check nodes iteratively until convergence, when all errors get corrected. The maximum number of iterations value is set to 30. For Sum-Product algorithm, the check-node update equation is defined in Eq. 1.

$$E_{j,i} = 2\tanh^{-1} \prod_{i' \in B, i' \neq i} tanh(M_{j,i}/2) \quad (1)$$

Where $E_{j,i}$ presents the update of messages from check node j to variable node i and $M_{j,i}$ is the message from bit node to check node. In the MS algorithm, Eq. 2 below is used to replace the complex equation in Eq. 1 to simplify the computation.

$$E_{j,i} = \prod_{i'} sign(M_{j,i}) \, . min\, |M_{j,i}| \quad (2)$$

Where, $sign(.)$ operation refers to extracting the sign (positive or negative) of a value without considering its magnitude and "min" is used to find the minimum value. MS decoding is computationally simpler than SP decoding since it only considers signs of probabilities. As a result, it requires fewer arithmetic operations and less memory, making it more suitable for resource-constrained environments such as low-power devices or real-time systems. When the value of min in the equation [2] is less than β, it is set as zero. This algorithm avoids sending the very small data to update the variable node to make it fast with reducing computational complexity. The value of beta (where 0<β<1) is 0.5, it is added to each message before passing it to the next iteration in order to mitigate biases in Log-Likelihood Ratio (LLR) values.

Ⅲ. Result Analysis

This section describes performance comparison of the LDPC decoding algorithms in terms of BER and FER. In figure 1, it is shown that the decoding accuracy of OMS is close to SP in both AWGN and Rayleigh channels. As SP results in good BER but the presence of tanh and $\tanh^{-1}$ functions and their products make it challenging and slower. On the other hand, in OMS after marginalizing the node variable values to decrease the numerical computations, then an optimized factor value is determined and adjusted that enables an improved decoding accuracy as well. Furthermore, in Rayleigh fading channels, where multipath propagation causes fluctuations in signal strength, OMS gains the BER value of less than 10^{-4}. Although SP still gains the better BER value, but for future network applications where low latency and low battery power is desired, it is impossible to implement. Similarly, figure 2 compares the FER that provides a more holistic view of the performance of communication systems by considering the impact of errors on entire frames or blocks instead of bits.

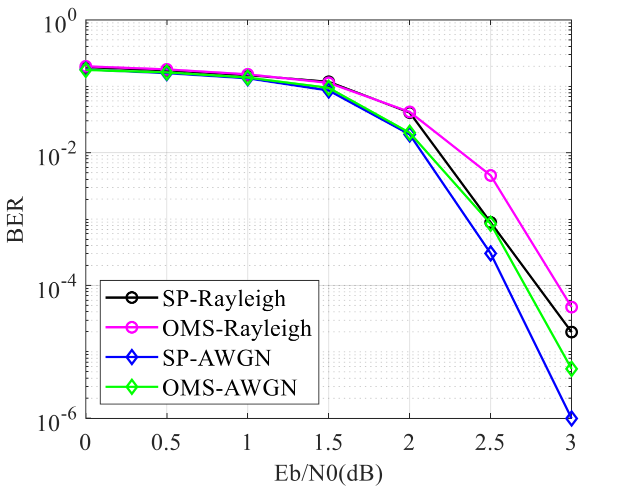

Figure 1. BER comparison

Ⅳ. Conclusion and Future Work

This paper compares the SP and OMS decoding algorithms. The offset factors in OMS is determined and set to the optimized value before the decoding process so as to cause no additional complexity in the decoding process. Simulation results show OMS perform well over Rayleigh channel. Therefore, this reduced-complexity decoding algorithm which has considerable advantages in terms of mitigating computational complexity and hence appropriate for power-constrained environments and in applications where low latency and less hardware resources are required. Therefore, it is a suitable candidate for next generation wireless communication networks. In future, the machine learning can be used to determine the offset values for adaptive OMS algorithms.

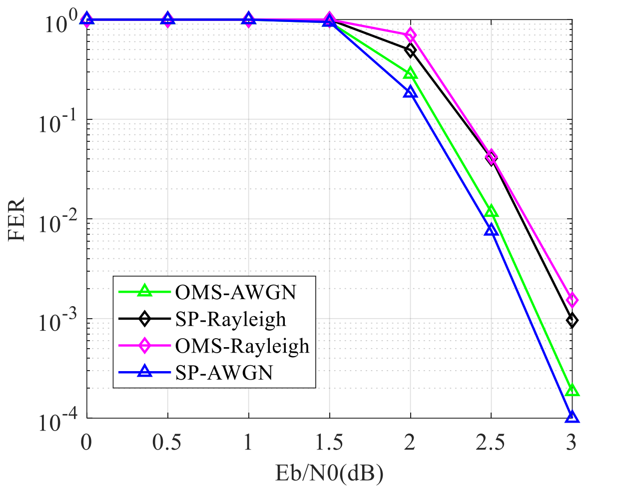

Figure 2. FER comparison

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