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New low-density-parity-check decoding approach based on the hard and soft decisions algorithms

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ABSTRACT

It is proved that hard decision algorithms are more appropriate than a soft decision for low-density parity-check (LDPC) decoding since they are less complex at the decoding level. On the other hand, it is notable that the soft decision algorithm outperforms the hard decision one in terms of the bit error rate (BER) gap. In order to minimize the BER and the gap between these two families of LDPC codes, a new LDPC decoding algorithm is suggested in this paper, which is based on both the normalized min-sum (NMS) and modified-weighted bit-flipping (MWBF). The proposed algorithm is named normalized min sum- modified weighted bit flipping (NMSMWBF). The MWBF is executed after the NMS algorithm. The simulations show that our algorithm outperforms the NMS in terms of BER at 10-8 over the additive white gaussian noise (AWGN) channel by 0.25 dB. Furthermore, the proposed NMSMWBF and the NMS are both at the same level of decoding difficulty.

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1. INTRODUCTION

The low-density-parity-check (LDPC) codes are used in the next generation of optical communication organisms, as they are incorporated in the International Telecommunication Union Telecommunication (ITU-T) standards, like G.709 and G.975. LDPC codes are known by their highest coding gains and are suitable for any code-word length. They are generally iterative and based on information exchanged between the variable and check nodes. Indeed, many worldwide wireless application researchers have been drawn to the LDPC codes because of their importance in communication standards [1]. The min-sum (MS) algorithm is obtained by simplifying the check node processing of the sum-product (SP) algorithm, which also gives good results, and they belong to the soft decision algorithm which is based on the “extrinsic log likelihood ratio (LLRs) [2]–[6]. However, these algorithms require significant arithmetic operations with parallel implementation [7], [8] making them highly complex [9], [10]. Hard decision decoders, on the other hand, are similar to bit-flipping decoders [4], [11], [12] and they have a lower performance bit error rate (BER) than the min–sum (MS) and sum–product (SP) algorithms. However, they are less efficient computationally.

Initially [4] proposed a weighted bit flipping (WBF) method as an upgrade to the bit flipping algorithm (BFA) in order to reduce error rates and boost a decoding stability. Following that, other WBF algorithm advancements were proposed, such as the modified weighted bit flipping (MWBF) algorithm [13], improved modified WBF (IMWBF) algorithm [14], improved reliability ratio WBF (RRWBF) algorithm [15], mixed modified weighted bit flipping (MMWBF) algorithm [16], improved low complex hybrid WBF (ILCHWBF) algorithm [17], channel independent WBF (CIWBF) algorithm [18], and new reliability ratio weighted bit flipping (NRRWBF) [19].

Researchers proposed a new decoding algorithm that gives good results to increase the BF algorithm's performance. Among the algorithms that have been proposed and have produced exciting results, we can cite the MMWBF [16], this algorithm outperforms the WBF algorithm in terms of performance and complexity, besides, it achieves a balance between the BF and SP algorithms. For other algorithms, reliability is based on the extrinsic information used in the inversion function in contrast to the modified weighted bit flipping algorithm based on intrinsic information (MWBFII) [20]. The reliability is based on intrinsic information. This method only employs additions and subtractions instead of multiplications and divisions to improve reliability. Later, in order to improve the errors corrected during iterations, for each bit, hard decision bit flipping decoder based on adaptive bit-local threshold (HDBFABLT) of LDPC codes employed a threshold that may be adaptively modified [21]. In the multistage bit flipping decoding (MSBFD) algorithms of LDPC codes [22], the two algorithms are mixed. The first one belongs to the soft decision and the other one to the hard decision BF decoding. This approach is based on switching from one algorithm to another and selecting the algorithm that performs the first. We performed the proposed algorithm by modifying specific parameters to produce the best results.

In this work we suggest a new algorithm to increase the performance of the decoding by mixing the normalized min-sum (NMS) and MWBF algorithms that belong to the soft and hard decision families respectively. This new method will improve the obtained result in terms of BER by including the inversion function of MWBF in the processing with the soft decision algorithm NMS. The remainder of this paper is arranged as follows: the second section introduces the different BF decoding techniques and NMS algorithm. Whereas the third section is devoted to the description of the proposed normalized min sum modified weighted bit flipping (NMSMWBF) algorithm. Finally, in the last section, we discuss the results from the simulation executed on MATLAB. Section 5 concludes with a summary of this paper.

2. LDPC DECODING ALGORITHMS

The LDPC codes were first proposed by Gallager in the 60s of the last centuries since different researchers essentially use them. Subsequently, the BF was developed and had the lowest computational complexity. As mentioned in the above section, the LDPC codes perform information exchanged between the variable and check nodes. H is the parity check matrix that specifies the LDPC codes, with M rows and N columns representing the parity check equation and code length, respectively. The number of ones per column (column degree) is denoted by dc, and the number of ones per row (row degree) is denoted by dr. A two-dimensional graph, known as a tanner graph, may also be used to define the LDPC code. This graph has two types of nodes: variable and control nodes. Variables correspond to N in the H matrix, while control nodes correspond to M. Figure 1 presents the parity check matrix and tanner graph representation with a code length N=8.

$$H = \begin{bmatrix} 0 & 1 & 0 & 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 & 1 & 0 \end{bmatrix}$$

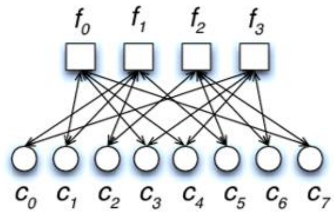

Figure 1. Representation of a LDPC code with (dc = 2, dr = 4, N = 8)

2.1. Bit Flipping algorithms

We denote $c(c_1, c_2, \cdots, c_N)$: the binary code-word message. and $(y_1, y_2 \ldots \ldots \ldots y_N)$: the received symbol modulated with binary phase shift keying (BPSK) across an AWGN channel. The variable z_j is an approximate parameter that would be used in the decoding procedure with $j \epsilon$ [1, N], to which the hard decision is applied on each received bit y_j.

$$\begin{aligned} z_j &= 1 \quad \text{if} \quad y_j \geq 0 \\ z_j &= 0 \quad \text{if} \quad y_j < 0 \end{aligned} \tag{1}$$

In general, the decoding steps for hard decision algorithm are as follow:
1) After calculating the syndromes S_m by (2), we check the value of S_m. If it is equal to zero, the process will be finished, and the decoder is approved. Otherwise, we proceed to the second phase.

$$S_m = \sum_{n=0}^{N-1} z_n H_{m,n} \quad (2)$$

where m = 1, 2, 3, …, M.
2) For every variable node, the inversion function is determined by (3):

$$E_n = \sum_{m\epsilon C(n)} (2S_m - 1)\gamma - \delta|y_n| \quad (3)$$

where, $m \in [1, M]$ γ and δ are factors that differ from one algorithm to another, and $|y_n|$ reflects the absolute value of y_n as received by variable node channel *n*.
3) Locate the variable's node which has the max value of *En*:

$$En(n = \text{argmax}_{1\leq n\leq N} \quad (4)$$

This node with the estimated value must be flipped.
4) The steps from 1-3 are repeated until the maximum number of iterations is reached, or the syndromes are checked.

The decoding algorithm's inversion function "IF" is heavily influenced by the interactions of the assigned values to the variables γ and δ. where: $\gamma = y_m^{min}$ and $\delta = \alpha$. For the MWBF algorithm, where α is an experimentally obtained coefficient.

$$y_m^{min} = \min_{\{n:n\in V(m)\}} |y_n| \quad (5)$$

The (5) represents the minimum absolute value of y_n connected with each variable node. Finally, the inversion function of the MWBF is:

$$E_n = \sum_{m\epsilon C(n)} (2S_m - 1) y_m^{min} - \alpha|y_n| \quad (6)$$

2.2. Min-sum algorithm

The simplification of the belief propagation algorithm BP is the MS algorithm [23], where the hyperbolic tangent (tanh) is replaced by the MS procedure, the (7) is for updating the check node to the variable node clinical target volume (CTV) messages and the (8) is for updating the variable node to the check node virtual topology system (VTS).

$$\alpha_{cv}^{(i)} = \prod_{n\epsilon N(c)\backslash v} \text{sign}(\beta_{nc}^{(i-1)}) \times \min_{n\epsilon N(c)\backslash v} |\beta_{nc}^{(i-1)}| \quad (7)$$

$$\beta_{vc}^{(i)} = L_{ch} + \sum_{m\epsilon M(v)\backslash c} \alpha_{mv}^{(i)} \quad (8)$$

To determine the estimated information bit, we applied a hard decision on *LLr* information. The expression of a variable node *v* is:

$$\beta_{vc}^{(i)} = L_{ch} + \sum_{m\epsilon M(v)} \alpha_{mv}^{(i)} \quad (9)$$

2.3. The normalized min-sum algorithm

The NMS method [24] is a prominent approach for decoding LDPC. It is appealing for hardware/software implementations as it decreases the SP algorithm's implementation complexity without missing much of its efficiency. By regulating the check node processing element generated messages, the NMS [25] optimizes the MS algorithm's decoding performance. The equation for updating the check node to the variable node CTV messages is given by (10):

$$\alpha_{cv}^{(i)} = \theta. \prod_{n\epsilon N(c)\backslash v} \text{sign}(\beta_{nc}^{(i-1)}) \times \min_{n\epsilon N(c)\backslash v} |\beta_{nc}^{(i-1)}| \quad (10)$$

where $\theta < 1$ is a parameter of normalization.

3. PROPOSED ALGORITHM

We propose an enhanced decoding method that integrates soft and hard decisions algorithms. Moreover, it is based on the NMS and MWBF algorithms. This approach will improve the obtained result by including the y_m^{min} of the inversion function of MWBF in the processing with the soft decision algorithm NMS. The importance of y_m^{min} stems from the fact that it is the least reliable bit for each parity-check node. As a result, there is a good chance that the inversion function provided y_m^{min} leads us to the proper bit to flip during every iteration. Figure 2 describes the NMSMWBF decoding.

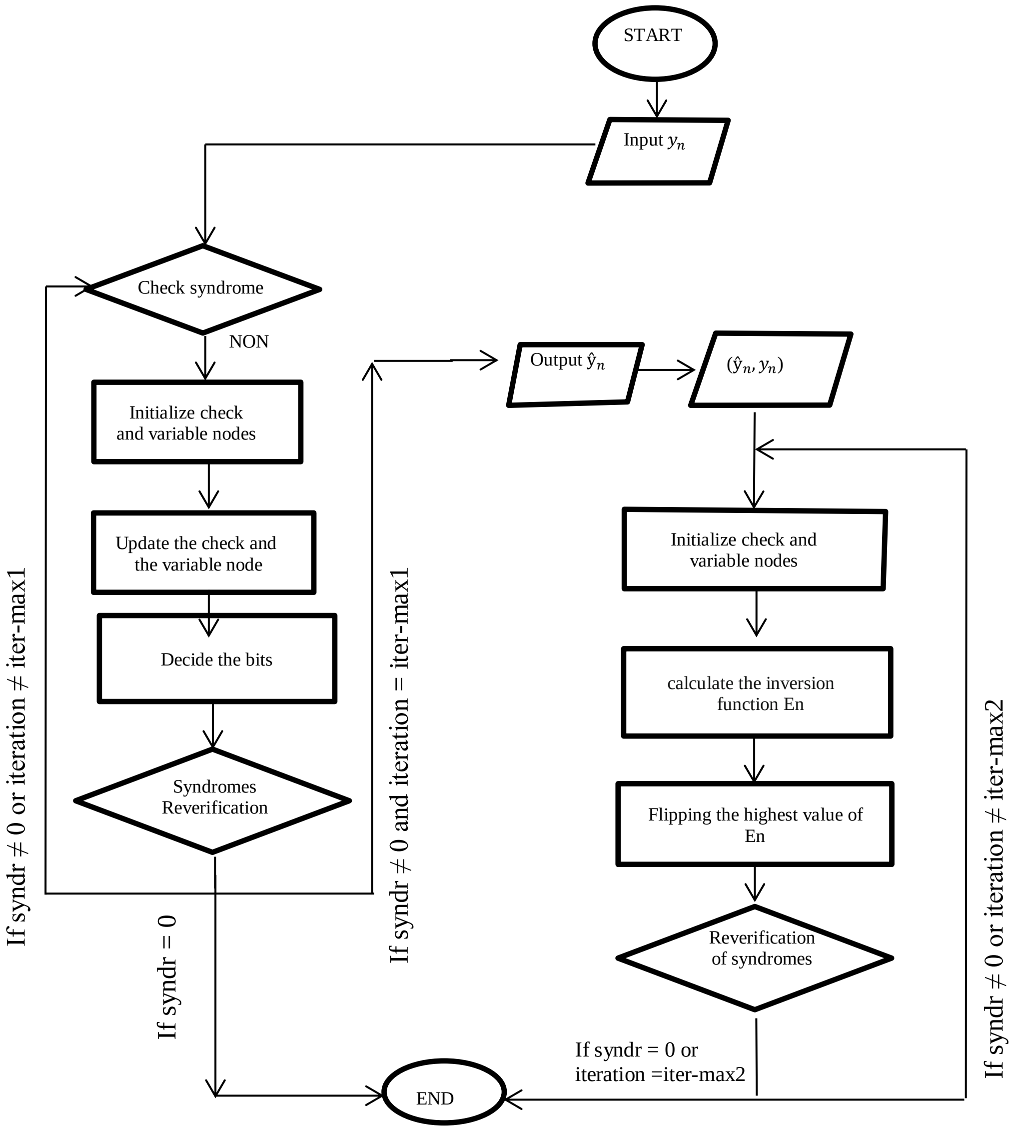

Figure 2. Flowchart for the proposed MSMWBF decoding

The proposed algorithm, NMSMWBF, is based on two stages. The first one is similar to the NMS algorithm; the second stage executes the inversion function of the MWBF in order to achieve a better performance in terms of BER and less computational time by decreasing the number of iterations. Moreover, NMSMWBF consists of two successive stages: in the first stage, the extrinsic LLR messages exchanged between the check and the variable nodes is calculated; then the syndrome vector *s* is verified. Achieving the maximum number of iterations of NMS (*iter_max1*) with an unverified syndrome, the second stage will then be performed until the syndromes are verified or the maximum number of iterations of NMSMWBF (*iter_max2*) is reached. If the syndrome is checked (*s=0*) in the first stage, the correct code-word is reached, the decoding is stopped, and the code-word is returned.

4. RESULTS AND DISCUSSION

Two regular LDPC codes are employed for this simulation, as shown in Table 1, and Gaussian noise AWGN is introduced. The simulation results are obtained by using MATLAB software. For the NMS and both codes, the maximal number of iterations is fixed at $lmax = 5$. For the proposed algorithm, the $lmax = 3$, for MWBF and IMWBF $lmax = 50$.

Table 1. Parameters used in the simulations

Parameters	Code1	Code2
Codeword length N	1008	4095
Parity check-equations Number M	504	737
Number of bits of information K	504	3358
Coding rate	0.5	0.82
Column weight DC	3	3

In order to assess the MSMWBF algorithm, it must be compared to other decoding algorithms cited in the introduction. The NMS approach was chosen for the soft decision as a decent variation of the original SP algorithm. For the hard decision, we used the MWBF and IMWBF algorithms.

Figures 3 and 4 represent the BER performance obtained with the regular LDPC codes (1008, 504), (4095,737), as well as the rate of 0.5 and 0.82, respectively. The figures show that the proposed NMS-MWBF based decoding algorithm improves performance compared to the MWBF and IMWBF over an AWGN channel. Compared to the soft decision, they have a minor reduction in error correction performance. For the first code, NMSMWBF outperforms other algorithms like MWBF and IMWBF with more than 3.7 dB at 10^{-3} BER, and also it exceeds NMS with 0.25 dB at 5×10^{-8} BER. The proposed algorithm gives excellent results compared to the hard decision algorithm.

For the second code, as presented in Table 1, it is clear that the NMSMWBF surpasses the MWBF and IMWBF by 2 dB at 10^{-2} BER and the NMS by 0.1 dB at 2.10^{-5} BER. We notice for code two, a slight degradation of the performances in comparison to code 1 which is due to the length of code, which is very wide. However, the algorithm generally still gives the best results compared to the hard decision algorithm. It is noticed that the computational complexity and run-time are increased with the large size of the parity check matrix.

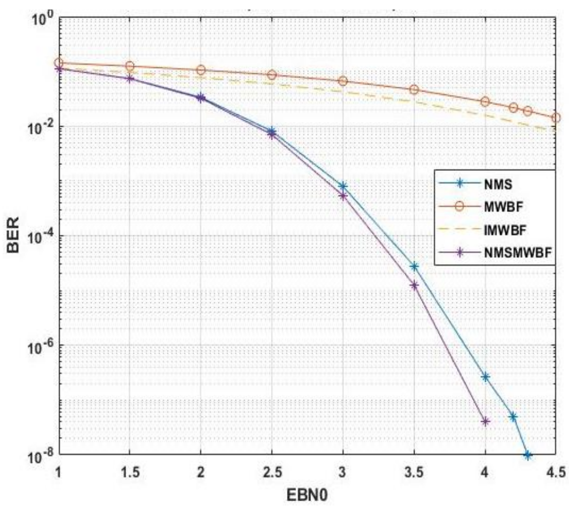

Figure 3. BER Simulation with code 1 parameters

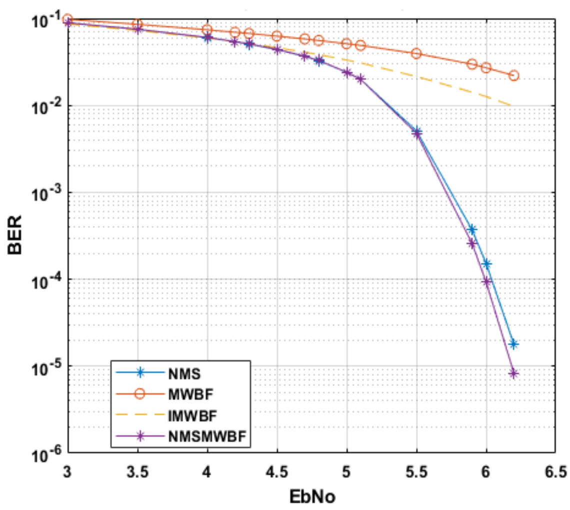

Figure 4. BER Simulation with code 2 parameters

For different algorithms abovementioned the BER is illustrated in Figure 5 as a function of the iteration number at Eb/N0 = 3.5 dB is. The results show that our method is faster than the others in terms of computational time, it reaches the minimum BER value with minimum number of iterations compared to other algorithms that require a larger number of iterations to reach the same value of BER. Moreover, for example with 4 iterations, we obtain the best BER among all the other algorithms.

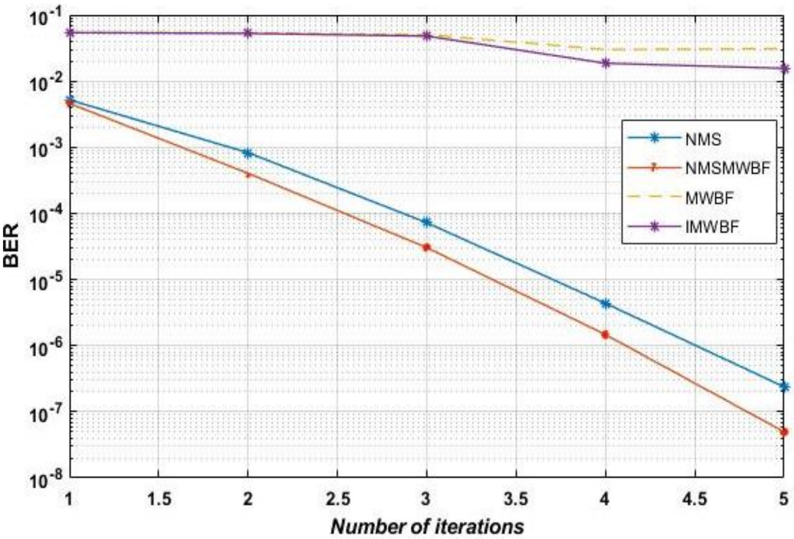

Figure 5. Comparison of the convergence of the NMSMWBF, NMS, MWBF and IMWBF for decoding LDPC code (1008,504) at EbN0= 3.5 db

5. CONCLUSION

The objective of this research paper is to propose a new algorithm in order to improve the BER. The proposed algorithm, NMS-MWBF, is based on hard and soft decision algorithms. The MWBF and the NMS are mixed, and better results are obtained, as shown in the section related to results and discussion. The results show that the proposed algorithm requires less computational time as a result of fewer decoding iterations, and it gives good performance compared to the MWBF for different signal-to-noise ratio (SNR) values as well as a high SNR for the NMS algorithm.

Simulation results show for first code n=1008, at BER of 10^{-3}, the NMSMWBF achieves in the region of 3.7 dB gain over the MWBF and IMWBF. Furthermore, at BER of 5.10-8, achieves a gain of 0.25 db over the NMS. For the second code, n=4095, at BER of 10^{-2}, the NMS-MWBF achieves approximately a gain of 2 dB over the MWBF and IMWBF, and at BER of 2.10 to 5 achieves a gain of 0.1 over the NMS. This degradation in performance compared to the first code is due to the large size of the second matrix.

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