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Parallel Genetic Algorithm Decoder Scheme Based on DP-LDPC Codes for Industrial IoT Scenarios

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Abstract

The new concept of Industry 4.0 has been developed: it includes both Internet of Things (IoT) structure and the local networks that are still needed to carry out real-time tasks. Genetic algorithms are successfully used for decoding some classes of error correcting codes, and offer very good performances when solving large optimization problems. This article proposes a decoder based on parallel Genetic Algorithms (PGAD) for Decoding Low Density Parity Check (LDPC) codes. The proposed algorithm gives large gains over the Sum-Product decoder, which proves its efficiency, the best performances are obtained for Ring Crossover (RC) as a type of crossover and the tournament as a type of selection. Furthermore, the performances of the new decoder are improved using Multi-criteria method. For the LDPC code, simulation results showed that our Proposed PGAD exceeds the sum-product by a gain of 1.5 dB at $BER = 10^{-4}$, and the PGAWS exceeds the sum-product by 2.5 dB.

Keywords: Parallel Genetic Algorithms decoder, Fitness Function, Sum-Product decoder, LDPC codes, Multi-criteria method, Weighted sum method, Error correcting codes.

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1. Introduction

In the past decade, we have witnessed explosive growth in the number of low-power embedded and Internet-connected devices, reinforcing the new paradigm, Internet of Things (IoT) [27]. IoT devices like smartphones, home security systems, smart electric meters, garage parking indicators, etc., have penetrated deeply into our daily lives [22,23].

The new concept of Industry 4.0 has been developed: it includes both Internet of Things (IoT) structure and the local networks that are still needed to carry out real-time tasks. This fact was in stark contrast to the practices of the time, which essentially combated the effects of noise only by increasing the power of the emitted signal. Unfortunately, this existence theorem also contains its limits. It does not specify what means should be put into play to construct these codes, nor does it provide an estimate of the costs required to achieve such results. Despite these weaknesses, a large number of work was undertaken to apply this theorem and it was then possible to lower the rates of residual errors in noisy environments to negligible levels while moving in transmission rates. The only practical obstacle to its application is the design of decoding algorithms and their complexity in computational time to correct the noise data. Low-Density Parity-Check (LDPC) codes have lately received extra attention and they have been exploited as encoding scheme numerous high data rate communication systems [1]. This encoding family is an error correcting code invented by Gallager in 1963 [6]. This family is adopted by the cited systems above of their excellent error-correcting performance and highly parallelizable decoding algorithm aided by the capability of today's microelectronics technology [26,27].

As depicted on the Fig. 1 for decoding of the received data, based on the state of the arte there are two ways are commonly discussed [2]. The first one is named symbol-by-symbol maximum a posteriori (SBS-MAP) decoding. The objective of this method is to minimize the bit error probability of the decoded data. The second one is named maximum likelihood sequence decoding (MLSD). The objective of this approach is to minimize the word error probability of the decoded data. These approaches are iterative algorithms.

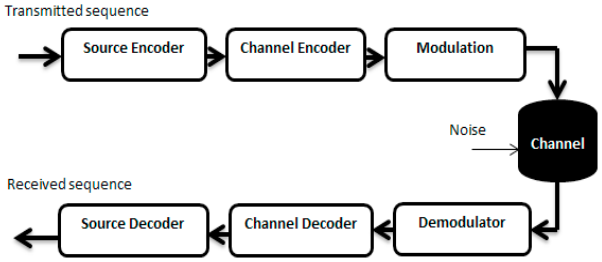

Fig. 1. Brief communication system model

When LDPC codes are decoded using Gallager’s iterative probabilistic decoding algorithm SBS-MAP. This also identified as the Sum-Product algorithm or Belief propagation algorithm, according to [3], [4], [5] this algorithm gives good BER performances for the big code vector. The LDPC Sum-Product decoding algorithm [6], [7], [8], makes an estimation of the A Posteriori Probability (APP) of each symbol as a function of the received symbol and the properties of the channel. Motivated by the obtained results in this work [9] regarding the good performances and complexity, we have developed a decoder based on Parallel Genetic Algorithm for LDPC codes. This introduced new Parallel Genetic Algorithm for decoding LDPC codes (PGAD)is based on framework in [10] for the parallel aspects of the algorithm, and we show that the fitness function must be improved by Multi-criteria method, for this we applied the Weighted Sum method to improve PGAD, this new version is called (PGAWS). In effect, a comparison with other decoder, that is currently the most successful algorithms for LDPC, shows its efficiency, and gives higher performances.

This paper is organized as follows. Section III introduces the parallel Genetic algorithm; Section IV presents our decoder PGAD, and analyzes their performances. Section V presents and analyzes the performances of our optimized version of PGAD decoder. Finally, Section VI presents the conclusion and future trends.

2. Parallel Genetic Algorithm

Genetic algorithms (GAs) are implicitly parallelizable or many of the operators can be carried out independently of each other's. The efficiency of parallel GA is to reaches the desired solution in the shortest time possible with the best performances. Parallel GAs are particularly easy to implement and promise substantial gains in performance [14],[15],[16], and are effective in solving problems of large sizes. Most of these algorithms have been implemented on massive parallel machines and their effectiveness depends on the parallel computing system. In many of these problems the fitness evaluations for each candidate solution can be calculated independently. This means that each candidate solution can be calculated at the same time, in other words in parallel. Performing these evaluations in parallel will obviously result in an increase in speed of the algorithm - roughly proportional to the number of processors used. There are, however, reasons for performing GAs in parallel that are believed to give improved performance. If we consider the GA as simply a model of natural systems then some parallel implementations can be viewed as consisting of separate sub-populations evolving independently of each other, with occasional migration allowed between these sub-populations. There are three main types of parallel GAs [11]: global single-population master-slave GAs, single-population fine-grained, and multiple-population coarse-grained Gas [11], [17,25]. The most popular parallel GAs consists in multiple populations that evolve independently as separate sub-processes or 'islands'. After each generation the fittest individuals from each 'island' can then 'migrate' to other 'islands' (Fig. 2). If a neighborhood structure is defined over the set of populations, and once in a while each population sends its best individuals to its neighbors, we say we're running a distributed genetic algorithm. If no swapping of individuals to neighbors is done, we have a special case of the distributed model, which we call the partitioned genetic algorithm [13], our work focuses on the last model.

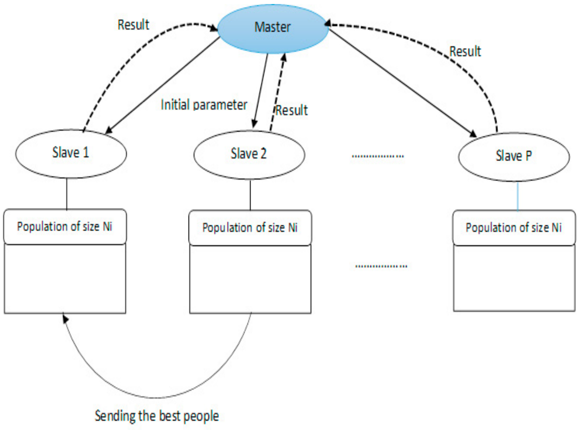

Fig. 2. Principle of parallelism islands.

3. Parallel Genetic Algorithm Decoder (PGAD)

This work is a parallelization of a new decoder based on Genetic Algorithm, the master computes the syndrome of the received vector, if the syndrome is null, the master machine returns the decoded vector that is equal to the binary decision of the received one, if not, the slaves turns GAs (Fig. 4) in parallel with an initial population randomly generated for each one. Each process develops independently its population until he decided to gather his best individual which will be a candidate for the decision step (Fig. 3).

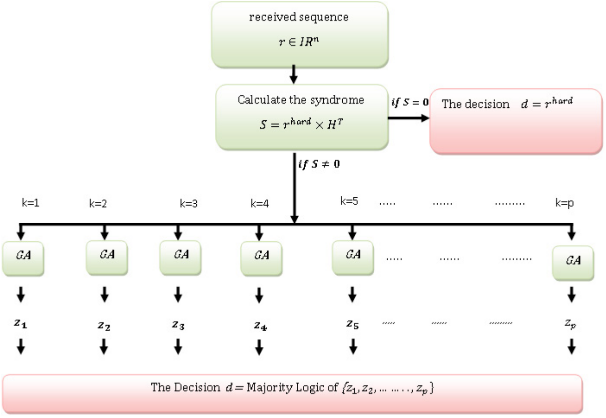

Fig. 3. Parallelization of the Genetic Algorithm Decoder.

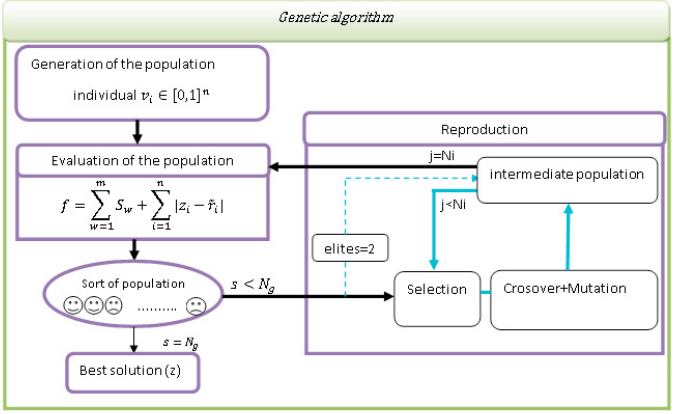

Fig.4.The proposed Genetic Algorithm flowchart.

3.1. Simulation Results and Discussions related to PGAD:

In order to prove the effectiveness of PGAD, we do intensive simulations.

The simulations where made with default parameters outlined in Table 1. The performances are given in terms of BER (bit error rate) as a function of SNR (Signal to Noise Ratio E_b/N_0).

Table 1. An example of a table.

Simulation parameter	Parameter value
Pc (crossover rate)	0.95
Pm (mutation rate)	0.01
Ng (generation number)	25
Ni (population size)	500
Ne (elite number)	2
Channel	AWGN
Modulation	BPSK
Minimum number of bit errors	100
Minimum number of bloc	300
P(GA runs)	15
Default code	Regular LDPC(60,30)
Type of crossover	Ring Crossover (RC)
Type of selection	Tournament

3.2.1 Comparison between different number of population size

The Fig.5 emphasizes the influence of the number of the population size on the performance of PGAD. Increasing the population size from 100 to 500, we can gain 1dB at 10^{-4}.

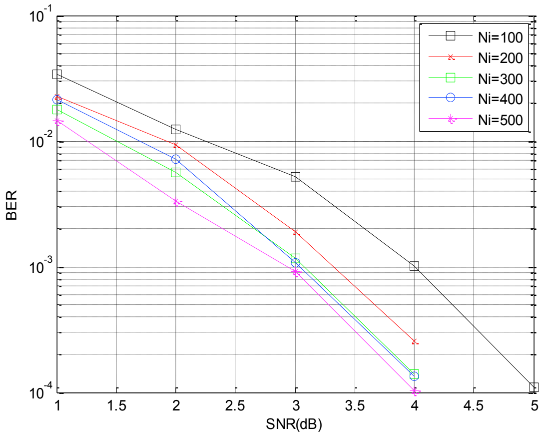

Fig. 5. Comparison between different number of population size in PGAD for a regular LDPC (60,30).

3.2.2 *Comparison between different selections operators in PGAD*

In this simulation we use the single point as a type of crossover and we applied different types of selection.

Fig. 6 presents a comparison between the results obtained using tournament, linear ranking, Roulette Wheel, Rank, Elitism and random selection in PGAD for LDPC (60, 30). Simulation results show that the tournament selection is better than all other selection.

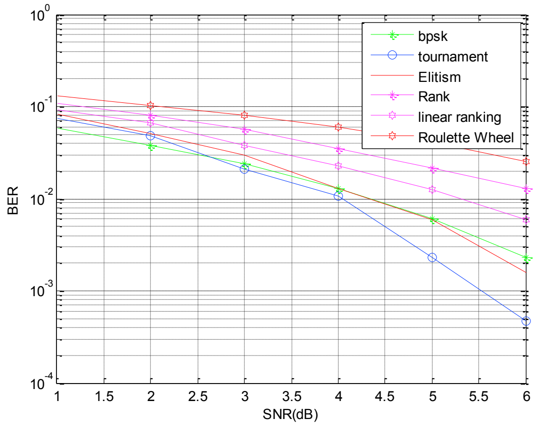

Fig. 6. Comparison between different selection operators in PGAD for a regular LDPC(60,30).

3.2.3 Comparison between different crossover operators in PGAD

In this simulation we use the tournament selection as a type of selection and we applied different types of crossover.

In the Fig. 7, we compare results obtained using the ring crossover, single points, two point and tree points crossover, in PGAD for regular LDPC(60,30) code.

Simulation results show that the ring crossover is better than all other ones. The gain between the RC and the tree other crossovers is 2.5 dB at 10^{-3}.

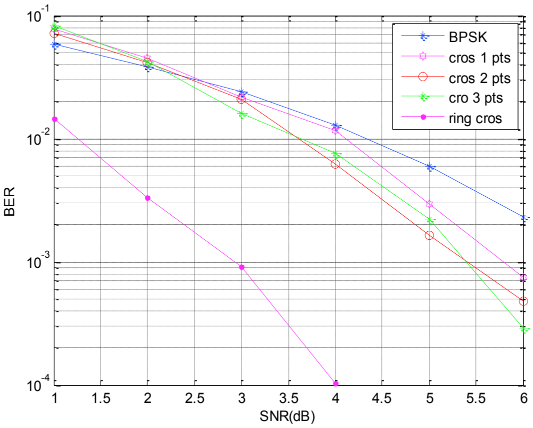

Fig.7.Comparison between different crossover operators in PGAD for a regular LDPC (60,30).

3.2.4 *Comparison between different execution number of GA.*

The number of runs used in our decoder has an effect in the performance's quality, Fig. 8 shows this effect.

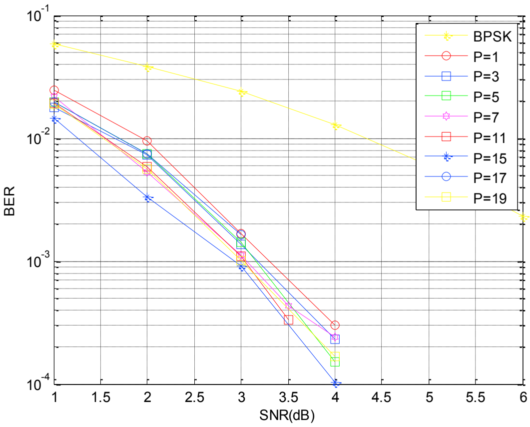

Fig. 8. Performance of PGAD increasing the number of GA execution (P).

The Fig. 8 shows that the performances improve by increasing the number of GA execution until 15 runs, after, the performances decrease by increasing the number of runs. So the number of runs must be chosen carefully to give good impact into the performances of our decoder.

3.2.5 Comparison with Sum-Product Decoder

Our new decoder has been compared with the Sum-Product Decoder for regular LDPC(60,30), LDPC(75,45) and LDPC(96,48) codes. The results are given in Fig. 9, Fig. 10 and Fig. 11:

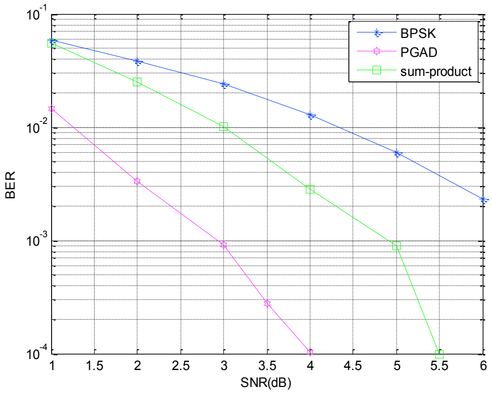

Fig. 9. Performances of PGAD compared to sum-product decoder for a regular LDPC(60,30) code.

The Fig. 9 shows that the PGAD provides good performances compared to sum-product decoders for regular LDPC (60,30) code. The gain between the PGAD and sum-product decoder is 1.5 dB at10-4. Fig. 10 compares the performances of PGAD with sum-product decoder for regular LDPC (75,45) code. We remark that the PGAD is better than sum-product decoder. The gain between the PGAD and sum-product decoder is 2.5 dB at 10-3.

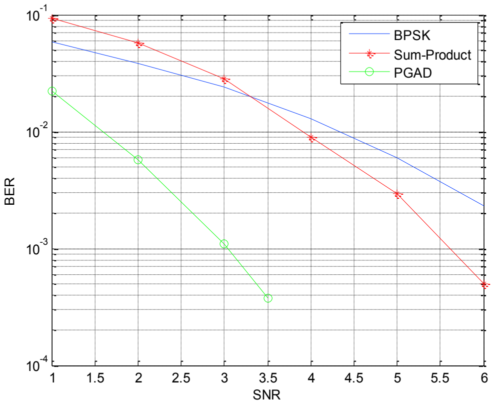

Fig.10. Performances of PGAD compared to sum-product decoder for a regular LDPC(75,45) code.

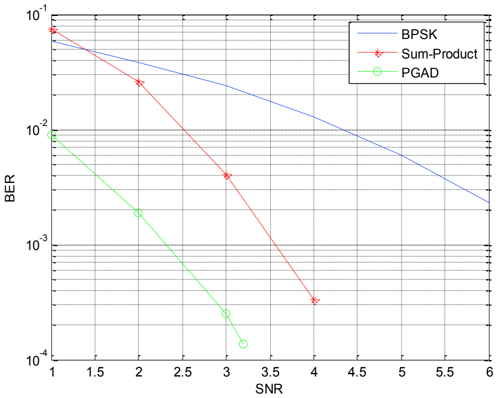

Fig.11. Performances of PGAD compared to sum-product decoder for a regular LDPC(96,48) code.

Fig. 11 compares the performances of PGAD with sum-product decoder. We remark that the PGAD is better than sum-product decoder for regular LDPC (96,48) code. The gain between the PGAD and sum-product decoder is 1.5 dB at 10^{-3}.

4. Multi-criteria Optimization to Improve Fitness Function:

In this section we show that the fitness function (eq.9), must be improved using multi-criteria optimization.

Based on a comparison between the PGAD decoder where the fitness is equal to the first part of fitness (Syndrome Weight (SW)) and where it is equal to the second part of the fitness (Distance between the Candidate vector and the Received vector (DCR)) (Fig. 12), we remark that:

For all SNR when the fitness is equal to SW, the performances are always better than the case when the fitness is equal to DCR.

$$\boldsymbol{fitness} = \underbrace{\sum_{w=1}^{m} \boldsymbol{S_w}}_{f_1:\ \mathrm{SW}} + \underbrace{\sum_{i=1}^{n} |\boldsymbol{z_i} - \boldsymbol{\tilde{r}_i}|}_{f_2:\ \mathrm{DCR}} \quad (9)$$

We also note that the SW as fitness gives better results than both functions in the fitness. Then, we can deduce that the SW affects much more the performances than the DCR.

We also note that the performances presented by the DCR are very degraded compared to those given by the SW. Nevertheless, the SW has managed to mitigate their effects, and as a result, the performances of the two functions together are closer to those presented by the SW than the ones presented by the DCR.

Whereby, when we trace the performances of both functions, we gave the SW and DCR the same importance by factoring theme to equal coefficients. This is not just because, we valorize the same way two things that do not have equal importance. Let's give an example to clarify our concern:

For a scientific profile student, trying to maximize it's Overall Score (OS). Consider the coefficient of Mathematical (Math) equal to 7 and the coefficient of Geography & History (GH) equal to 2. If we assume that these two subjects are the only ones that contribute to the overall score. We will have:

OS=7*(N. Math) + 2*(N. GH)

Here we see very well that the Math is more important than the GH.

In our case, it is very remarkable that the SW is more important than the DCR (Fig. 12), which pushes us to introduce coefficients (α and β) for the two functions (f1 and f2) (eq.9).

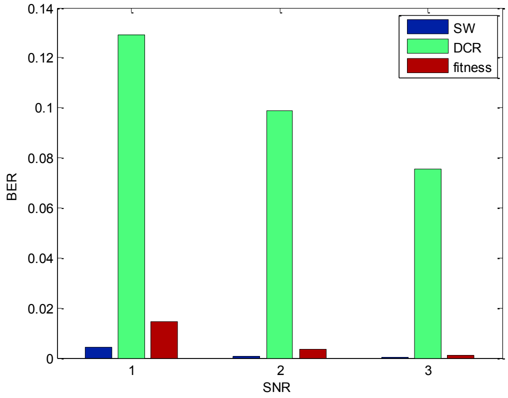

Fig. 12. Performances of PGAD decoder for a regular LDPC (60, 30) codes for tree fitness.

The coefficients α and β must have specific values to have the best possible performances. In order to find these values, we made intensive simulations, first to find the optimum value of α and, after, to find the optimum value of β.

The Fig. 13, shows the performances of PGAD decoder for β=1 by varying α. And The Fig. 14 shows their performances for $\alpha = 1$ by varying β.

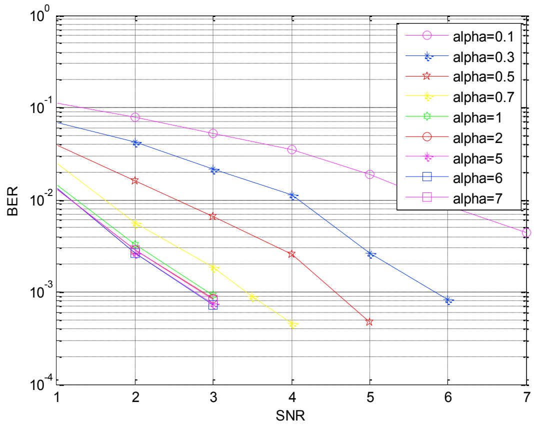

Fig. 13. Performances of PGAD decoder for a regular LDPC (60, 30), forβ=1 by varying α.

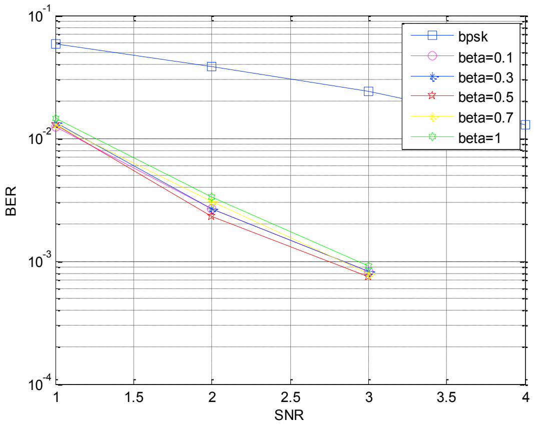

Fig. 14. Performances of PGAD decoder for a regular LDPC (60, 30) code, for α =1 by varying β.

According to the different figures (Fig.13 and Fig.14), we see that increasing the α coefficient improves the performances until reaching stability, and decreasing the value of β do the same.These observations validate our early hypothesis (SW has more importance than the DCR).It remains to find the best couple (α, β)which gives the best performances. Therefore, we are in front of a multi-criteria optimization problem.

5. Conclusion

In this paper, we have proposed a new decoder based on parallel GA for LDPC codes. The simulations applied on some LDPC codes; show that the proposed algorithm is an efficient one. The comparison between our PGAD and sum-product decoder shows that our decoder is better in terms of performances. we have shown that the fitness function must be improved by multi-criteria, for this purpose, we applied the weighted sum in PGAD decoder which gives better performances compared to our decoders.

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