External Bit Duplication Method for Rate-Compatible LDPC Codes

Le Van Son [1] and Evgeny Likhobabin[1,2]

[1] Moscow Institute of Physics and Technology, 9, Institutskiy per., Dolgoprudny, Moscow Region, 141701, Russian

[2] Ryazan state radio engineering university, 59/1, Gagarina Street, Ryazan, 390005, Russian

levanson09081992@gmail.com

Abstract. This paper proposes new method for changing the coding rates of low-density parity-check (LDPC) codes. This method allows obtaining a code set with different rates from a higher-rate code (mother code). The proposed method can be applied to any mother code; especially it is more efficient for mother code with an irregular parity-check matrix, where the 1s are unevenly distributed on the columns. In addition, this method differs in that the structure of the parity-check matrix is completely preserved, which reduces the computational cost of reconstructing the pair encoder/decoder. Simulation results demonstrate that the designed method is superior to the conventional method puncturing of bits as the rate decreases.

Keywords: Multi-Rate, LDPC Code, External Bit Duplication, Puncturing Method.

1 Introduction

In modern information transmission systems, depending on the degree of interference on the communication channel, different code rates are used. Under low interference conditions, codes with higher rates are used, and under poor conditions with strong interference, codes with lower rates are used. Typically for this, each parity-check matrix is specifically designed for each code rate to achieve maximum performance. However, such a design requires large costs for building the plurality of pairs of coder/decoder. Therefore, to solve such a problem, various methods have been developed, such as puncturing, extending, row combining and splitting [1-9]. But the main drawback of these methods is that the structure of the parity-check matrix changes, which greatly affects the complexity of the code.

In this paper, we propose a new method called "external bit duplication" for rate-compatible LDPC codes. The main idea of this method is that after encoding, its duplicated part is added to the resulting codeword, the length of which depends on what code rate we want to get. For example, if we want to get a code rate of 1/4 from the mother code rate of 1/2, then the duplicated part is the fully codeword. And if we want to get a code rate of 1/3 from the mother code rate of 1/2, then the duplicated part is the informational part of the codeword. The advantage of this method is that the parity-check matrix parameters of the mother code do not change, which reduces the cost of rebuilding it. Also, the length of information bits before encoding is preserved when switching from one code rate to another.

2 Materials and methods

2.1 Puncturing of bits method

Puncturing of bits (PB) [10] is one of methods for obtaining lower-rate codes from a higher-rate mother code. To explain the method, we introduce the following notation. n is the block-length of the mother code, k is the length of information bits, R is the rate of the mother code, r is the rate of the designed code. The length of the original message (l_i) and the length of the discarded information bits (l_o) are calculated as follows:

$$l_i = \frac{r(n-k)}{1-r} \tag{1}$$

$$l_o = \frac{(k-rn)}{1-r} \tag{2}$$

It can be seen from the above formulas that $l_i + l_o = k$. Below are examples of obtaining three rates 1/3, 1/4 and 2/5 from the code rate 1/2.

The PB code with rate of 1/3. In this case, $l_i = k/2$ and $l_o = k/2$. At the transmitter of the data transmission system, in addition to the main elements, there are 2 multiplexers (MUX.1 and MUX.2) for setting the parameters of the transmitted information stream (Figure 1). The original message $x=(x_1,x_2,\dots,x_{k/2})$ with a length of $k/2$ is transmitted to MUX.1, the output of which is a new message, comprising in addition to the original message x zero sequence with length of $k/2$**.**

Then the formulated message is transmitted to the LDPC encoder, the output of which is a codeword. The received codeword is transmitted to the MUX.2, here a sequence of zeros with length of k is removed from the codeword, since their values are already known to the transmitter and receiver, so they do not need to be transmitted. Thus, due to the removal of the zero sequence, the code rate became 1/3.

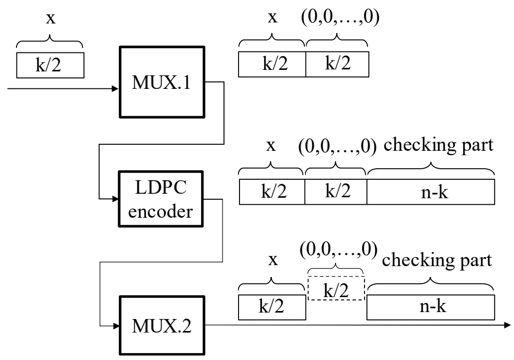

Fig. 1. PB method for obtaining a code rate of 1/3 from the mother code rate of 1/2 at the transmitter.

At the receiver, the codeword is transmitted to DEMUX.1 in the form of a logarithmic likelihood function (LLR) (Figure 2).

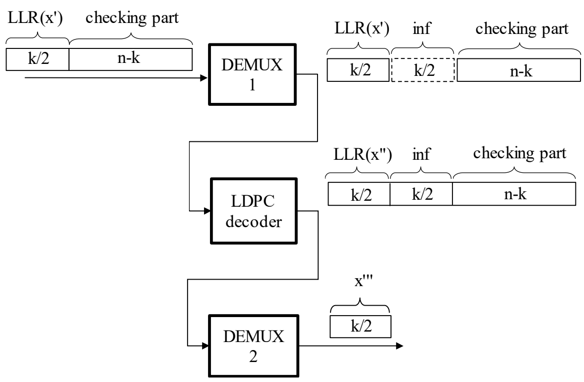

Fig. 2. PB method for obtaining a code rate of 1/3 from the mother code rate of 1/2 at the receiver.

In DEMUX.1, the structure of the codeword is restored, at the place where there was the zero sequence, a sequence of maximum possible LLR (inf) values is inserted.

Then the obtained LLR values are decoded using an LDPC decoder, the output of which is transmitted to DEMUX.2 to extract useful information.

The PB code with rate of 1/4. In this case, $l_i = k/3$ and $l_o = 2k/3$, The process of obtaining this code is shown in Figure 3 and Figure 4.

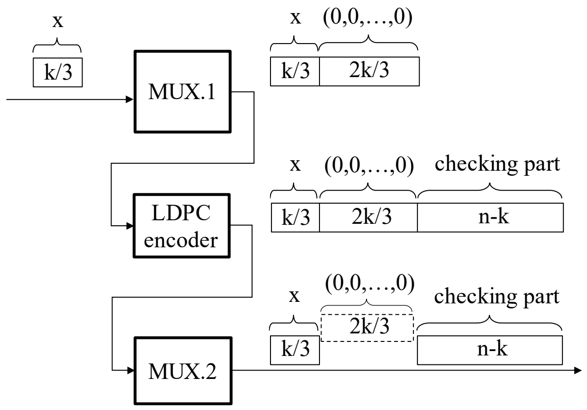

Fig. 3. PB method for obtaining a code rate of 1/4 from the mother code rate of 1/2 at the transmitter.

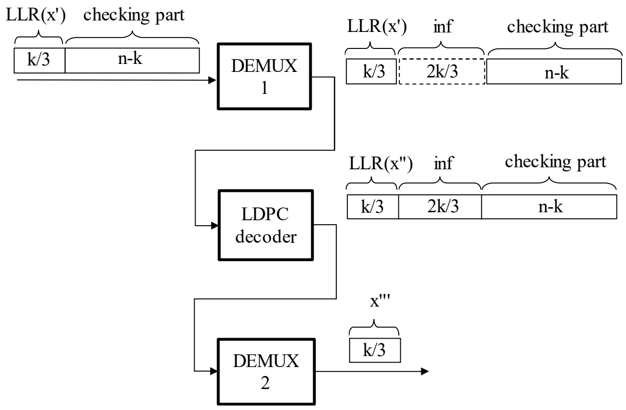

Fig. 4. PB method for obtaining a code rate of 1/4 from the mother code rate of 1/2 at the receiver.

The PB code with rate of 2/5. In this case, l_i = 2k/3 and l_o = k/3, the process of obtaining this code is shown in Figure 5 and Figure 6.

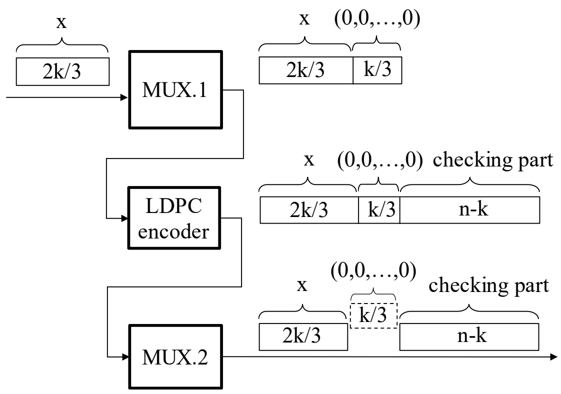

Fig. 5. PB method for obtaining a code rate of 2/5 from the mother code rate of 1/2 at the transmitter.

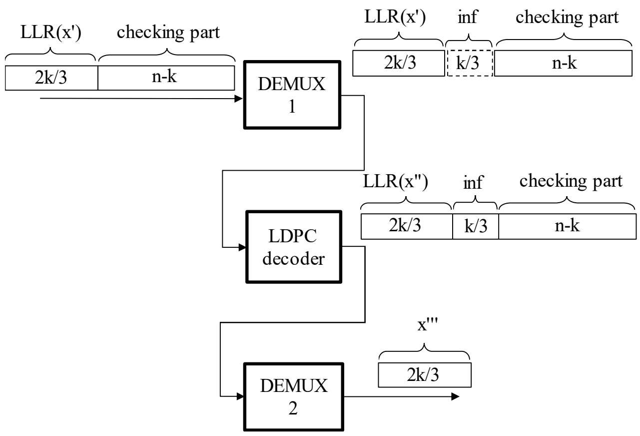

Fig. 6. PB method for obtaining a code rate of 2/5 from the mother code rate of 1/2 at the receiver.

2.2 External bit duplication method

In this paper, we propose a new method called external bit duplication (EBD), for obtaining lower-rate codes from a higher-rate mother code. The peculiarity of the method is that after encoding, either the entire duplicated codeword or its duplicated part is added to the codeword, depending on the selected code rate that we want to obtain. In this method, the length of the duplicated part (l_d) is calculated by the following formula:

$$l_d = \frac{k}{r} - n \tag{3}$$

The EBD code with rate of 1/3. In this case, $l_d = k$, the proposed method is described as follows.

At the transmitter (Figure 7), the original message $y=(y_1,y_2,...,y_k)$ with length of k is encoded buy an LDPC encoder, the output of which is a codeword with length of n. Then, it is passed to the MUX to reforming the codeword structure. This codeword is supplemented with its duplicated information part. The obtained codeword has length of $n + k$ and the code rate became 1/3.

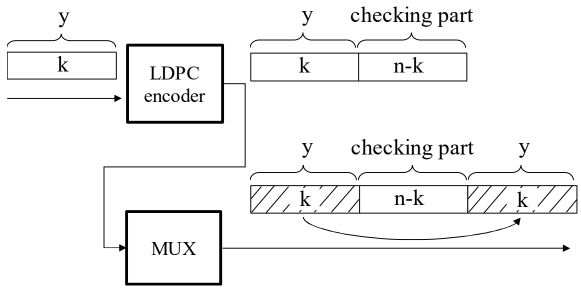

Fig. 7. EBD method for obtaining a code rate of 1/3 from the mother code rate of 1/2 at the transmitter.

At the receiver (Figure 8), the codeword is transmitted to DEMUX.1 as an LLR function, where the LLR values of the information part are summed with the values of its LLR of the duplicated part. The result will be inserted in the place of the information part, and its duplicated part is discarded.

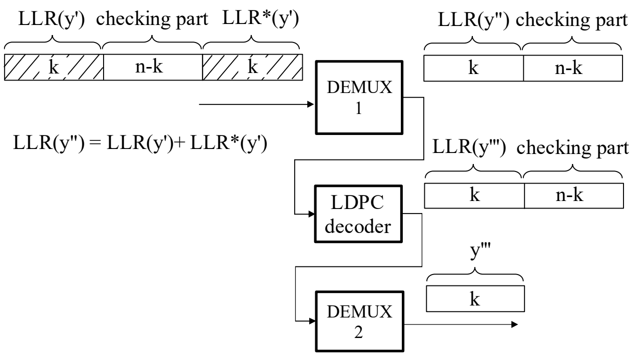

Fig. 8. EBD method for obtaining a code rate of 1/3 from the mother code rate of 1/2 at the receiver.

Then, the obtained codeword is decoded by an LDPC decoder, the result of which are transmitted to DEMUX.2 to extract the useful information.

The EBD code with rate of 1/4. In this case, $l_d = n$, the difference is that now the duplicated part is the entire codeword. The process of obtaining this code is shown in Figure 9 and Figure 10.

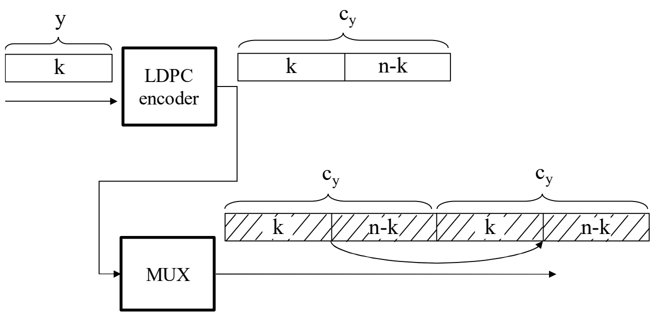

Fig. 9. EBD method for obtaining a code rate of 1/4 from the mother code rate of 1/2 at the transmitter.

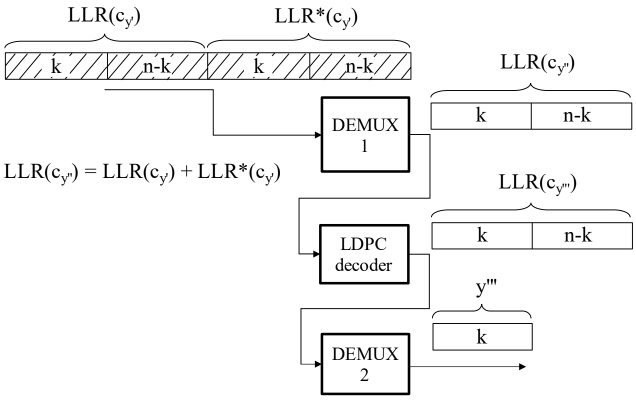

Fig. 10. EBD method for obtaining a code rate of 1/4 from the mother code rate of 1/2 at the receiver.

The EBD code with rate of 2/5. In this case, the duplicated part is part of the codeword with length l_d = k/2. The process of obtaining this code is shown in Figure 11 and Figure 12.

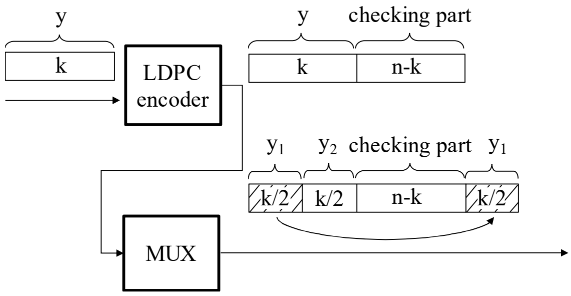

Fig. 11. EBD method for obtaining a code rate of 2/5 from the mother code rate of 1/2 at the transmitter.

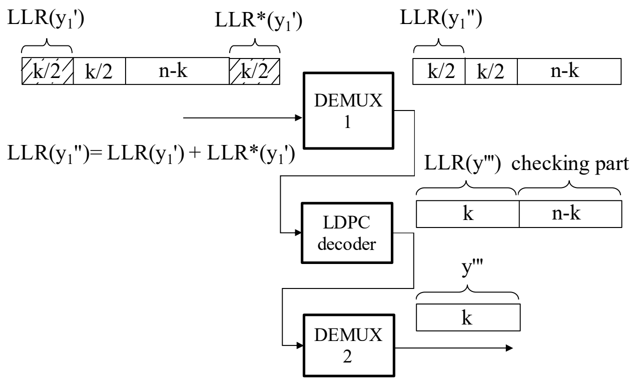

Fig. 12. EBD method for obtaining a code rate of 2/5 from the mother code rate of 1/2 at the receiver.

3 Results

In this section, a comparison of two methods PB and EBD is carried out at three rate of 2/5, 1/3 and 1/4 in the Matlab simulation environment when transmitting the codeword over AWGN communication channel with BPSK modulation. As the mother code, a DVB-S2 check matrix with a rate of 1/2 is used, the decoding algorithm is sum-product (SPA) and the maximum number of iterations is 50. The simulation results are shown in Figure 13.

In Figure 13 shows that EBD codes outperform PB codes at two rates 1/3 and 1/4, gains are respectively 0.15 and 0.45 dB at the BER of 10^{-5}. At the rate of 2/5, the EBD code is inferior to the PB code, the loss is 0.1 dB at the BER of 10^{-5}.

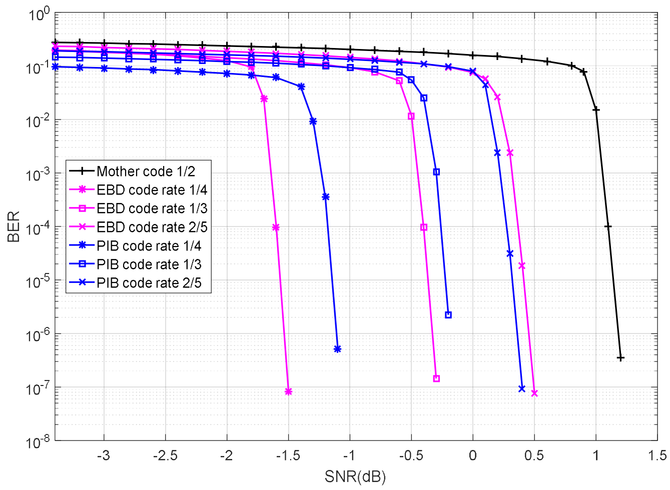

Fig. 13. Performance of PB and EBD codes with rates of 1/3, 1/4 and 2/5, block-length is 64800.

4 Discussion

Due to the fact that the message structures of both methods are different, their computational complexity must be compared not within one block, but over several blocks.

At the rate of 1/3, The difference between the two methods is that in the PB method, 2 codewords are required to transmit k information bits, while in the EBD method, only 1 code word is required to transmit the same number of information bits. Consequently, the computational complexity of the EBD method is about 2 times better than that of the PB method (Figure 14).

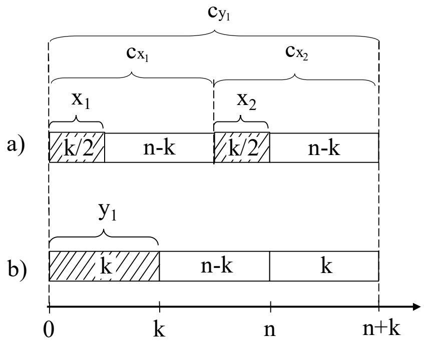

Fig. 14. Code block structures with rate $r = 1/3$ of the PB (a) and EBD (b) methods.

At the rate of 1/4, the computational gain of the EBD method is 3 times better than that of the PB method (Figure 15).

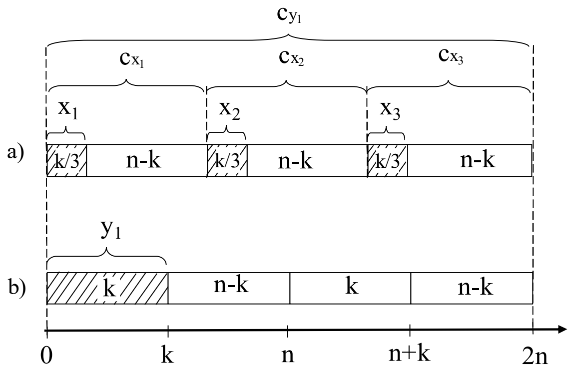

Fig. 15. Code block structures with rate $r = 1/4$ of the PB (a) and EBD (b) methods.

And at the rate of 2/5, the computational gain of the EBD method is 1.5 times better than that of the PB method (Figure 16).

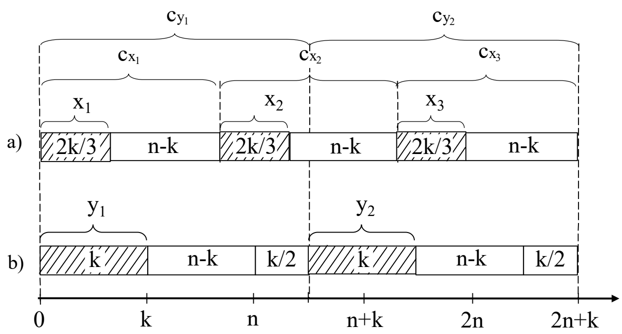

Fig. 16. Code block structures with rate $r = 2/5$ of the PB (a) and EBD (b) methods.

5 Conclusion

In the paper, an "external bit duplication" design method for rate-compatible LDPC codes is described. The proposed EBD method was compared with the conventional PB method. The results show that EBD method outperforms PB method as the code rate decreases. And also computational complexity of the EBD codes is less than computational complexity of the PB codes.

References

1. Gallager, R.: Low-density parity-check codes. In: IRE Transactions on Information Theory, 8,1, 21–28 (1962).
2. Liu Z., Peng, K., Lei, W., Qian, C. and Wang, Z.: Rate-compatible QC-LDPC codes design based on EXIT chart analysis. In: 2012 8th International Wireless Communications and Mobile Computing Conference (IWCMC), 921–926, Limassol (2012).
3. Chu, T., Jiang, X., Hou, J., Hui-Ming, W. and Kong, L.: Construction of multiple-rate LDPC codes using modified PEG. In: 2017 9th International Conference on Wireless Communications and Signal Processing (WCSP), 1–5, Nanjing (2017).
4. Zhou, H., Mitchell, D.G.M., Goertz, N. and Costello, D.J.: Robust Rate-Compatible Punctured LDPC Convolutional Codes. In: IEEE Transactions on Communications, 61, 11, 4428–4439 (2013).
5. Vila Casado, A. I., Weng, W., Valle, S. and Wesel R. D.: Multiple-rate low-density parity-check codes with constant blocklength. In: IEEE Transactions on Communications, 57, 1, 75–83 (2009).
6. Asvadi, R. and Banihashemi, A.H.: A Rate-Compatible Puncturing Scheme for Finite-Length LDPC Codes. In: IEEE Communications Letters, 17, 1, 147–150 (2013).
7. Xiao, M.: Design of finite-length rate-compatible LDPC codes. In: 2015 IEEE International Conference on Communication Software and Networks (ICCSN), 232–235, Chengdu (2015).
8. Park, S.I. et al: Quarter-rate LDPC code and its truncated performance for the cloud transmission. In: 2013 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), 1–3, London (2013).

9. Zhao, P., Wang, Z. and Wang, Q.: Construction of Multiple-Rate QC-LDPC Codes Using Hierarchical Row-Splitting. In: IEEE Communications Letters, 20, 6, 1068-1071 (2016).
10. Wei, Y., Yang, Y., Jiang, M., Chen, W. and Wei, L.: Joint Shortening and Puncturing Optimization for Structured LDPC Codes. In: IEEE Communications Letters, 16, 12, 2060–2063 (2012).