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Ahmed Aftan
The university of Sheffield /Al-Furat Al-Awsat Technical University

Hatim Behairy
General Authority for Military Industries

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Ahmed Aftan
EEE Department, the University of Sheffield, UK. AL-Furat AL-Awsat Technical University, Iraq
e-mail: aoaftan1@sheffield.ac.uk

Mohammed Benaissa
EEE Department, the University of Sheffield,
UK
e-mail: m.benaissa@sheffield.ac.uk

Hatim Behairy
National Electronics Communication and Photonic Centre, King Abdulaziz City for Science and Technology, SA
e-mail: h.behairy@kacst.edu.sa

Abstract— **WiMAX system performance can be significantly improved to achieve excellent error correction performance by utilizing powerful Forward Error Correction Codes. We present a class of parallel concatenated codes called Multiple Parallel Concatenated Gallager Codes (MPCGC) based on using (LDPC) component codes that is used in IEEE 802.16/WiMAX. Computer simulation results confirm that the proposed MPCGCs-WiMAX system shows better performance with an improvement by 0.3 dB gain when compared to a single long LDPC-WiMAX system. Moreover, by using the proposed coding scheme, lower computational complexity can be achieved than the long LDPC code due to multiple smaller lower codes. The advantages of the MPCGCs structure have the potential to be extended to other applications where reduced complexity and flexibility in forward error control coding are required.**

Keywords— ***LDPC, Parallel concatenation, WiMAX 802.16 standard, physical layer*)**

I. INTRODUCTION

Channel coding in digital wireless communication systems is becoming very important. Low density parity check (LDPC) codes have played an important role in error correction for achieving reliable data transmission in a communication systems over a noisy channel because of their performance that is very close to the Shannon limit. LDPCs are based on linear block codes and can be considered as a better error-correcting scheme when compared with other codes. LDPC was first introduced by Gallager five decades ago and then remained largely forgotten for over 33 years [1].

The only distinguished work was by Michael Tanner in 1981 when he introduced diagrammatic representations of the codes subsequent called the Tanner graph [2]. Since the invention of Turbo codes in 1993 [3], researchers started to focus on finding low complexity codes that have a performance approaching the Shannon channel capacity.

Finally, LDPC was rediscovered again by Mackay and Nael in 1995 [4]-[5]. MPCGCs is a new class of parallel concatenated codes designed from parallel concatenation of LDPC codes. It is a concatenation of two or more LDPC codes built in parallel concatenation [6]. A benefit from applying concatenated small codes instead of a single long code is to achieve a low error rate with an overall encoding and decoding complexity that is lower than what is required for a single long LDPC code. The lower complexity can be achieved by encoding and decoding each component code separately. The reason for applying LDPC codes in the well-known turbo code structure is to conquer the fairly complex encoding and decoding of a long code into steps, while maintaining the information flow between the component decoders and minimizing any information loss between the decoding steps [7].

The puncturing of parity check bits is applied to forward error correction (FEC) codes in order to design the best rate compatible (RC) codes to obtain a higher code rate from a low rate mother code [8]. WiMAX (Worldwide Interoperability for Microwave Access) is a telecommunication technology that was first introduced in 2001 [9].

The IEEE 802.16 standard is a fixed broadband Wireless Access. This standard specifies the physical layer and the medium access control layer. Moreover it offers an alternative way to wired broadband standards such as DSL. There are different physical layer specifications due to different applications and frequency bands that are supported by the WiMAX standard [10].

In IEEE 802.16e, a modified iterative decoding method like belief propagation (BP) and Min-Sum Decoding Algorithm (MSA) by partitioning check nodes are applied. This method achieves good improvement in convergence speed while reducing the computational decoding complexity by half [11]. An efficient encoder architecture was presented under the WiMAX standard in [12] suitable for both ½ rate and 2/3B rate where the idea of storing two lines of data in one ROM was applied to achieve the sharing of resources.

A proposed operation of WiMAX quasi cyclic LDPC (QC-LDPC) decoding under high channel quality was proposed to reduce implementation complexity and power consumption. In [13], the reliability of the check nodes was tagged using a check node stopping (CNS) scheme by detecting the magnitudes of the check node belief messages with a threshold.

In this paper, we further explore MPCGCs by evaluating these codes for WiMAX over both AWGN and flat Rayleigh fading channels; we also investigate the puncturing of these codes and any performance improvements.

The rest of this paper is organized as follows. In section II we describe the MPCGC encoder. In section III and IV, we describe the MPCGC-WiMAX physical layer model. Computer simulations for several scenarios to demonstrate the system performance is presented in section V followed by a conclusion in section VI.

II. MPCGC Parallel Encoder

MPCGCs are constructed to gather two or more relatively simple LDPC encoders' component codes. This irregular LDPC combination highly improves the system performance when compared with single long LDPC code. If M represents the number of (two or more) LDPC parallel encoders that are used to encode the information bits K leading to generate a codeword. Each component code can be described by a (K, P) generator matrix. The parallel concatenation method is used to build an overall length N and a codeword rate, R=1/$(M+1)$ code. LDPC codes can be defined in IEEE 802.16 standard that are based on number of essential LDPC codes. Each code of the collection of LDPC codes are systematic linear block code that can be defined by the parity check matrix $H = [h_{i.j}]_{T,P}$ where T represents the number of parity check bits in the code and P represents the number of bits in the code block. Furthermore, the number of information bits are $K = P - T$. Moreover, when the entry $h_{i,j}$ of H matrix is equal 1 a bit node is directly connected to a check node. The H matrix is described by Tanner graph. An irregular LDPC parity check matrix of dimensions (T, P) contains P columns with Hamming weight C_n where 1≤ $C_n \leq T$. Let us consider the dimension of the parity check matrix of LDPC to be (T, P). We have,

$$\lambda(x) = \sum_{i=1}^{T} \lambda_i x^i, \qquad (1)$$

where λ_i represents the fraction of columns of weight i in the matrix. The average weight over all P columns in the matrix can be defined as the Mean Column Weight (MCW) of the LDPC code for H matrix.

$$MCW \cong \sum_{i=1}^{T} i\, \lambda_i. \qquad (2)$$

The MCW is an easy and flexible measure to describe the structure of an MPCGC. The parity check matrices of the component LDPC codes are constructed based on selecting the appropriate value for the MCW [14]. After MPCGC encoder as shown in Fig. 1 the redundant bits will be cancelled or combined by a multiplexer. Thus, the final codeword of MPCGC is $(S, P1, P2, P3)$, where S is the information bits, while $P1, P2$ and $P3$ are the parity bits generated by the first, second and third encoders respectively. The overall complexity of the encoder part can be reduced by breaking the encoding of a long code length into shorter (in this case 3) codes. For the channel, both AWGN and flat fading were considered. The flat fading channel has complex impulse response $h(t)$ and can be represented as:

$$h(t) = h_1(t) + jh_2(t). \qquad (3)$$

Where, $h_1(t)$ and $h_2(t)$ represents the zero mean Gaussian distribution which have Rayleigh distributed as follows:

$$|h(t)| = \sqrt{|h_1(t)|^2 + |h_2(t)|^2}. \qquad (4)$$

The probability density function (pdf) of Rayleigh distribution of equation (4) can be as follows [15]-[16].

$$f(y) = \frac{2y}{\sigma^2} e^{\frac{-2y}{\sigma^2}}, \qquad (5)$$

where σ^2=E $(|h(t)|^2)$.

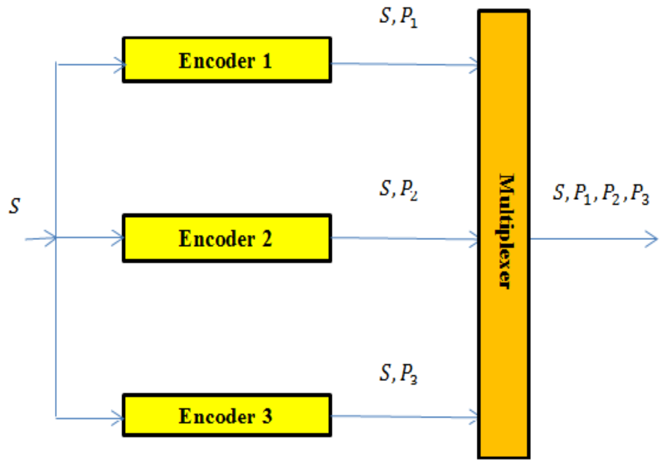

Fig.1 Block diagram of MPCGC encoder.

III. WiMAX Physical Layer Model

The WiMAX physical layer model, as shown in the block diagram in Fig. 2 is based on OFDM [9]. The system model combines MPCGCs with OFDM to implement and improve the WiMAX 802.16 standard. The baseband WiMAX system has four major parts:

1. MPCGCs Encoder/ Decoder for the WiMAX 802.16 standard
2. Interleaving/ Deinterleaving
3. Modulation/ Demodulation
4. OFDM transmitter/Receiver

In this block diagram random data is generated. The proposed MPCGC encoder is designed to provide the advantage of breaking the equivalent long single LDPC code into multiple smaller codes with lower complexity and thus improve the overall system performance. The irregular LDPC codes provide lower encoding/decoding complexity with better performance. The entire parity check matrix is a set from a systematic linear block with different cyclic shifts, which allows reduction in complexity as well. Many improvements can be achieved by blocking short cycles in the parity check bits of H matrix, while optimizing the bipartite graph depending on better MCWs that are found in the structure phase [14].

The decoding process of MPCGCs follows the turbo decoding scenario except not using an interleaver among the component decoders. The process of exchanging information between the component decoders can be defined as super iteration, whereas a local iteration can be defined as a complete one cycle from sum product algorithm decoding. The MPCGC has the flexibility to stop both the local and super iterations at convergence. When the first super iteration is completed, each LDPC component decoder will get its own a priori information from the extrinsic information of all other (M-1) decoders. For all other subsequent super iterations the decoding process continues until all (M) component decoders converge to valid codeword, or reaching the maximum number

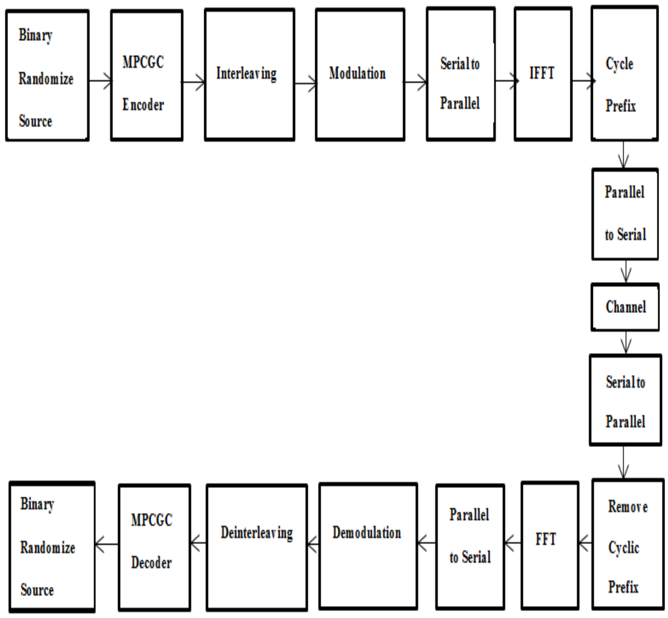

Fig. 2 Block diagram of WiMAX-OFDM physical layer model.

of super iterations. Finally, the output from the highest MCW value component decoder is stated as the best estimation of the transmitted sequence [6]. The process of reordering the data sequence in deterministic format is called interleaving. The interleaving is used by making permutation process to the encoded data. The inverse of interleaving is the deinterleaving at the receiver side, where the original data has been restored from the received sequence. There are four code rates supported in the WiMAX standard 1/2, 2/3, 3/4 and 5/6. Every base of the H matrix has 24 columns. For every code rate, the base model parity check matrix is defined for the largest acceptable code length (N=2304). The expansion factor (z) varies from 24 to 96 with increments 4 and is equal to N/24 for code length N. For instance, the code length 768 has expansion factor z=32. Fig. 3 shows the structure of the parity check matrix H (384,768) of the standard for a single LDPC with code rate 1/2, z=32, N=768 [17].

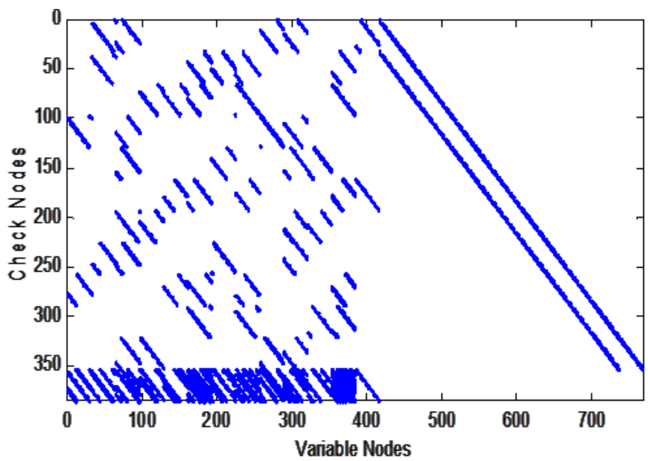

Fig. 3 Structure of the parity check matrix of WiMAX IEEE 802.16 with ½ code rate and 768 code length.

IV. SIMULATION RESULTS AND DISCUSSION

A. BER PERFORMANCE ANAYLYSIS

Firstly, the characteristics of MPCGCs parallel decoding are evaluated separately as shown in Fig. 4 using three LDPC component codes where each component is allowed a maximum of 38 local iterations whereas the overall MPCGCs have 30 super iterations. The BER performance of the MPCGCs is evaluated and is illustrated in Fig. 5. The parameters of the three parallel LDPC components of MPCGC have the same parity check dimensions, H (192,384) with different MCWs: code rate R=1/4, MCW1=1.94, MCW2=2.81, MCW3=1.81 and N=768. Again, the parameters of the equivalent single irregular LDPC code that is used for comparison are: R=1/4, MCW= 3.07, N=768, the MPCGC has a gain of 0.5 dB (at BER 2e-4) when compared to the equivalent single irregular LDPC with the same parameters. Furthermore, the MPCGCs performance outperforms by 1 dB the single short LDPC code with parameters: R=1/2, H (192,384), and MCW=2.8. The MPCGCs show 0.2 dB gain improvements when compared with the result of reported proposed method by Kim et. al using the same parameters [18].

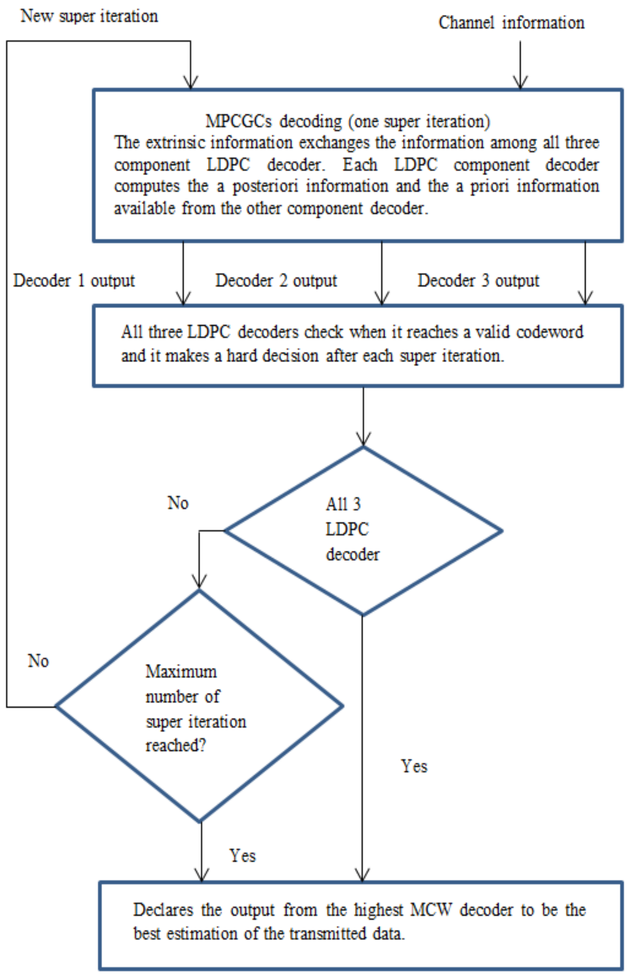

Fig. 4 MPCGCs decoding flow chart.

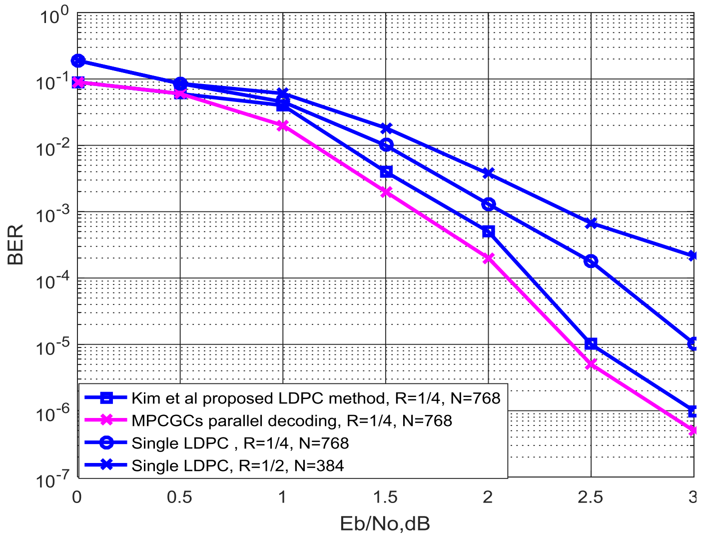

Fig. 5 BER comparison for different LDPC coding model.

Secondly, the performance of a single LDPC-WiMAX baseband transceiver for IEEE 802.16 has been calculated according to the simulation parameters in table (1) with a 256 size FFT [19]. The parameters of the LDPC code used for comparison are R=1/2, N=768 and the WiMAX parity check matrix standard H (384,768). The encoding process of single LDPC-WiMAX is calculated by constructing the generator matrix G, such that $G.H^T$=0 where G is obtained by inversion of the parity check matrix concatenated with the identity matrix of the same size. Then the codewords are calculated by multiplying the message frame with the generator matrix G.

The encoding process of MPCGCs-WiMAX is calculated by concatenated three small random LDPC codes into parallel concatenation with the same parity check matrix dimensions H (192,384) with different MCWs. The decoding process is calculated by parallel concatenation of three LDPC components by using the sum product algorithm. As shown in Fig. 6, the performance is enhanced and its provide 0.3 dB gain improvement at BER 2e-4 when compared with the same parameter of single LDPC-WiMAX according to the reported result by Teodor et. al [17]. Also shown in Fig. 6, that the MPCGCs-WiMAX outperforms single LDPC-OFDM by 0.8 dB at the same parameters. We noticed also at moderate SNR region the packet error rate PER performance of the MPCGCs parallel decoding outperforms single irregular LDPC-OFDM component decoder at the same parameter by achieving gain about 0.4 dB at BER=1e-3 as shown in Fig. 7. To enhance the BER performance of the standard MPCGC-WiMAX application and reduced the decoding complexity. The puncturing performance of the proposed designed MPCGCs were applied to upgrade the code rate to half [8]. The puncturing process is removing some bits from the codeword to change the code rate and reduced the decoding complexity. The decoder has known the location of the punctured bits and set the likelihood ratios (LLR's) of punctured bits as 0.5 then proceeds with decoding operations of the other received bits. After encoding, the codeword N=768 is punctured by a puncturing fraction ϴ=0.5 to be N=384 for enhancing the BER performance at only high Eb/No region as well as reduce the d-

Table 1 WiMAX simulation Parameter.

OFDM, FFT size	**256**
Number of data subcarriers	**192**
Code length	**768**
Modulation scheme	**BPSK [-1,+1]**
Channel model	**AWGN, Flat fading channel**
Cyclic prefix	**¼**
Channel Bandwidth	**2.5 MHz**

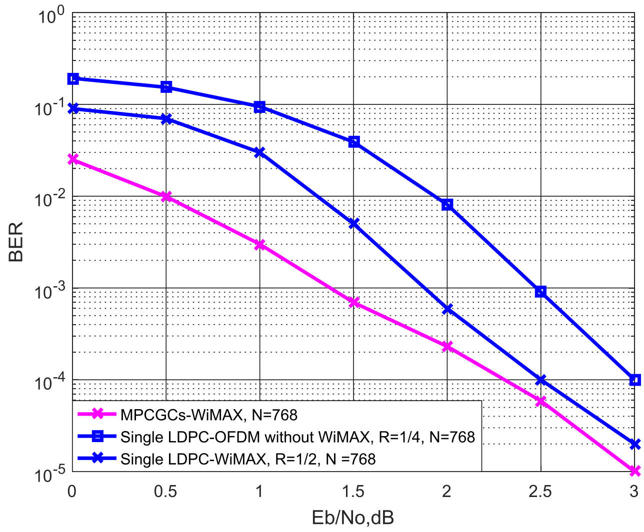

Fig. 6 BER comparison of WiMAX physical layer model.

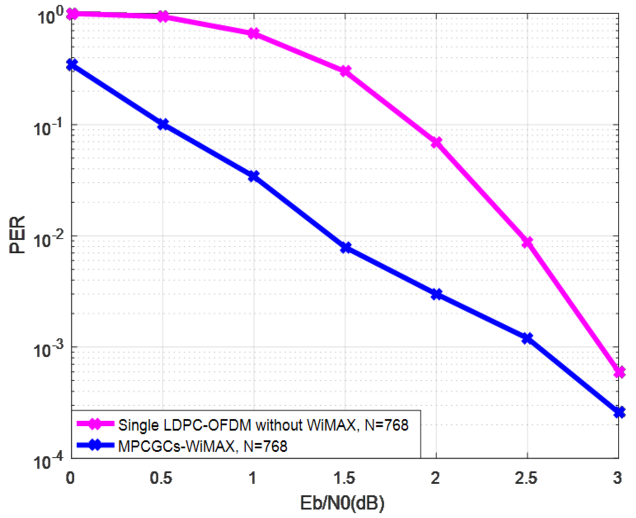

Fig. 7 PER comparison for MPCGC-WiMAX system and single LDPC-OFDM.

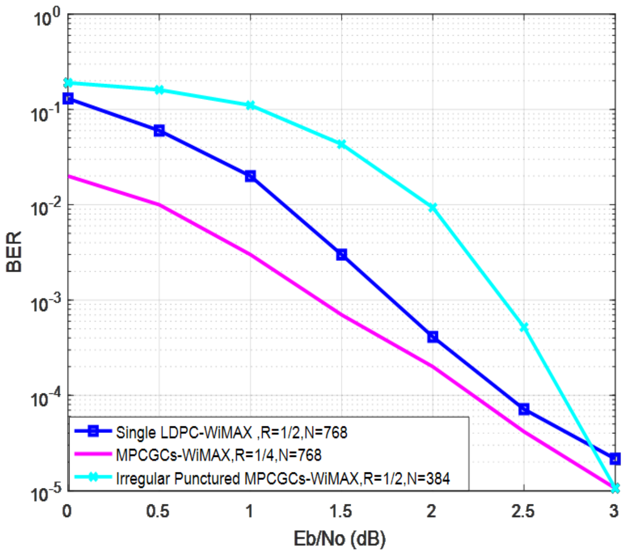

Fig. 8 BER comparison of WiMAX model over AWGN channel.

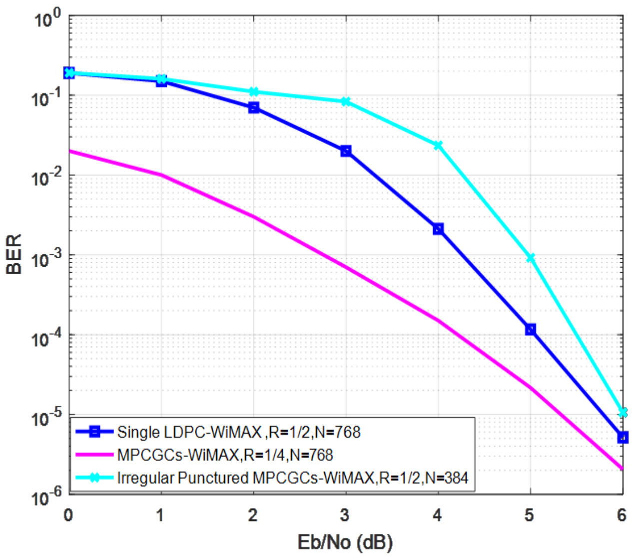

Fig. 9 BER comparison of WiMAX model over flat fading channel.

ecoding complexity and to increase the transmission code rate from ¼ to ½. In the punctured design, we will use the irregular puncturing to get the best performance for the WiMAX system.

The process of puncturing the codeword is done by removing fixed 128 bits from the different locations of the three parity check bits of the codeword.

Fig. 8 shows the different BER comparison of WiMAX application over AWGN channel, the punctured MPCGCs-WiMAX outperforms both single LDPC-WiMAX and MPCGCs-WiMAX without puncturing at high Eb/No region only but provides worse BER at low and medium Eb/No region at the same parameters. Another BER comparison of WiMAX application over flat Rayleigh fading channel as shown in Fig. 9.

B. MPCGC COMPLEXITY ANALYSIS

LDPC complexity for a particular code is proportional with the type of decoder and the density of the parity check matrix. The sum product algorithm has an important advantage that is it is less complex than other decoding algorithms used in turbo codes.

To estimate the complexity of MPCGC, we calculated the average number of local iterations per each LDPC code needed with different E*b*/N0 values [20].

In our case, a MPCGC of three parallel component decoders executes a maximum of 30 super iterations; each component decoder in each super iteration performs a maximum of 38 local iterations at the received data then passes the extrinsic information to the next decoder and so on. The MPCGC decoder generally for each super iteration performs a maximum of (3× 38) local iterations, which are done by 3 LDPC decoders. For the sake of a fair comparison between MPCGC and single conventional LDPC codes, the decoding complexity per iteration can be estimated in terms of the maximum number of edges in the Tanner graph of the code which can be calculated as (NxMCW) for a single LDPC code. Therefore for a MPCGC in each super iteration, the maximum number of edges can be calculated according to,

$$\text{Total edges} = \text{Number of Iterations} \times \sum_{i=1}^{M} N_i\, MCW. \quad (6)$$

On this basis, a preliminary complexity analysis and comparison have been carried out in terms of Eb/No and the results in terms of the maximum number of iterations and edges are illustrated in Fig. 10 and Fig. 11. The results show that the advantages of MPCGC can be exploited without significant additional complexity.

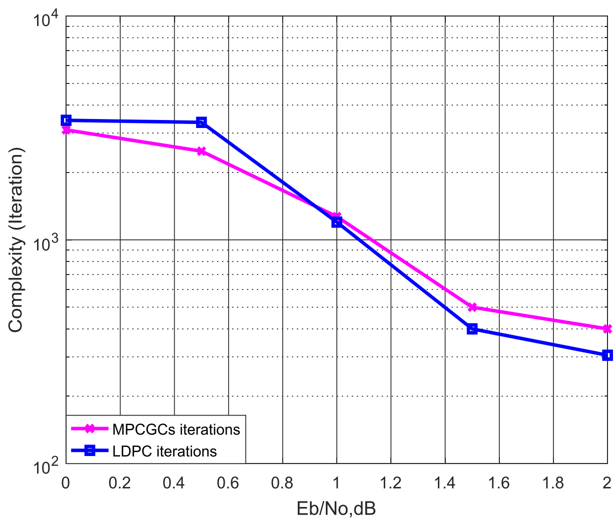

Fig. 10 Complexity and performance comparison between LDPC and MPCGC.

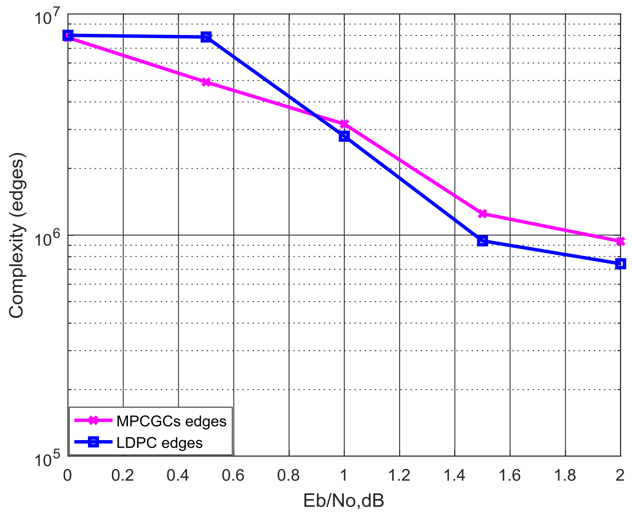

Fig. 11 Complexity and performance comparison between LDPC and MPCGC.

V. CONCLUSION

This paper focused on investigating the deployment of MPCGCs in the IEEE 802.16 standard physical layer system based on the basic modulation scheme, over AWGN transmission and flat Rayleigh fading channel. For the same parameters, the proposed MPCGCs-WiMAX achieves better gain than single-long LDPC based WiMAX. In addition, the MPCGCs scheme shows further advantages when applying irregular puncturing for enhancing the code rate from ¼ to ½ to be compatible with non-puncturing standard WiMAX system. Furthermore, our MPCGCs scheme shows that can be exploited without significant additional decoding complexity than that of the conventional single LDPC.

The MPCGC scheme can be a potential scheme for the channel coding in the WiMAX communication system.

REFERENCES

[1] R. G. Gallager, "Low density parity check codes, Research Monograph series." MIT Press, Cambridge, 1963.

[2] R. Tanner, "A recursive approach to low complexity codes," *IEEE Trans. Inf. Theory*, vol. 27, no. 5, pp. 533–547, 1981.

[3] C. Berrou, A. Glavieux, and P. Thitimajshima, "Near Shannon limit error-correcting coding and decoding: Turbo-codes. 1," in *Communications, 1993. ICC '93 Geneva. Technical Program, Conference Record, IEEE International Conference on*, 1993, vol. 2, pp. 1064–1070 vol.2.

[4] D. J. C. MacKay and R. M. Neal, "Near Shannon limit performance of low density parity check codes," *Electron. Lett.*, vol. 32, no. 18, p. 1645-, 1996.

[5] D. J. C. Mackay, D. J. C. Mackay, R. M. Neal, and R. M. Neal, "Good codes based on very sparse matrices," *Cryptogr. Coding, 5th IMA Conf. (Lecture Notes Comput. Sci. C. Boyd, Ed*, vol. 111, no. 1025, p. 1025pp110-111, 1995.

[6] H. M. Behairy and M. Benaissa, "Multiple Parallel Concatenated Gallager Codes (MPCGC): Code Design and Decoding Techniques," 1995.

[7] H. Behairy and S. C. Chang, "Parallel Concatenated Gallager Codes, In Proc. 5th CDMA Inter. Conf. (CIC2000), pp. 123-127, Seoul, R. O. Korea, Nov.2000.

[8] H. Pishro-Nik and F. Fekri, "Results on punctured low-density parity-check codes and improved iterative decoding techniques," IEEE Transactions on Information Theory, vol. 53, pp. 599–614, Feb. 2007

[9] M. Weiss "WiMAX general information about the standard 802.16." Rohde & Schwartz Application Note, Munich, Germany (2006).

[10] K. ElMahgoub and M. Nafie, "Symbol based log-map in concatenated LDPC-convolutional codes," in *Consumer Communications and Networking Conference (CCNC), 2010 7th IEEE*, 2010, pp. 1–4.

[11] M.-H. Jang, B.-K. Shin, W.-M. Park, J.-S. No, and I.-S. Jeon, "Decoding method of LDPC codes in IEEE 802.16 e standards for improving the convergence speed," *J. Korean Inst. Commun. Inf. Sci.*, vol. 31, no. 12C, pp. 1143–1149, 2006.

[12] X. Wang, F. Hong, T. Ge, Y. Wang, B. Xiao, and N. I. Sarkar, "The Design of LDPC Encoder Based on the WIMAX Standard," *Int. J. Futur. Gener. Commun. Netw.*, vol. 8, no. 4, pp. 25–32, 2015.

[13] Lin, C.H., Huang, T.H., Lin, S.Y. and Lee, Y.H., 2017. Design and Implementation of Operation-Reduced LDPC Decoder Based on a Check Node Stopping Scheme. *Journal of Circuits, Systems and Computers*, *26.02 (2017)*, p.1750028.

[14] H. Behairy and S. C. Chang, "On the Design, Simulation, and Analysis of Parallel Concatenated Gallager Codes, in Proc. 2002 IEEE Int. Conf. Com-(ICC.02), New York, NY, pp. 1850-1854, May 2002.

[15] P. Matthias, "Mobile fading channels: modelling, analysis & simulation." S. l.]= John Wiley, 2002.

[16] M. K. Simon and M.-S. Alouini, *Digital communication over fading channels*, vol. 95. John Wiley & Sons, 2005.

[17] T. B. Iliev, G. V Hristov, P. Z. Zahariev, and M. P. Iliev, "Application and evaluation of the LDPC codes for the next generation communication systems," in *Novel Algorithms and Techniques In Telecommunications, Automation and Industrial Electronics*, Springer, 2008, pp. 532–536.

[18] K. S. Kim, S. H. Lee, Y. H. Kim, and J. Y. Ahn, "Design of binary LDPC code using cyclic shift matrices," *Electron. Lett.*, vol. 40, no. 5, pp. 325–326, 2004.

[19] M. A. Kadhim and W. Ismail, "Implementation of WIMAX IEEE 802.16e Baseband Transceiver on Multi-Core Software Defined Radio Platform," *Int. J. Comput. Theory Eng.*, vol. 2, no. 5, p. 820, 2010.

[20] H. M. Behairy, "Parallel concatenated gallager codes and their applications in CDMA wireless networks", Ph.D. dissertation, George Masson University, 2002.