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Source: **ZTE Corp., ZTE Microelectronics**
Title: **Discussion on LDPC codes for NR**
Agenda item: **8.1.4.1**
Document for: **Discussion/Decision**

1. Introduction

At the 3GPP TSG RAN #71 meeting, the Study Item of “Study on New Radio Access Technology " was approved [1]. And, at 3GPP TSG RAN #84 and #85 meetings, the LDPC code scheme was presented by many companies and was agreed as a candidate channel coding for NR system.

2. 5G Requirements for Channel Coding

In the technical report, several channel coding related KPIs have been proposed for New RAT system, include [12]:

- the target for peak data rate should be 20 Gbps for downlink and 10 Gbps for uplink;
- the target for peak spectral efficiency should be 30 bps/Hz for downlink and 15 bps/Hz for uplink;
- for URLLC the target for user plane latency should be 0.5 ms for UL, and 0.5 ms for DL;
- the target for reliability should be $1\text{-}10^{-5}$ within 1 ms;
- the target for UE battery life should be [15 years].

The major scenarios are eMBB (enhanced Mobile Broadband), mMTC (massive Machine Type Communications) and URLLC (Ultra-Reliable and Low Latency Communications).

In mMTC, the core requirement is to provide massive service connectivity with low energy consumption and low cost. In URLLC, extreme requirements on availability and reliability of transmission are emphasized, which means low error probability and low outage rate are the main targets in this usage scenario. While in eMBB, high system capacity, high data rate, and high spectrum efficiency are the main targets. Obviously, legacy LTE channel coding scheme will face a great challenge to meet various demands of the new RAT.

In last RAN1#85 meeting, some LDPC code schemes were presented [2 - 6] and some basic consensus on LDPC code was agreed. It is generally observed that LDPC has lower complexity and higher throughput with similar or better performance as turbo code. A uniform base matrix with very low code rate (1/5) was shown in [4] and [5] which can support IR-HARQ scheme. In [2], a code rate of 1/3 for LDPC base matrix was presented. Extended methods were mentioned by [3] and [6] to support IR-HARQ. Row-orthogonal property of LDPC codes was presented by [5] for high data throughput.

In this contribution, some considerations for LDPC codes design, as well as the LDPC codes with flexibility of code block sizes, code rates and IR-HARQ are presented.

3. Low Density Parity Check (LDPC) Codes

A LDPC code is defined by a sparse parity check matrix, which can be mapped to a bipartite graph composed of check nodes and variable nodes, as shown in Figure .

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

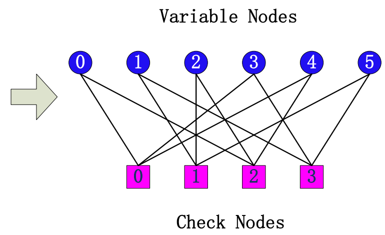
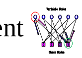


Figure 1 Tanner Graph for LDPC Codes

3.1. QC-LDPC Code

The (Quasi-Cyclic)QC-LDPC code is defined by a base matrix $\mathbf{Hb}$ of size $mb \times nb$, an expanding factor (lift size) Z and a permutation matrix $\mathbf{P}$ of size $Z \times Z$. The size of information bits is $K = kb \times Z$, $kb = nb - mb$, the size of codeword is $N = nb \times Z$, and the code rate is $R = K/N$. If each element  in the base matrix  is replaced by zero sub-block matrix of size $Z \times Z$ or the sub-block matrix $\mathbf{P}^{hb_{ij}}$, the parity check matrix $\mathbf{H}$ of QC-LDPC can be obtained. The base matrix $\mathbf{Hb}$, parity check matrix $\mathbf{H}$ and the permutation matrix $\mathbf{P}$ are shown in Figure 2.

$$
\mathbf{Hb} = \begin{bmatrix} hb_{00} & hb_{01} & \cdots & hb_{0(nb-1)} \\ hb_{10} & hb_{11} & \cdots & hb_{1(nb-1)} \\ \cdots & \cdots & \cdots & \cdots \\ hb_{(mb-1)0} & hb_{(mb-1)1} & \cdots & hb_{(mb-1)(nb-1)} \end{bmatrix}
\qquad
\mathbf{H} = \begin{bmatrix} \mathbf{P}^{hb_{00}} & \mathbf{P}^{hb_{01}} & \cdots & \mathbf{P}^{hb_{0(nb-1)}} \\ \mathbf{P}^{hb_{10}} & \mathbf{P}^{hb_{11}} & \cdots & \mathbf{P}^{hb_{1(nb-1)}} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{P}^{hb_{(mb-1)0}} & \mathbf{P}^{hb_{(mb-1)1}} & \cdots & \mathbf{P}^{hb_{(mb-1)(nb-1)}} \end{bmatrix}
$$

$$
\mathbf{P} = \begin{bmatrix} 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & 1 \\ 1 & 0 & 0 & \cdots & 0 \end{bmatrix}
$$

Figure 2 Base Matrix ($\mathbf{Hb}$), Parity Check Matrix ($\mathbf{H}$) and Permutation Matrix ($\mathbf{P}$) of QC-LDPC Code

Wherein, if $hb_{ij} == -1$ in base matrix, $\mathbf{P}^{hb_{ij}}$ in $\mathbf{H}$ equals a zero matrix of size $Z \times Z$; otherwise, $\mathbf{P}^{hb_{ij}}$ equals a permutation matrix $\mathbf{P}$ to hb_{ij} power. The base matrix ($\mathbf{Hb}$) can be divided into 2 parts: systematic part and parity part which are illustrated in Figure 3. The systematic part includes kb columns (also known as systematic columns) and parity part includes mb columns (also known as parity columns).

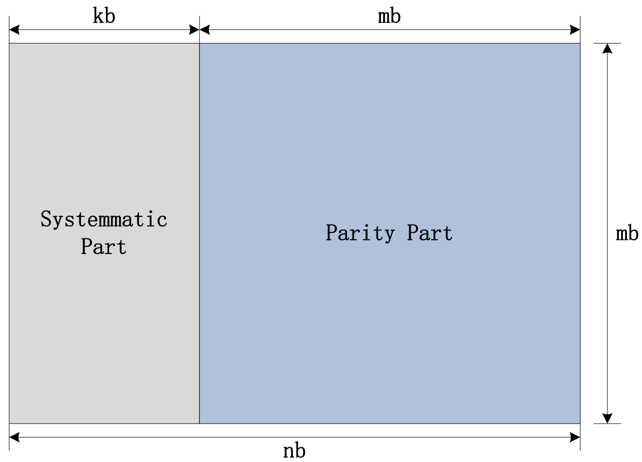


Figure 3 Example of Base Matrix of Systematic Part and Parity Part

QC-LDPC code has been used widely in high-throughput systems, such as IEEE802.11n, IEEE802.16e and IEEE802.11ad. It is observed that, LDPC codes are very suitable for high-throughput and low-latency system. Although IR-HARQ was not supported for these communication specifications, it doesn't mean that LDPC cannot support IR-HARQ.

3.2. LDPC Code Design Considerations

In RAN1 #84bis meeting, the following simulation assumptions for eMBB and URLLC&mMTC are agreed: block size of [100, 400, 1000, 2000, 4000, 6000, 8000, Optional(12K, 16K, 32K, 64K)] & rate of [1/5, 1/3, 2/5, 1/2, 2/3, 3/4, 5/6, 8/9] for eMBB scenario; block size of [20, 40, 100, 200, 600, 100] & rate of [1/12, 1/6, 1/3] for URLLC/mMTC scenario. That means any channel coding scheme candidate must support flexible code block size and code rate. And, incremental redundancy HARQ also needs to be supported.

1. Uniform Base Matrix

Uniform base matrix means that code base matrix is derived from a uniform base matrix for any code block size or code rate. A sub-base matrix of corresponding number of rows and columns is extracted from the uniform base matrix to support different code rates. The expanding factor (lift size) can be changed to support different code block sizes. An example for code rates of R_i and R_j is shown in Figure 4. An example of different expanding factor (lift size) (Z_s and Z_t) is also shown in Figure 4.

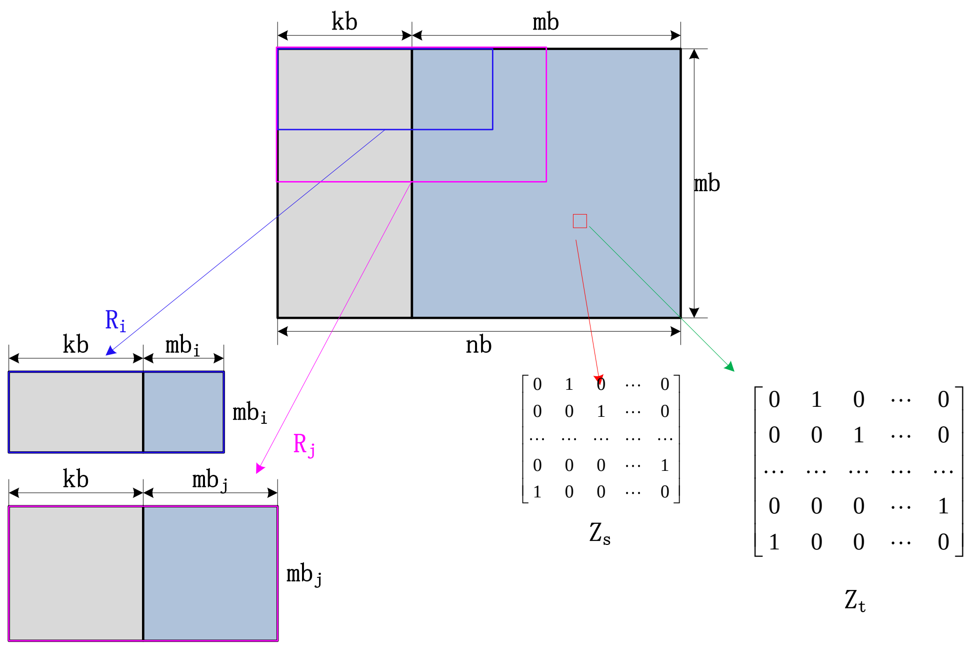


Figure 4 Uniform Base Matrix for different Code Rates (R_j<R_i) and different Code Block Sizes (Z_s<Z_t)

The advantages of uniform base matrix are described as following.

- Simplicity. Designing multiple LDPC base matrices for each code block size and/or code rate, will for sure bring certain extra complexity for LDPC code design.
- Uniform Decoder. Since the uniform base matrix has a fixed number of rows and columns, a codeword for any code rate or retransmission may be decoded with the same decoder.
- Less Storage. Only a uniform base matrix is stored instead of multiple LDPC base matrices for each code block size and/or code rate.
- Easy to achieve flexible code rate. Since the uniform base matrix can support very low initial code rate, the extracting operation for sub-base matrix (puncturing bits off initial codeword) can provide any continuous code rates larger than initial rate of uniform base matrix.
- Easy to achieve IR-HARQ. In IR-HARQ scheme, if the first transmitted data block with high rate is received incorrectly, more coded parity bits will be retransmitted for better performance (coding gain) of lower code rate. Since the initial code for uniform base matrix has many coded parity bits, it is very easy and suitable to support IR-HARQ.

Proposal 1: Uniform base matrix should be considered for LDPC code design.

2. Base Matrix Size

The number of total columns in the base matrix is proportional to systematic columns (kb) and inversely proportional to code rate (R), expressed as nb=kb/R. For example, the number of total columns will be 3 or 5 times as kb and the number of parity columns (or number of rows) will be 2 or 4 times as kb when the code rate (R) equals 1/3 or 1/5. The more columns in a base matrix, the more likely it will have large average row weight (average number of non -1 for all rows). And, the large average row weight will lead to high decoder complexity [7] and high decoding latency in parity node updating [7].

If the number of total columns is larger, the number of total rows will be larger for the same code rate. And, large number of total rows will increase the number of layers in layered decoder which will lead to high decoder latency

[7], such as row-parallel decoder. Although the number of total rows can be reduced by decreasing the systematic columns (kb) for low code rate, it may destroy the unity of base matrix.

The LDPC code information size is proportional to the number of systematic columns (kb) and expanding factor (lift size) (Z), shown as: $K = kb \times Z$. The granularity of code block sizes will be large when kb is a big value for large size of base matrix. Therefore, the small size of base matrix (or small value of kb) is preferred.

Proposal 2: LDPC code base matrix should have small size.

3. Different Code Block Size

As discussed above, flexible LDPC information size can be supported by changing the expanding factor (lift size) (Z). However, the expanding factor (lift size) should not change continuously (the gap equals 1), leading to the granularity of information sizes may be a little large. And, for layered decoder, the expanding factor (lift size) (Z) should equal to an integral multiple of decoder parallelism when the decoder parallelism is less than Z. For example, it equals a prime integral multiple of 2^a, which will have more positive integer factors for parallelism choice, where a is a positive integer. Therefore, both scaling expanding factor (lift size) and shortening encoding (padding operation) are used for flexibility of LDPC code block size.

4. Structure of Parity Part

The parity part in the base matrix can be designed for two structures: low triangular structure and double diagonal structure, as shown in Figure 5. The low triangular structure for base matrix was used in IEEE802.11ad as shown in Figure 5(a) and the double diagonal structure was used in IEEE802.16e and IEEE802.11n as in Figure 5(b). The simulation results of the two kinds of base matrices are shown in Figure 6. We can see that two structures have almost the same performances. The encoder may have lower complexity for low triangular structure. Thus low triangular structure is considered in LDPC uniform base matrix design in this contribution.

Systemmatic Part								Parity Part							
40	-1	38	-1	13	-1	5	-1	18	-1	-1	-1	-1	-1	-1	-1
34	-1	35	-1	27	-1	-1	30	2	1	-1	-1	-1	-1	-1	-1
-1	36	-1	31	-1	7	-1	34	-1	10	41	-1	-1	-1	-1	-1
-1	27	-1	18	-1	12	20	-1	-1	-1	15	6	-1	-1	-1	-1
35	-1	41	-1	40	-1	39	-1	28	-1	-1	3	28	-1	-1	-1
29	-1	0	-1	-1	22	-1	4	-1	28	-1	27	-1	23	-1	-1
-1	31	-1	23	-1	21	-1	20	-1	-1	12	-1	-1	0	13	-1
-1	22	-1	34	31	-1	14	-1	4	-1	-1	-1	13	-1	22	24

(a) 11ad

-1	94	73	-1	-1	-1	-1	-1	55	83	-1	-1	7	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
-1	27	-1	-1	-1	22	79	9	-1	-1	-1	12	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	24	22	81	-1	33	-1	-1	-1	0	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1
61	-1	47	-1	-1	-1	-1	-1	65	25	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1
-1	-1	39	-1	-1	-1	84	-1	-1	41	72	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	46	40	-1	82	-1	-1	-1	79	0	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
-1	-1	95	53	-1	-1	-1	-1	-1	14	18	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1
-1	11	73	-1	-1	-1	2	-1	-1	47	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1
12	-1	-1	-1	83	24	-1	43	-1	-1	-1	51	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1
-1	-1	-1	-1	-1	94	-1	59	-1	-1	70	72	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1
-1	-1	7	65	-1	-1	-1	-1	39	49	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0
43	-1	-1	-1	-1	66	-1	41	-1	-1	-1	26	7	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0

(b) 16e

Figure 5 Base Matrix with Low Triangular Structure and Double Diagonal Structure (Rate of 1/2)

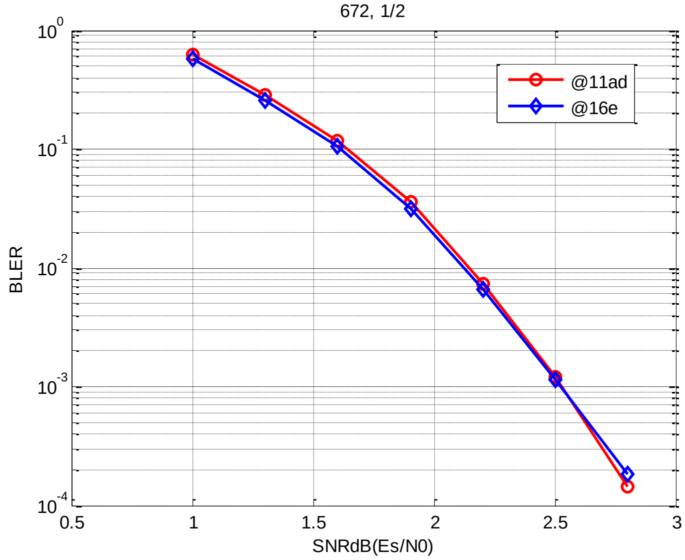


Figure 6 Performance of LDPC in 11ad & 16e for Codeword Length 672 and Rate 1/2

5. Different Code Rates

The initial (lowest) code rate supported by the uniform base matrix is named R0, and the highest code rate supported by the least number of rows & columns by extracting operation is called R1, as shown in Figure 7. There are 3 cases for code rate (R) in Figure 7.

1). R<R0, some bits of extended bits will be transmitted. The extended bits can be obtained by XOR operation or repetition on mother codeword of R0.

2). R0≤R≤R1, the first $\lceil kb/R \rceil$ columns and $\lceil kb/R \rceil - kb$ rows are intercepted from the uniform base matrix to form the code base matrix for code rate (R).

3). R>R1, the codeword is obtained by puncturing from the codeword with rate of R1. That is because better performance can be obtained by puncturing operation.

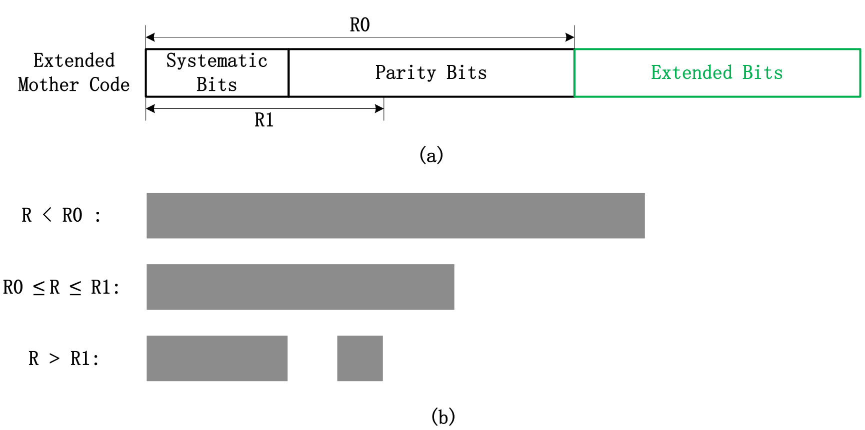


Figure 7 Example for Different Code Rates of LDPC

6. Elements in Base Matrix

In the LDPC decoder, each element (non -1) in the base matrix corresponds to a cyclic shift. The value of element equals ‘0’, which means that there is no need for cyclic shift. Therefore, the more of ‘0’ elements in the base matrix, the lower complexity of LDPC decoder. For any column in base matrix, the first non -1 element is equal to ‘0’. The design may have much greater potential to optimize the decoder in future.

3.3. LDPC Base Matrices

According to the design considerations described above, two uniform base matrices for eMBB and URLLC & mMTC are shown in Figure 8. The parameters of the two base matrices are shown as: nb=24, mb=16, kb=8, R0=1/3, R1=2/3 of 4 rows & 12 columns. In our companion contributions [7] and [8], the performance, complexity and latency are analyzed and evaluated based on these two uniform base matrices. Note this is mainly an illustration of LDPC for simulation and evaluation, other LDPC uniform base matrix design can also be obtained along the principles above.

	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	-1	211	348	96	280	172	180	232	493	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	306	136	490	442	82	232	478	270	-1	208	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
R1=2/3	456	4	282	268	430	150	42	227	-1	-1	242	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	108	268	232	-1	36	-1	358	-1	-1	-1	-1	466	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	206	238	106	-1	-1	441	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	226	210	-1	172	-1	381	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
	6	148	-1	196	88	-1	279	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1
	6	58	-1	-1	-1	352	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1
	4	130	-1	-1	-1	-1	-1	-1	-1	378	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1
	10	358	40	-1	-1	-1	-1	-1	-1	-1	405	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1
	438	30	-1	190	-1	-1	-1	-1	-1	-1	-1	333	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1
	136	70	-1	-1	310	-1	456	-1	-1	-1	-1	-1	203	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1
	358	306	-1	-1	-1	228	-1	194	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1
	382	256	-1	-1	-1	-1	441	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1
R0=1/3	256	2	-1	-1	-1	-1	-1	432	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0

(a)

	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	928	126	306	106	952	352	36	486	860	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	335	52	262	876	690	996	502	742	-1	561	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
R1=2/3	256	726	886	570	630	138	946	44	-1	-1	911	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	910	310	928	-1	40	-1	396	-1	-1	-1	-1	544	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	280	876	418	-1	-1	365	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	28	660	-1	442	-1	814	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
	438	646	-1	772	30	-1	257	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1
	420	768	-1	-1	-1	330	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1
	136	936	-1	-1	-1	-1	-1	-1	-1	71	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1
	148	40	382	-1	-1	-1	-1	-1	-1	-1	268	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1
	486	928	-1	399	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1
	781	400	-1	-1	618	-1	296	-1	-1	-1	-1	-1	756	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1
	290	606	-1	-1	-1	418	-1	748	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1
	502	420	-1	-1	-1	-1	705	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1
R0=1/3	756	100	-1	-1	-1	-1	-1	977	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0

(b)

Figure 8 Uniform Base Matrices. (a) URLLC & mMTC with expanding factor (lift size) of Z_{max}=500. (b) eMBB with expanding factor (lift size) of Z_{max}=1000.

3.4. Flexibility of LDPC Code Rate

Based on the uniform base matrices and the method to obtain flexible LDPC code rate described as above, the operation for how to obtain flexible LDPC code rate (R) can be described as follows.

1). R<1/3, the initial codeword and some of extended bits are transmitted. The extended bits can be obtained by XOR operation or repetition of initial (mother) codeword (R0=1/3). An example of XOR operation can be described as the following. The initial codeword can be expressed as [S P0 P1], wherein, S is the information sequence, P0 and P1 are two sub parity sequence with the same size as the information sequence S. The extended bits sequence is shown as [P2 P3], where in $P2 = S \oplus P0$ and $P3 = S \oplus P1$. Therefore, it can support the lowest code rate of 1/5 by adding the extended bits sequence [P2 P3] to the initial codeword with XOR operation.

2). 1/3≤R≤2/3, the sub-base matrix of first nb' columns and mb' rows is extracted from the uniform base matrix to form the coded base matrix for code rate R. The values of nb' and mb' are calculated respectively as the following.

$$mb' = \lceil 8/R \rceil - 8 \qquad nb' = 8 + mb'$$

3). R> 2/3, the codeword of rate (R) is obtained by puncturing operation from the codeword with rate of 2/3 whose coded base matrix consist of the first 12 columns and first 4 rows of uniform base matrix. Another way to describe the puncturing operation is a rearrangement index for 2/3 codeword (Z bits as a unit) is PV=[1, 2, 3, 4, 5, 6, 7, 8, 12, 10, 9, 11], and the N transmitted bits are selected from the rearranged 2/3 codeword in the order of front to back, wherein, $N = \lceil CBS/R \rceil$.

Observation 1: The LDPC code rates can be very flexible through intercepting from a uniform base matrix or puncturing operations to obtain the same rates as turbo code in LTE system.

Proposal 3: LDPC code design should support flexibility of code rate.

3.5. Flexibility of LDPC Code Block Size

According to the LDPC coding principle, the LDPC information size (K) is determined by the expanding factor (lift size) (z) and systematic columns (kb), shown as: $K = kb \times z$. Therefore, different LDPC code block sizes can be obtained by changing the expanding factor (lift size) (z). If the systematic columns (kb) is fixed, the LDPC information size (K) can equal to an integral multiple of kb by scaling expanding factor (lift size) (z). However, if code block size $CBS \neq K$, some dummy bits may be padded (shorten encoding), whose locations must be known for transmitter & receiver. During the decoding, infinite values are filled in the padding bits' location.

According to the simulation condition for eMBB scenario, the code block size set is [100 400 1000 2000 4000 6000 8000]. The smallest value of expanding factor (lift size) (Z) can be calculated by $Z = \lceil CBS/kb \rceil$, and the expanding factor (lift size) (Z) set is [13 50 125 250 500 750 1000]. Note that, it needs 4 padding bits for the case of CBS=100 (K=104 and Z=13). Because the maximum expanding factor (lift size) of uniform base matrix for eMBB scenario equals 1000, the elements (non -1) in the uniform base matrix need modification when the coded expanding factor (lift size) Z<1000. In our companion contribution [8], the scaling floor operation is used for elements modification, expressed as below.

$$(h_{ij}{}^{b})_{modified} = \begin{cases} -1 & if \quad (h_{ij}{}^{b})_{uniform} == -1 \\ \left\lfloor (h_{ij}{}^{b})_{uniform} \times Z/Z_{\max} \right\rfloor & else \end{cases}$$

wherein, $Z_{\max}$ is the maximum expanding factor (lift size) (=1000), $(h_{ij}{}^{b})_{uniform}$ is the element of *i*th row and *j*th column in uniform base matrix.

In addition to the scaling floor operation mentioned above, a modulus operation can also be used for elements modification, expressed as the following.

$$(h_{ij}{}^{b})_{modified} = \begin{cases} -1 & if \quad (h_{ij}{}^{b})_{uniform} == -1 \\ \mathrm{mod}((h_{ij}{}^{b})_{uniform},\ Z) & else \end{cases}$$

Observation 2: Flexible code block size for LDPC can be achieved by combining the scaling expanding factor (lift size) and padding operation.

Proposal 4: LDPC code design should support flexibility of code block size.

3.6. IR HARQ

For energy-efficient data transmission, it is necessary to support incremental redundancy (IR) for retransmission. For IR HARQ, extra parity bits are retransmitted to get coding gain for lower code rate. In Figure 9, an IR HARQ scheme for LDPC codes is depicted for different retransmissions. In the 1st transmission, the high rate LDPC code is transmitted, and the decoder operates on small size of base matrix. If the decoding fails, the 2nd transmission data is transmitted which allows the decoder to operate on a bigger base matrix with low rate and to achieve successful decoding. If the code rate of retransmission data is less than R0 (mother code rate), some extended bits may be retransmitted. The 1st transmission has the smallest base matrix, whose decoding latency is low and throughput is high. The decoding latency for other retransmissions may increase successively. However, compared with system HARQ latency, the decoding latency of retransmission may be negligible. The normalized throughput performances of HARQ for LDPC and turbo (LTE) are shown in Figure 10.

Observation 3: LDPC can support IR-HARQ and achieve the same normalized throughput as LTE turbo.

Proposal 5: LDPC code design should support IR HARQ.

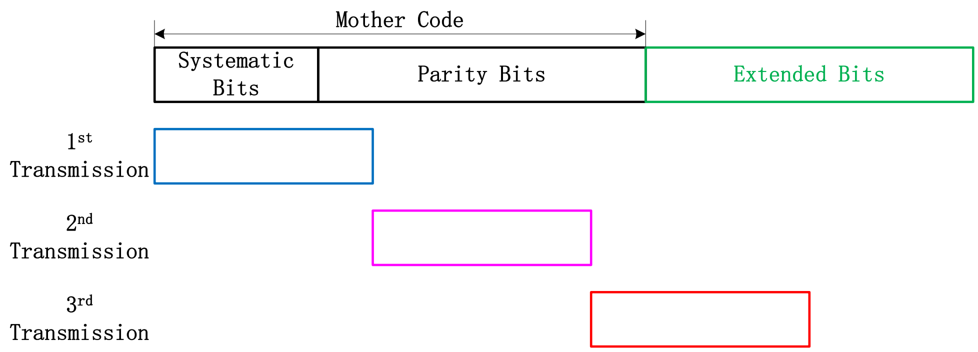


Figure 9 Example of IR-HARQ for LDPC

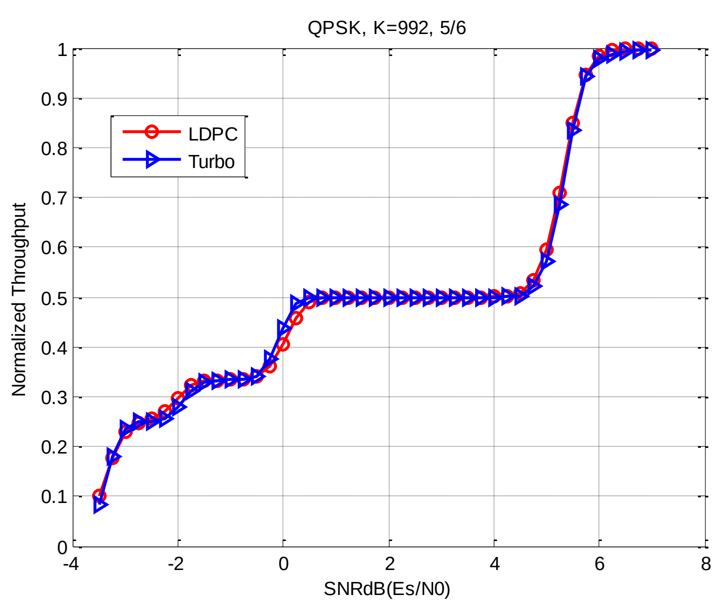


Figure 10 the Throughput of HARQ for LDPC Code and Turbo Code

4. Advantages of LDPC codes

1. Performance. LDPC has almost the same performance as turbo code, or even better than Turbo in some cases [9].

2. Flexibility. LDPC can support flexible code block sizes and code rates by scaling the expanding factor (lift size) and the shorten coding method. Therefore it can fully support all the code block sizes and code rates as LTE turbo code.

3. Throughput. LDPC can achieve a greater throughput than the turbo codes under the same code block size and code rate due to the inherent parallelism of LDPC code. Especially, LDPC codes can get higher throughput in high code rate and big code block size case. The maximum 5G system throughput (20 Gbps) could generally be obtained in high code rate and long code block sizes case, which is very difficult for turbo coding.

4. Latency. LDPC decoder has parallel characteristics, so its decoding speed will be relatively fast, that is, the decoding delay will be very low, which will meet the requirements of URLLC scenario.

5. Complexity. Turbo code's complexity will become bigger in a higher rate, while LDPC code is opposite. LDPC code's complexity will be lower at a high code rate, which means it is more conducive to realize a higher throughput and lower complexity;

6. Power consumption. BLER needs to be below the 10e-5 for URLLC scenarios. To achieve this object, LDPC code just needs a low number of iterations, e.g. normally 1 to 2 times will be enough. However, turbo codes usually need many times iterations. So the power consumption of the LDPC codes is far lower than that of turbo codes.

7. Maturity. LDPC code has already been adopted in IEEE802.16e, IEEE802.11n, IEEE802.11ad, IEEE802.11ac, DVB, microwave communication, optical fiber and so on, and the decoder implementation is very mature.

5. Conclusion

In this contribution, some considerations of LDPC coding schemes for the new RAT are presented. In summary, we have the following proposals and observations:

Proposal 1: Uniform base matrix should be considered for LDPC code design.

Proposal 2: LDPC uniform base matrix should have small size.

Proposal 3: LDPC code design should support flexibility of code rate.

Proposal 4: LDPC code design should support flexibility of code block size.

Proposal 5: LDPC code design should support IR HARQ.

Observation 1: The LDPC code rates can be very flexible through intercepting and puncturing operations to obtain the same rates as turbo code in LTE system.

Observation 2: Flexible code block size for LDPC can be achieved by combining the scaling expanding factor (lift size) and padding operation.

Observation 3: LDPC can support IR-HARQ and achieve the same normalized throughput as LTE turbo.

References

[1]. 3GPP SID in RP-160671.

[2]. 3GPP R1-164278, Consideration on LDPC codes for NR.

[3]. 3GPP R1-164697, LDPC Design Overview.

[4]. 3GPP R1-164007, Flexibility of LDPC - Length, Rate and IR-HARQ.

[5]. 3GPP R1-164813, Design of LDPC code for high throughput.

[6]. 3GPP R1-164183, LDPC code design for NR.

[7]. 3GPP R1-166412, Complexity, throughput and latency analysis on channel coding candidates for NR

[8]. 3GPP R1-166411, Performance evaluation on channel coding candidates for NR

[9]. 3GPP R1-164277, Evaluation on performance and complexity of channel coding for NR

[10]. 3GPP R1-164278, Consideration on LDPC codes for NR

[11]. 3GPP R1-164279, Throughput and latency analysis on New channel coding candidates for NR

[12]. 3GPP TR 38.913 V0.3.0, “Study on Scenarios and Requirements for Next Generation Access Technologies (Release 14)”, 2016-03.

[13]. 3GPP R1-060022, LDPC Codes for E-UTRA, RAN1#44.

[14]. 3GPP R1-060874, Complexity Comparison of LDPC Codes and Turbo Codes.

[15]. Jin Xu, Jun Xu., Structured LDPC Applied in IMT-Advanced System. International Conference on Wireless Communications, Networking & Mobile Computing, 2008:1-4

[16]. 3GPP TSG RAN WG1 #44,R1-060499, Structured LDPC coding with rate matching. Denver, USA, February 13-17, 2006

[17]. Robert Xu, David Yuan, Li Zeng. High Girth LDPC Coding for OFDMA PHY. IEEE 802.16 Broadband Wireless Access Working Group. IEEE C802.16e-05/031