Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Draft text for LDPC coding scheme for OFDMA**
Date Submitted	**2004-04-26**
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Re:	802.16REVd Sponsor Ballot Recirculation comment
Abstract	This contribution describes the LDPC coding scheme
Purpose	Proposal to include the LDPC FEC scheme as an option for OFDMA
Notice	
Release	
Patent Policy and Procedures	

Following is text intended for 802.16RevD. The equations, figures, tables and appendix will need to be numbered appropriately for the full document.

8.4.9.2.4 Low Density Parity Check Code (optional)

8.4.9.2.4.1 Code Description

The fundamental LDPC code is a systematic linear block code with (n,k) = (2000, 1600), eighteen edges per check node, and Rate = 4/5. There is only one code definition for the system and lower code rates may be achieved by shortening the basic code. Varying data field lengths are accommodated by shortening the basic code, concatenating codewords, and a combination of shortening and concatenation.

8.4.9.2.4.2 LDPC encoding

In a general analysis an (n,k) LDPC code has k information bits and n coded bits with code rate r = k/n. The parity-check matrix H is of dimension (n-k)×n, and it defines a set of equations

Equation 1 $v \cdot H^t = 0$

for all codewords v.

An example parity-check matrix is shown below for an LDPC code (9,3) as well as the expanded parity-check equations

$$H = \begin{bmatrix} 1 & & & 1 & & & 1 & & \\ & 1 & & & 1 & & & 1 & \\ & & 1 & & & 1 & & & 1 \\ 1 & & & & 1 & & & & 1 \\ & 1 & & & & 1 & 1 & & \\ & & 1 & 1 & & & & 1 & \end{bmatrix} \Longleftrightarrow \begin{cases} v_1 + v_4 + v_7 = 0 \\ v_2 + v_5 + v_8 = 0 \\ v_3 + v_6 + v_9 = 0 \\ v_1 + v_5 + v_9 = 0 \\ v_2 + v_6 + v_7 = 0 \\ v_3 + v_4 + v_8 = 0 \end{cases} .$$

LDPC codes are encoded via a generator matrix G. For a given information vector u, the corresponding codeword v is encoded via

Equation 2 $v = u \cdot G$

From (1), we have $u \cdot G \cdot H^t = 0$. Since u is an arbitrary vector, we have $u \cdot G \cdot H^t = 0$

$$G \cdot H^t = 0$$

For a given parity-check matrix H which defines the code, there are 2^k different G that satisfy (2) provided that H's rank is n-k. One of these generator matrices has the format

Equation 3

$$G = [I_{k \times k} \mid P_{k \times (n-k)}]$$

and is denoted a systematic encoder since the first k code bits are identical with the information bits.

Denote H=[H1|H2], where H1 and H2 have dimensions (n-k)*k and (n-k)*(n-k), respectively. Then according to (2), (assume H2 is non-singular), we have

Equation 4

$$I \cdot H_1^{\,t} + P \cdot H_2^{\,t} = 0 \Rightarrow P = H_1^{\,t} H_2^{\,-t}$$

and the codeword is in the format of

Equation 5

$$\bar{v} = \bar{u} \cdot G = [\bar{u} \mid \bar{u}P] = [\bar{u} \mid \bar{u}H_1^{\,t} H_2^{\,-t}]$$

For some LDPC codes, high encoding complexity arises from the high density of H_2^{-t} in (5). However, for this code H_2 is simply $f(D) = 1 + D$, and hence H_2^{-t} can be implemented by a differential encoder. One possible encoding process is then

Equation 6

$$v = [u \mid uH_1^{\,t} H_2^{\,-t}] = \left[u \mid uH_1^{\,t} \frac{1}{1+D} \right]$$

and is illustrated in Figure 1.

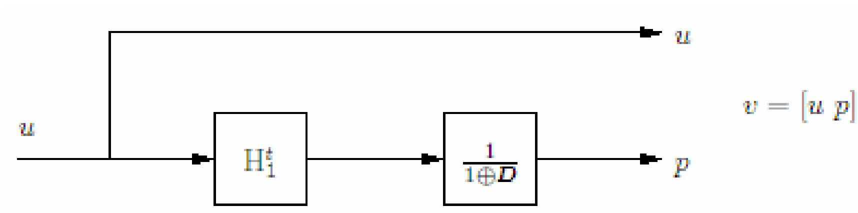

Figure 1. Block Diagram of one possible encoder architecture for specified LDPC code.

For the described code H_1 is low-density, with a uniform column weight of four. A detailed description of the H matrix of the code is contained in the LDPC Code Definition Appendix. The code is fully described by the definition of the H matrix as indicated in the appendix.

8.4.9.2.4.3 Rate Adjustment

The code is rate flexible in that it can be easily shortened to reduce the overall rate, R, of the code. By “shortening” of the codewords we mean reducing the length of the systematic portion of the codeword by stuffing zeroes in the unused portion, encoding, and transmitting the systematic information and parity bits, but not the stuffed zeroes. Table 1 shows the parameters for shortening the code to the desired code rates.

R Code Rate	N_{cw} (bits)	N_i (bits)	N_i (bytes)
R = 4/5	2000	1600	200
R = ¾	1600	1200	150
R =2/3	1200	800	100
R =1/2	800	400	50
R = 1/3	600	200	25

Table 1. Parameters for code rate adjustment using code shortening. For each rate shown, N_{cw} is the length of the codeword, and N_i is the length of the information field. The R = 1/3 code is not used as a basic code rate but represents the lowest code rate realized in a codeword using the algorithm in the Packet Encoding section.

8.4.9.2.4.4 Packet Encoding

Since transported data packets can be any size from typically about 40 bytes up to 12000 bytes and larger, the system must be able to encode variable length packets in a consistent manner. This consistency is required to ensure that the receiver always knows how to reconstruct the information field from the encoded transmitted data.

Each packet is encoded as an entity. In other words, the data boundary of a packet is respected by the encoder. Headers are encoded using the Viterbi decoder at R = ½ and BPSK modulation.

The length of the packet that is to be encoded is all that is needed to encode or decode the packet using the following rules:

1. If Length <= N_i bits, then shorten the code as necessary to the size of the packet.
2. If Length > N_i bits and <= 2 N_i bits, divide the data field in half and encode with two LDPC codewords that have been shortened equally. If the total number of bytes is odd, the even-length portion of the field goes in the first codeword (corresponding to the first (beginning) portion of the data).
3. If Length > 2 N_i bits, then compute N_r = modulo(Length, N_i) (in bits). If N_r is less than or equal to $N_i/2$ bits, encode the first Length – ($N_r + N_i$) bits using full-length, unshortened codewords, and encode the remaining N_r+N_i bits using rule #2. If N_r is greater than $N_i/2$ bits, encode the first Length – N_r bits using full-length, unshortened codewords and encode the remaining N_r bits as in rule #1.

The intent of the above rule set is to provide a means for data transmission without the need for additional information beyond the packet field length. This scheme does so with a simple rule set that reduces the rate of the last codewords in order to reduce the number of iterations (and therefore the latency) that must be performed on the last portion of the data. By “shortening” of the codewords we mean reducing the length of the systematic portion of the codeword by stuffing zeroes in the unused portion, encoding, and transmitting the systematic information and parity bits, but not the stuffed zeroes. The length and position of the shortened codewords and erased bits are deterministic when the above rules are followed.

For all packets the codeword bits can be indexed using the corresponding column indices of the H matrix. Using this convention the systematic codeword bits comprise the leftmost bits starting at bit location zero, and fill the codeword to bit 1599. The remaining four hundred bits of the codeword, from indices 1600 to 1999 are the parity bits. The codeword systematic bits are filled in an order consistent with the indices, so that the first bits of the packet fill the codeword from the lowest indices linearly to the highest indices. The codeword is then transmitted in a linear fashion starting from the lowest indices so that the systematic bits are transmitted first, followed by the parity bits. For shortened codewords the zeros are padded in the low order bits, so that the final codeword starting at the lowest indices contains first zero-padded bits and then the systematic data bits followed by the parity bits.

Appendix (normative) LDPC Code Definition

A full definition of an LDPC code can be accomplished through identification of the locations of the "edges" between the variable nodes (codeword bits) and check nodes (parity relationships). Figure 2 shows a Tanner graph of an example LDPC code, depicting the arrangement of the check nodes, variable nodes, and the "edges" connecting them.

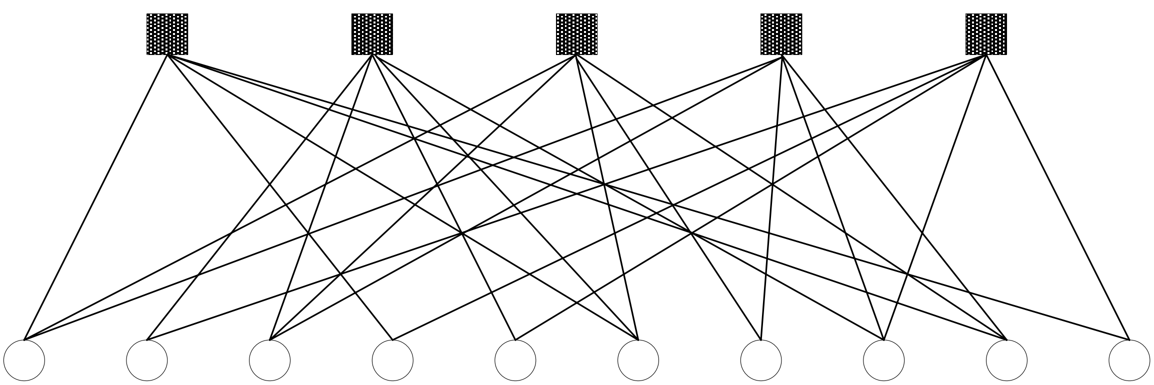

Figure 2. This is an example Tanner graph of an LDPC code, showing the check nodes, variable nodes, and edges. The codeword is made up of the bits represented by the variable nodes. In this case the codeword has ten bits.

Each check node represents a parity relationship between the codeword bits represented by the variable nodes connected to it by the edges. The number of edges connected to a check node is the "degree" of the check node, and the number of edges connected to a variable node is the "degree" of the variable node. For the specified code all check nodes are of degree eighteen, all variable nodes related to the systematic information bits are of degree four, and all variable nodes corresponding to parity bits are of degree two except for the last, which is of degree one.

Check Nodes

Since the organization of the edges in LDPCs appears random, the edge locations must be explicitly defined by means of a list. A straightforward means of describing the code by means of such a list follows.

The matrix H = [H1 H2] comprises a regular matrix H1 with constant column weight 4 and a weight-2 lower-triangular-inverse matrix H2 for efficient encoding purposes.

This LDPC code list file contains three parts to describe the parity-check matrix H (all the 1's):

- matrix size (column row)
- column weights (number of 1's) of each column
- locations of 1's in each column

It should be noted that the convention for the indices is zero-based, with the index of the first element of each column being zero.

An example for a (9,3) code:

H matrix:

```
1 0 0 1 0 0 1 0 0
0 1 0 0 1 0 0 1 0
0 0 1 0 0 1 0 0 1
1 0 0 0 0 1 0 1 0
0 1 0 1 0 0 0 0 1
0 0 1 0 1 0 1 0 0
```

list file:

```
9 6
2 2 2 2 2 2 2 2 2
0 3
1 4
2 5
0 4
1 5
2 3
0 5
1 3
2 4
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Following the above example, the list file for the (2000, 1600) LDPC code appears below.

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2000 400

4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
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4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
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4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
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4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
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143 225 316 323
92 140 191 358
69 315 329 343
6 121 205 284
58 66 254 337
1 47 178 395
129 151 212 228
66 146 243 265
22 140 157 180
120 208 313 321
290 350 370 382
56 94 184 215
84 119 337 344
2 156 244 398
9 106 200 336
22 37 150 270
3 110 326 367
235 276 290 335
82 187 193 297
43 183 297 379
194 239 243 293
90 144 228 350
170 206 321 395
72 138 254 300
25 196 201 279
56 59 362 379

28 121 170 277
61 273 351 386
71 76 232 328
62 109 190 201
111 162 190 227
189 272 288 302
14 49 147 334
33 53 213 238
53 219 368 379
126 149 188 339
108 118 182 393
0 37 160 295
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11 20 229 397
77 86 212 250
79 193 262 336
43 104 125 376
55 114 134 293
240 283 299 333
0 24 57 100
46 84 322 341
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93 174 213 231
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47 52 339 346

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26 54 170 197
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44 53 124 323
0 113 315 358
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37 170 209 342
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18 23 31 373
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173 245 356 376
57 230 240 314
1 89 153 166
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12 291 311 348
34 220 258 282
52 58 109 379
116 248 337 369
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42 96 318 361
32 176 312 361
69 258 310 389
1 84 182 300
45 124 161 396
15 76 99 101
62 248 354 375
78 258 262 311
181 265 364 368
60 168 227 254
162 231 270 377
14 102 139 158
28 79 155 318
28 40 63 236
163 181 258 279
158 176 273 334
80 236 256 380
74 156 214 358
176 229 251 283
19 104 114 162
141 284 291 358
77 123 157 361
141 154 215 338
55 294 296 298
80 109 272 364
43 206 287 363
81 175 206 261
31 94 275 317
10 123 141 279
44 64 157 270
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19 185 312 389
211 271 277 291
19 148 155 324
24 94 124 314
3 85 193 349
68 175 202 253
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21 224 249 398
113 122 206 327
7 10 156 245
140 182 192 235
161 291 324 387
31 232 237 350
30 184 235 387
136 226 269 327
4 93 136 167
47 148 309 348
73 225 252 290
44 213 361 386
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117 188 340 346
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43 141 175 329
0 68 170 262
25 36 153 309
57 62 273 323
7 19 75 264
21 254 259 366
8 97 156 172
9 185 313 330
55 219 253 393
86 120 185 233
41 136 191 242
194 265 303 393
256 285 310 399
103 247 275 378
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98 196 217 328
177 267 306 350
82 299 320 395
139 251 364 381
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45 144 185 383
173 310 329 362
15 165 305 348
27 66 85 182
47 235 238 246
230 276 293 367
118 150 267 324
68 82 309 398
72 154 226 231
76 135 151 384
39 48 80 309
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88 136 196 321
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57 123 148 368
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16 70 242 338
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159 246 248 365
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50 287 294 327
149 259 356 367
3 12 178 309
63 92 166 368
97 190 199 363
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91 147 294 325
14 27 48 222
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10 50 357 393
35 89 248 252
6 55 319 345
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25 90 138 390
81 113 265 382
88 142 210 283
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2 195 268 328
117 240 257 374
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111 127 157 330
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230 245 277 352
49 202 350 381
34 56 167 242
36 58 61 83
107 110 133 251
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16 71 175 397
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177 308 371 387
89 122 207 362
3 166 190 305

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34 37 293 301
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38 75 137 166
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73 83 105 136
69 134 200 366
179 324 366 386
72 82 188 192
100 120 189 375
244 252 318 329
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280 282 288 365
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38 196 330 369
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2 30 165 366
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133 153 273 383
152 174 269 355
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194 298 317 331
22 112 139 222
147 152 221 365
20 48 130 353
58 100 125 172
79 181 242 313
174 254 304 321
70 129 283 385
18 79 296 345
14 25 34 52
31 88 212 226
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27 206 209 324
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181 190 288 379
38 73 249 368
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144 186 297 343
152 177 233 237
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103 165 177 358
53 217 342 383
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5 96 155 354
7 61 214 237
90 241 261 367
39 161 202 206
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95 145 231 297
70 110 225 313
50 112 166 302
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90 264 269 280
22 132 258 368
65 124 129 325
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109 233 250 302
8 33 80 318
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9 141 229 306
0 114 219 300
242 289 318 335
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65 80 99 167
269 296 303 356
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86 195 293 391
140 193 245 321
88 150 183 380
230 253 315 373
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17 79 261 286
94 293 302 397
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41 107 187 298
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1 16 272 296
107 203 283 322
77 245 266 390
29 166 345 364
61 229 356 361
70 105 229 250
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