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Abstract	This contribution describes the LDPC coding scheme	
Purpose	Proposal to include the LDPC FEC scheme as an option for OFDMA	
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LDPC code for OFDMA

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Introduction

This contribution proposes LDPC as an optional coding scheme for inclusion in OFDMA PHY description in the 802.16REVd D4 draft.

Code Description

The fundamental 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.

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 $(n-k) \times n$, and it defines a set of equations

$$\text{Equation 1} \quad v \cdot H^t = 0$$

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

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

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

$$\text{Equation 2} \quad v = u \cdot G$$

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 $H=[H_1|H_2]$, where H_1 and H_2 have dimensions $(n-k) \times k$ and $(n-k) \times (n-k)$, respectively. Then according to (2), (assume H_2 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. The 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.

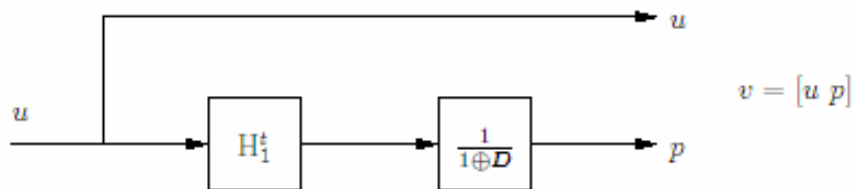


Figure 1. Block Diagram of encoder for specified LDPC code.

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 appendix.

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
$R = 3/4$	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.

Packet Encoding

Since transported data packets can be any size from a minimum of about 64 bytes (e.g., an ACK with CRC), 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 single MSDU covered by a single CRC checksum is encoded as an FEC entity. In other words, the data boundary of an MSDU is respected by the encoder. PLCP headers are encoded using the Viterbi decoder at $R = 1/2$ and BPSK modulation.

The MSDU length field indicated in the PLCP header is all that is needed to encode or decode the MSDU using the following rules:

1. If $\text{Length} \leq N_i$ bits, then shorten the code as necessary to the size of the MSDU.
2. If $\text{Length} > N_i$ bits and $\leq 2 N_i$ 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 $\text{Length} > 2 N_i$ bits, then compute $N_r = \text{modulo}(\text{Length}, N_i)$ (in bits). If N_r is less than or equal to $N_i/2$ bits, encode the first $\text{Length} - (N_r + N_i)$ 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 $\text{Length} - N_r$ 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 MSDU 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.

Appendix

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.

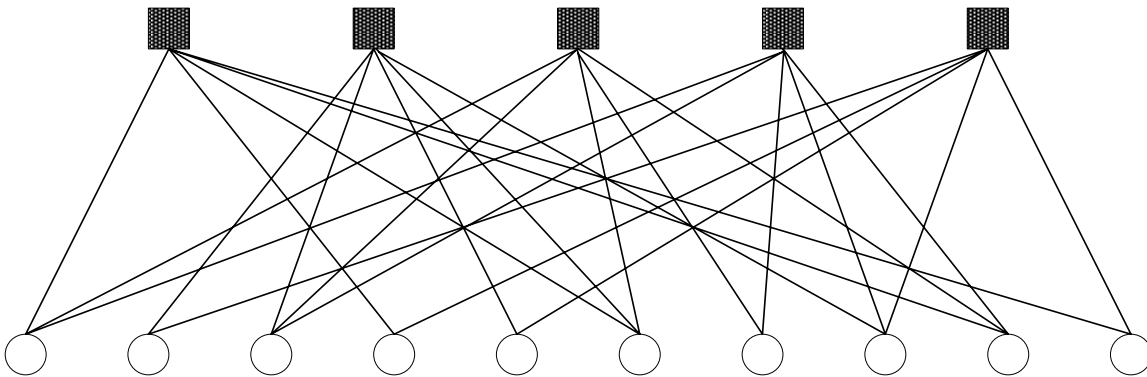


Figure 2. This is an example Tanner graph of an LDPC code, showing the check nodes, variable nodes, and edges. The codeword is made up of the bits represented by the variable nodes. In this case the codeword has ten bits.

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
158 200 335 356
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
5 43 45 221
29 217 274 301
81 93 116 278
93 174 213 231
64 201 251 385
76 134 278 370
71 93 182 398
38 174 250 377
19 116 357 372
81 91 164 307
180 186 241 251
239 254 331 342
107 149 250 295
73 221 295 362
75 97 242 279
32 197 244 313
245 248 276 296
59 230 322 347
17 246 291 364
125 157 227 390
122 205 279 348
61 298 340 380
12 31 256 328
119 163 178 217
61 129 185 200
34 38 104 295
119 289 349 377
50 314 322 367
28 48 248 382
32 41 128 201
91 115 220 368
45 151 196 265
152 190 198 317
157 212 242 275

2 40 249 283
195 280 299 345
142 151 220 395
70 121 252 382
52 244 279 297
22 131 256 349
47 52 339 346
50 288 342 388
26 87 247 283
67 127 132 136
146 264 321 323
210 275 319 346
57 160 252 261
26 54 170 197
120 218 229 341
44 53 124 323
0 113 315 358
110 144 246 298
89 91 99 346
21 32 216 393
37 170 209 342
49 58 357 399
18 23 31 373
159 172 195 366
213 335 337 378
1 103 159 277
96 159 209 387
102 165 234 378
173 245 356 376
57 230 240 314
1 89 153 166
25 32 264 342
265 276 321 324
57 211 274 360
12 291 311 348
34 220 258 282
52 58 109 379
116 248 337 369
87 146 183 278
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
160 243 290 373
39 217 262 324
19 185 312 389
211 271 277 291
19 148 155 324
24 94 124 314
3 85 193 349
68 175 202 253
139 160 337 377
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
79 319 361 381
74 251 339 356
100 105 246 293
68 101 191 285
32 103 323 355
122 188 228 305
6 77 291 397
70 76 259 276
72 270 335 348
93 147 255 312
92 112 259 388
9 18 61 308
3 137 139 257
165 217 345 354
78 134 263 280
186 213 227 303
68 194 294 346
35 225 284 312
117 188 340 346
258 299 306 331
83 194 207 349
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
115 218 225 285
98 196 217 328
177 267 306 350
82 299 320 395
139 251 364 381
42 118 178 194
73 100 198 286
68 249 292 376
13 216 221 256
127 138 177 398
20 69 239 264
3 126 132 163
66 88 169 271
88 197 201 387
1 51 135 149
257 294 331 356
204 260 288 294
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
0 178 305 353
88 136 196 321
37 95 222 300
23 343 358 369
195 252 303 349
9 81 102 317
20 219 285 316
219 281 304 354
33 121 319 351
21 157 191 260
0 88 303 307
13 23 62 268
13 173 279 320
117 189 253 392
32 40 57 350
57 123 148 368
18 96 164 326
84 103 107 359
92 338 350 355
16 70 242 338
20 74 141 179
159 246 248 365
207 292 387 399
38 148 303 347
68 113 296 389
12 257 286 325
50 287 294 327
149 259 356 367
3 12 178 309
63 92 166 368
97 190 199 363
13 86 92 308
132 141 221 322

213 257 348 396
91 147 294 325
14 27 48 222
11 81 110 360
10 50 357 393
35 89 248 252
6 55 319 345
107 116 223 271
168 240 261 384
54 204 295 351
3 51 146 299
74 184 307 361
9 202 272 387
106 198 281 329
36 105 225 236
90 139 183 299
152 160 292 354
11 115 227 236
152 202 211 373
4 173 346 374
132 197 238 279
16 94 150 222
241 344 375 386
31 121 161 231
9 33 197 350
87 197 233 312
100 111 129 368
184 278 289 346
76 177 227 356
11 132 246 314
46 93 103 309
20 33 64 196
111 134 194 204
76 116 140 238
189 298 326 381
235 317 320 333
127 301 348 376
51 286 309 377
17 70 139 187
54 180 184 344
85 311 318 327
263 312 364 369
97 149 198 336
31 141 151 285
72 163 187 311
24 54 249 297
64 143 322 360
53 73 122 256
100 138 214 226
265 348 373 378
42 62 113 174
29 313 349 358
154 179 217 268
164 289 380 392
109 165 236 312
92 141 193 238
190 243 267 275
95 143 203 393
130 213 264 308
102 133 217 226
69 88 116 295
108 217 273 322

26 287 306 343
8 18 136 152
110 240 245 334
225 255 278 310
63 168 170 303
8 17 255 314
28 92 98 200
112 201 244 392
134 216 344 383
21 97 115 396
28 69 120 380
34 259 267 314
55 72 87 223
43 180 185 252
23 113 133 277
258 285 347 350
246 253 318 399
12 78 90 369
17 93 96 102
109 162 318 360
22 83 151 290
141 191 240 266
25 90 138 390
81 113 265 382
88 142 210 283
10 40 43 140
2 195 268 328
117 240 257 374
298 332 350 365
60 122 240 313
157 215 274 397
11 41 164 274
67 76 92 104
19 192 305 344
23 35 125 224
152 163 352 385
40 161 165 329
113 215 245 378
80 168 262 382
81 136 165 239
2 42 248 323
111 127 157 330
79 125 239 341
147 172 187 397
230 245 277 352
49 202 350 381
34 56 167 242
36 58 61 83
107 110 133 251
100 245 295 330
16 71 175 397
106 206 229 236
177 308 371 387
89 122 207 362
3 166 190 305

155 171 289 336
34 37 293 301
143 189 255 338
38 75 137 166
62 92 124 366
73 83 105 136

69 134 200 366
179 324 366 386
72 82 188 192
100 120 189 375
244 252 318 329
3 105 116 203
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38 196 330 369
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210 271 330 334
60 109 199 348
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119 236 323 383
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152 174 269 355
107 193 210 320
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181 190 288 379
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7 61 214 237
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5 114 230 309
122 189 204 251
74 151 203 218
69 270 288 359
22 49 291 383
80 90 174 249
182 310 314 318
115 254 336 399
42 63 135 343
46 232 385 391
24 27 171 183
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158 246 275 352
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79 107 201 351
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16 203 207 237
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15 93 128 250
94 261 312 341
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8 166 301 397
11 47 141 184
7 112 256 377
108 300 310 312
208 218 364 378
53 114 278 291
131 138 201 365
225 279 371 378
122 275 376 395
169 217 239 357
18 65 128 288
6 62 86 198
37 80 119 211
0 46 139 339
0 30 216 306
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78 343 373 377
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90 107 293 370
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66 97 212 320
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164 197 311 398
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160 237 274 285
173 248 262 348
52 65 218 351
135 140 253 366

5 81 176 260
58 215 326 364
76 87 102 315
98 131 259 332
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0 122 269 346
38 162 311 373
143 313 329 340
80 260 316 348
44 158 220 292
117 241 295 363
187 321 355 378
167 226 281 351
0 200 309 384
36 171 193 328
107 178 228 240
80 146 156 375
75 90 290 312
20 55 131 215
99 127 231 344
156 176 301 313
41 146 247 290
49 52 61 76
24 74 310 326
56 196 212 332
76 205 335 385
75 101 209 349
28 172 242 294
18 71 267 297
84 115 233 384
63 139 216 325
23 64 310 348
63 130 188 352
23 45 160 165
42 114 382 399
25 207 339 365
16 334 374 398
86 251 274 277
157 166 297 316
171 200 230 265
34 107 325 364
71 220 227 330
177 263 277 344
75 138 262 293
189 300 366 377
147 175 296 320
2 51 145 208
126 271 310 351
144 197 277 360
28 35 115 289
54 108 270 279
23 82 144 396
78 93 95 275
145 169 211 278
29 163 300 320
33 147 219 391
199 214 265 280
62 133 156 219
31 34 72 115
246 260 267 286
7 266 309 337
24 69 142 394

98 138 228 351
72 181 336 355
12 47 160 172
84 178 230 343
80 238 321 376
170 213 331 367
12 136 274 326
13 51 96 147
23 264 334 346
29 122 183 356
78 287 330 349
42 69 131 198
36 43 189 216
44 142 195 344
40 147 260 330
125 325 379 387
90 111 126 301
113 177 226 273
96 172 181 218
17 124 154 373
87 285 306 376
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161 267 284 293
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141 170 183 232
5 40 167 238
15 44 95 239
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29 93 197 381
21 222 282 284
175 193 361 372
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93 169 209 328
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108 254 340 376
141 246 264 388
96 267 362 392
131 234 291 330
4 168 220 235
130 195 216 367
108 148 290 302
85 214 362 395
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91 104 355 358
176 342 351 390
6 45 123 126
69 241 268 274
158 324 371 399
62 232 264 373
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195 285 321 327
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55 112 179 381
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43 320 334 382
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11 119 339 359
5 36 231 316
15 138 354 389
25 82 136 180
20 103 167 266
112 292 359 371
184 201 240 328
77 160 307 339
74 147 280 389
127 149 358 387
50 59 117 185
11 189 212 220
123 135 226 372
83 86 149 386
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30 54 178 315
136 301 341 365
21 59 265 299
111 154 282 297
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121 142 174 236
108 129 152 261
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92 244 315 326
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161 171 307 317
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15 164 192 273
62 199 222 228
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85 227 250 321
91 121 295 324
3 16 308 340
143 157 307 395
36 77 116 340
3 98 101 125
39 151 364 377
194 227 231 267
59 200 206 389
21 106 287 389
33 268 340 387
140 150 395 398
88 352 360 367
55 91 145 168
126 130 181 323
34 120 227 316
237 337 355 394
34 186 219 313
280 330 340 375
76 230 354 378
5 178 293 297
142 223 234 381
48 239 260 399
58 270 336 360
24 123 271 347
12 76 137 280
107 226 302 367
175 186 208 366
65 183 369 376
60 169 292 350
44 169 240 362
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Proposed Text Changes

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