FORWARD ERROR CORRECTION PROPOSAL FOR EPOC PHY LAYER

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DVB-C2 VS. BRCM FEC STRUCTURE ON AWGN CHANNEL

- **BRCM FEC**
  - Single LDPC code
  - Codeword size: 12000
  - Code rate 75%
  - Use set-partition LDPC code on 4-LSB's for all QAM constellations
  - Apply both even-bit and odd-bit QAM constellations
  - No need for BCH outer code in AWGN channel (no error floor problem)
  - No Frequency Domain Interleaving
  - Use shortening to provide 0.5 bit/symbol increments (with BCH outer code)

- **DVB-C2 FEC**
  - 6 different LDPC codes (one for each code rate)
  - Code rates: 4/9, 2/3, 11/15, 7/9, 37/45, 8/9
  - Codeword size: 16200
  - Code all QAM symbol bits
  - Need BCH outer code (error floor mitigation)
  - Use interleaving within one LDPC codeword
  - Only on even-bits QAM constellations

PARTIAL BIT CODING

Approach

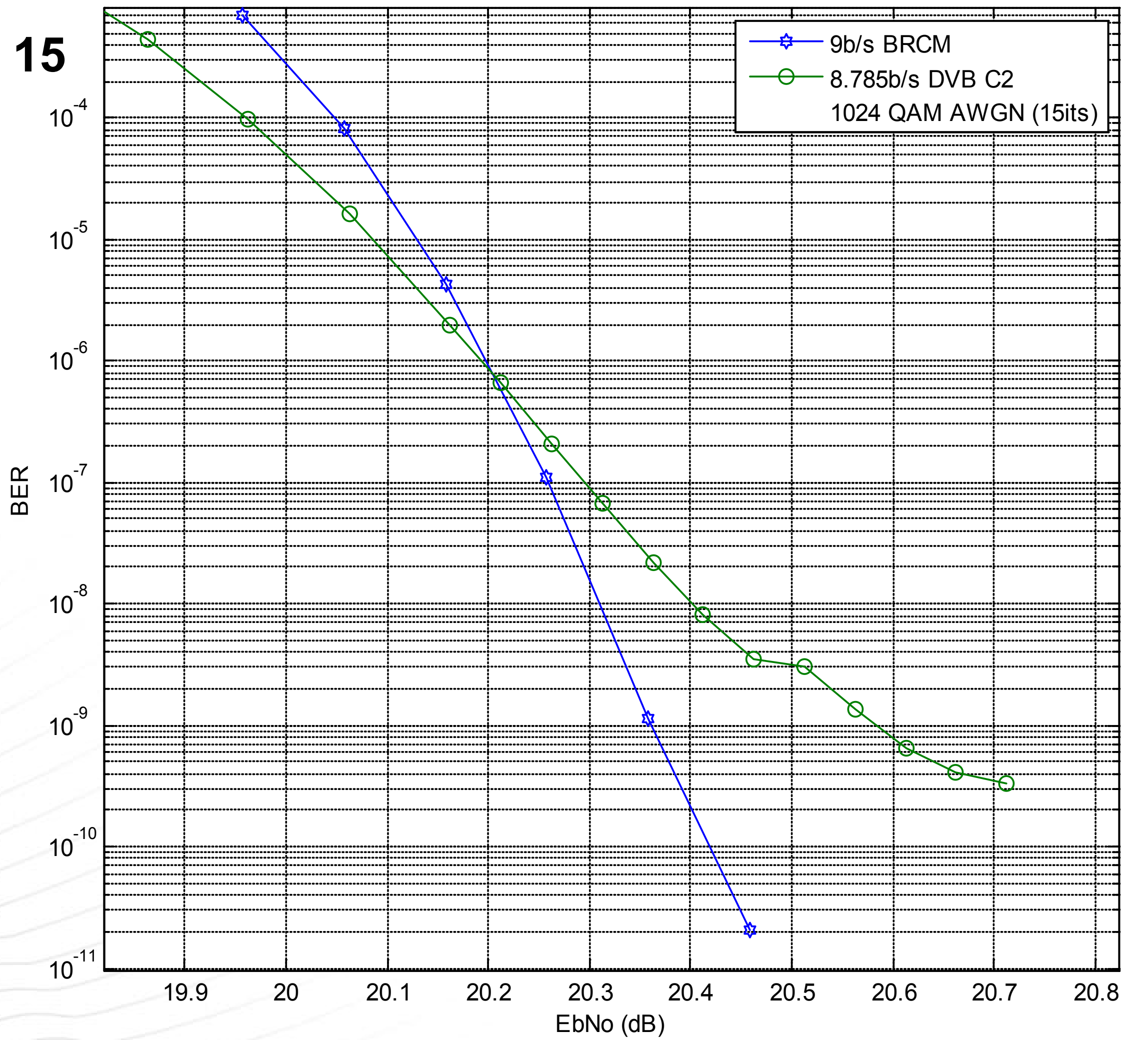
- LDPC Code applied to 4 Least Significant Bits of an QAM symbol
- Uncoded bits use Set Partitioning to maximize distance

Benefits

- Combined coding and modulation maintains error correction performance (coding gain) with a lower rate (stronger) code for the LSB's with the same overall higher code rate
- LDPC decoder rate is reduced by 4/M for M bit QAM symbols
- Reduction in decoder complexity

PERFORMANCE ON 1024-QAM (AWGN)

- **Max number of iterations: 15**
- **SNR@ 1E-8**
  - BRCM: 20.31dB
  - DVB-C2: 20.4dB
  - Difference: 0.09dB
- **SNR@1E-10**
  - BRCM: 20.41dB
  - DVB-C2: >20.71dB
  - Difference: >0.3dB



ALL QAM CONSTELLATION SUPPORT

Approach

- **Use conventional even (square) QAM constellations**
  - 256-QAM, 1024-QAM, 4096-QAM
- **Add odd (cross) QAM constellations**
  - 512-QAM, 2048-QAM

Benefits

- **Provides finer granularity in spectral efficiency choices**
- **Provides finer granularity in SNR threshold choices**

512-QAM MAPPING

BRCM, four coded bits, 512-QAM

				00000 1110	00001 1110	00011 1110	00010 1110	00000 1010	00001 1010	00011 1010	00010 1010	10000 1010	10001 1010	10011 1010	10010 1010	10000 1110	10001 1110	10011 1110	10010 1110				
				00000 1111	00001 1111	00011 1111	00010 1111	00000 1011	00001 1011	00011 1011	00010 1011	10000 1011	10001 1011	10011 1011	10010 1011	10000 1111	10001 1111	10011 1111	10010 1111				
				00000 1101	00001 1101	00011 1101	00010 1101	00000 1001	00001 1001	00011 1001	00010 1001	10000 1001	10001 1001	10011 1001	10010 1001	10000 1101	10001 1101	10011 1101	10010 1101				
				00000 1100	00001 1100	00011 1100	00010 1100	00000 1000	00001 1000	00011 1000	00010 1000	10000 1000	10001 1000	10011 1000	10010 1000	10000 1100	10001 1100	10011 1100	10010 1100				
00100 1010	00101 1010	00111 1010	00110 1010	01100 1010	01101 1010	01111 1010	01110 1010	01000 1010	01001 1010	01011 1010	01010 1010	11000 1010	11001 1010	11011 1010	11010 1010	11100 1010	11101 1010	11111 1010	11110 1010	10100 1010	10101 1010	10111 1010	10110 1010
00100 1011	00101 1011	00111 1011	00110 1011	01100 1011	01101 1011	01111 1011	01110 1011	01000 1011	01001 1011	01011 1011	01010 1011	11000 1011	11001 1011	11011 1011	11010 1011	11100 1011	11101 1011	11111 1011	11110 1011	10100 1011	10101 1011	10111 1011	10110 1011
00100 1001	00101 1001	00111 1001	00110 1001	01100 1001	01101 1001	01111 1001	01110 1001	01000 1001	01001 1001	01011 1001	01010 1001	11000 1001	11001 1001	11011 1001	11010 1001	11100 1001	11101 1001	11111 1001	11110 1001	10100 1001	10101 1001	10111 1001	10110 1001
00100 1000	00101 1000	00111 1000	00110 1000	01100 1000	01101 1000	01111 1000	01110 1000	01000 1000	01001 1000	01011 1000	01010 1000	11000 1000	11001 1000	11011 1000	11010 1000	11100 1000	11101 1000	11111 1000	11110 1000	10100 1000	10101 1000	10111 1000	10110 1000
00100 1110	00101 1110	00111 1110	00110 1110	01100 1110	01101 1110	01111 1110	01110 1110	01000 1110	01001 1110	01011 1110	01010 1110	11000 1110	11001 1110	11011 1110	11010 1110	11100 1110	11101 1110	11111 1110	11110 1110	10100 1110	10101 1110	10111 1110	10110 1110
00100 1111	00101 1111	00111 1111	00110 1111	01100 1111	01101 1111	01111 1111	01110 1111	01000 1111	01001 1111	01011 1111	01010 1111	11000 1111	11001 1111	11011 1111	11010 1111	11100 1111	11101 1111	11111 1111	11110 1111	10100 1111	10101 1111	10111 1111	10110 1111
00100 1101	00101 1101	00111 1101	00110 1101	01100 1101	01101 1101	01111 1101	01110 1101	01000 1101	01001 1101	01011 1101	01010 1101	11000 1101	11001 1101	11011 1101	11010 1101	11100 1101	11101 1101	11111 1101	11110 1101	10100 1101	10101 1101	10111 1101	10110 1101
00100 1100	00101 1100	00111 1100	00110 1100	01100 1100	01101 1100	01111 1100	01110 1100	01000 1100	01001 1100	01011 1100	01010 1100	11000 1100	11001 1100	11011 1100	11010 1100	11100 1100	11101 1100	11111 1100	11110 1100	10100 1100	10101 1100	10111 1100	10110 1100
00100 0110	00101 0110	00111 0110	00110 0110	01100 0110	01101 0110	01111 0110	01110 0110	01000 0110	01001 0110	01011 0110	01010 0110	11000 0110	11001 0110	11011 0110	11010 0110	11100 0110	11101 0110	11111 0110	11110 0110	10100 0110	10101 0110	10111 0110	10110 0110
00100 0111	00101 0111	00111 0111	00110 0111	01100 0111	01101 0111	01111 0111	01110 0111	01000 0111	01001 0111	01011 0111	01010 0111	11000 0111	11001 0111	11011 0111	11010 0111	11100 0111	11101 0111	11111 0111	11110 0111	10100 0111	10101 0111	10111 0111	10110 0111
00100 0101	00101 0101	00111 0101	00110 0101	01100 0101	01101 0101	01111 0101	01110 0101	01000 0101	01001 0101	01011 0101	01010 0101	11000 0101	11001 0101	11011 0101	11010 0101	11100 0101	11101 0101	11111 0101	11110 0101	10100 0101	10101 0101	10111 0101	10110 0101
00100 0100	00101 0100	00111 0100	00110 0100	01100 0100	01101 0100	01111 0100	01110 0100	01000 0100	01001 0100	01011 0100	01010 0100	11000 0100	11001 0100	11011 0100	11010 0100	11100 0100	11101 0100	11111 0100	11110 0100	10100 0100	10101 0100	10111 0100	10110 0100
00100 0010	00101 0010	00111 0010	00110 0010	01100 0010	01101 0010	01111 0010	01110 0010	01000 0010	01001 0010	01011 0010	01010 0010	11000 0010	11001 0010	11011 0010	11010 0010	11100 0010	11101 0010	11111 0010	11110 0010	10100 0010	10101 0010	10111 0010	10110 0010
00100 0011	00101 0011	00111 0011	00110 0011	01100 0011	01101 0011	01111 0011	01110 0011	01000 0011	01001 0011	01011 0011	01010 0011	11000 0011	11001 0011	11011 0011	11010 0011	11100 0011	11101 0011	11111 0011	11110 0011	10100 0011	10101 0011	10111 0011	10110 0011
00100 0001	00101 0001	00111 0001	00110 0001	01100 0001	01101 0001	01111 0001	01110 0001	01000 0001	01001 0001	01011 0001	01010 0001	11000 0001	11001 0001	11011 0001	11010 0001	11100 0001	11101 0001	11111 0001	11110 0001	10100 0001	10101 0001	10111 0001	10110 0001
00100 0000	00101 0000	00111 0000	00110 0000	01100 0000	01101 0000	01111 0000	01110 0000	01000 0000	01001 0000	01011 0000	01010 0000	11000 0000	11001 0000	11011 0000	11010 0000	11100 0000	11101 0000	11111 0000	11110 0000	10100 0000	10101 0000	10111 0000	10110 0000
				00000 0110	00001 0110	00011 0110	00010 0110	00000 0010	00001 0010	00011 0010	00010 0010	10000 0010	10001 0010	10011 0010	10010 0010	10000 0110	10001 0110	10011 0110	10010 0110				
				00000 0111	00001 0111	00011 0111	00010 0111	00000 0011	00001 0011	00011 0011	00010 0011	10000 0011	10001 0011	10011 0011	10010 0011	10000 0111	10001 0111	10011 0111	10010 0111				
				00000 0101	00001 0101	00011 0101	00010 0101	00000 0001	00001 0001	00011 0001	00010 0001	10000 0001	10001 0001	10011 0001	10010 0001	10000 0101	10001 0101	10011 0101	10010 0101				
				00000 0100	00001 0100	00011 0100	00010 0100	00000 0000	00001 0000	00011 0000	00010 0000	10000 0000	10001 0000	10011 0000	10010 0000	10000 0100	10001 0100	10011 0100	10010 0100				

Coded bits (LSB's) are grey-coded along each axis

LDPC CODE SHORTENING

Approach

- Use a shortened LDPC codeword for the 4 LSB’s as the inner code
- Add a very high code rate BCH outer code over the LDPC information bits and the uncoded bits of the partial bit coded QAM symbols containing the LDPC codeword

Benefits

- Provides finer granularity in spectral efficiency choices
- Only a single LDPC code is used
- Reduction in decoder complexity

BCH OUTER CODE WITH SHORTENED LDPC INNER CODE

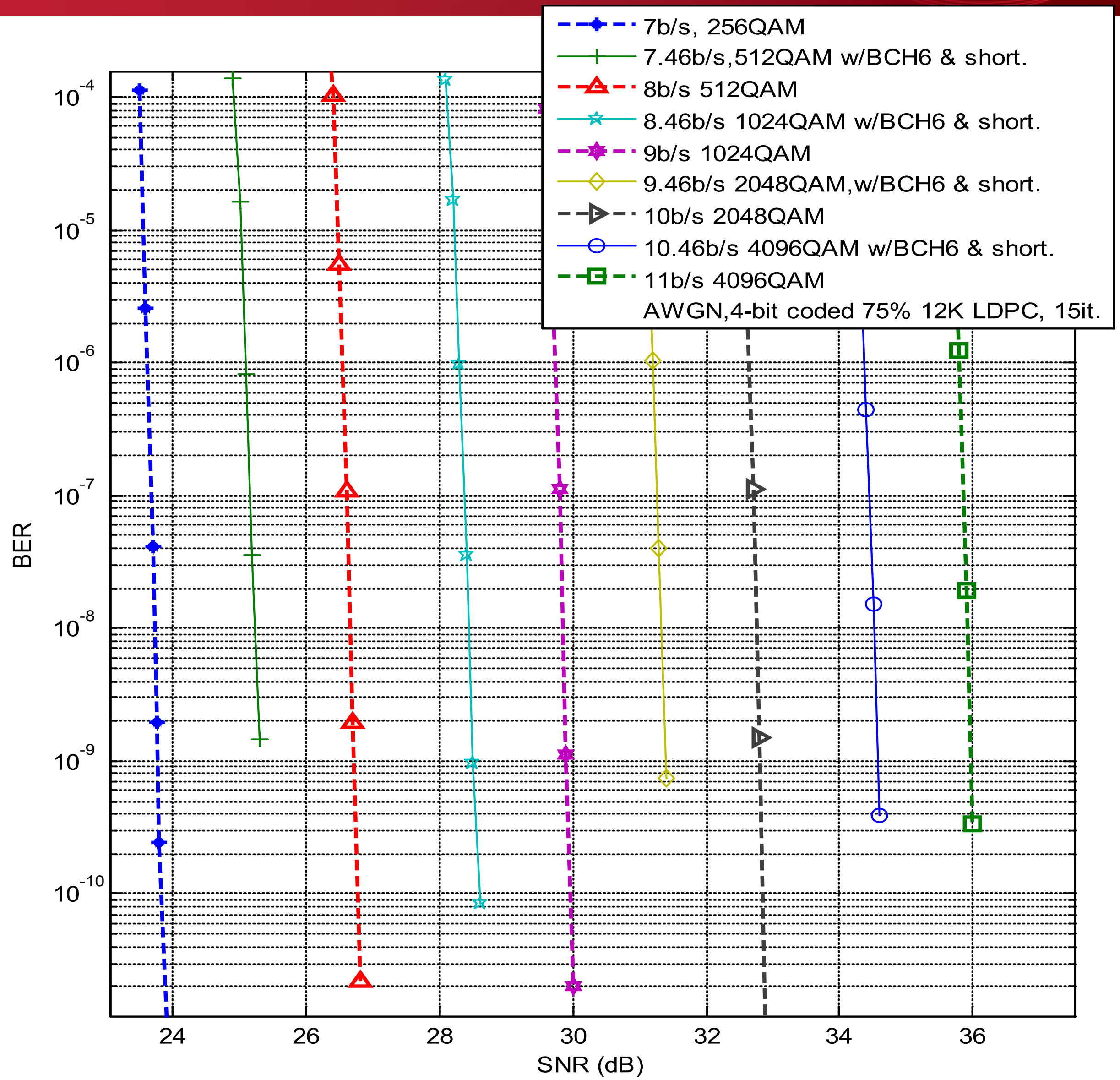
- **LDPC inner code shorting size: 4000 bit**
- **LDPC information bits after shortening: k=9000-4000=5000**
- **LDPC total bits after shortening: n=12000-4000=8000**
- **BCH codeword size: k+(n/4)*u (where u = number of uncoded bits/symbol)**
- **Binary BCH code with working field GF(2^{15})**

QAM Symbols				BCH outer code		
Constellation	Symbol size	Number of coded bits	Number of uncoded bits	BCH codeword size	Number of correctable bits	Number of redundancy bits
512	9	4	5	15000	6	90
1024	10	4	6	17000	6	90
2048	11	4	7	19000	6	90
4096	12	4	8	21000	6	90

256 TO 4096-QAM AND SHORTENING WITH BCH T=6

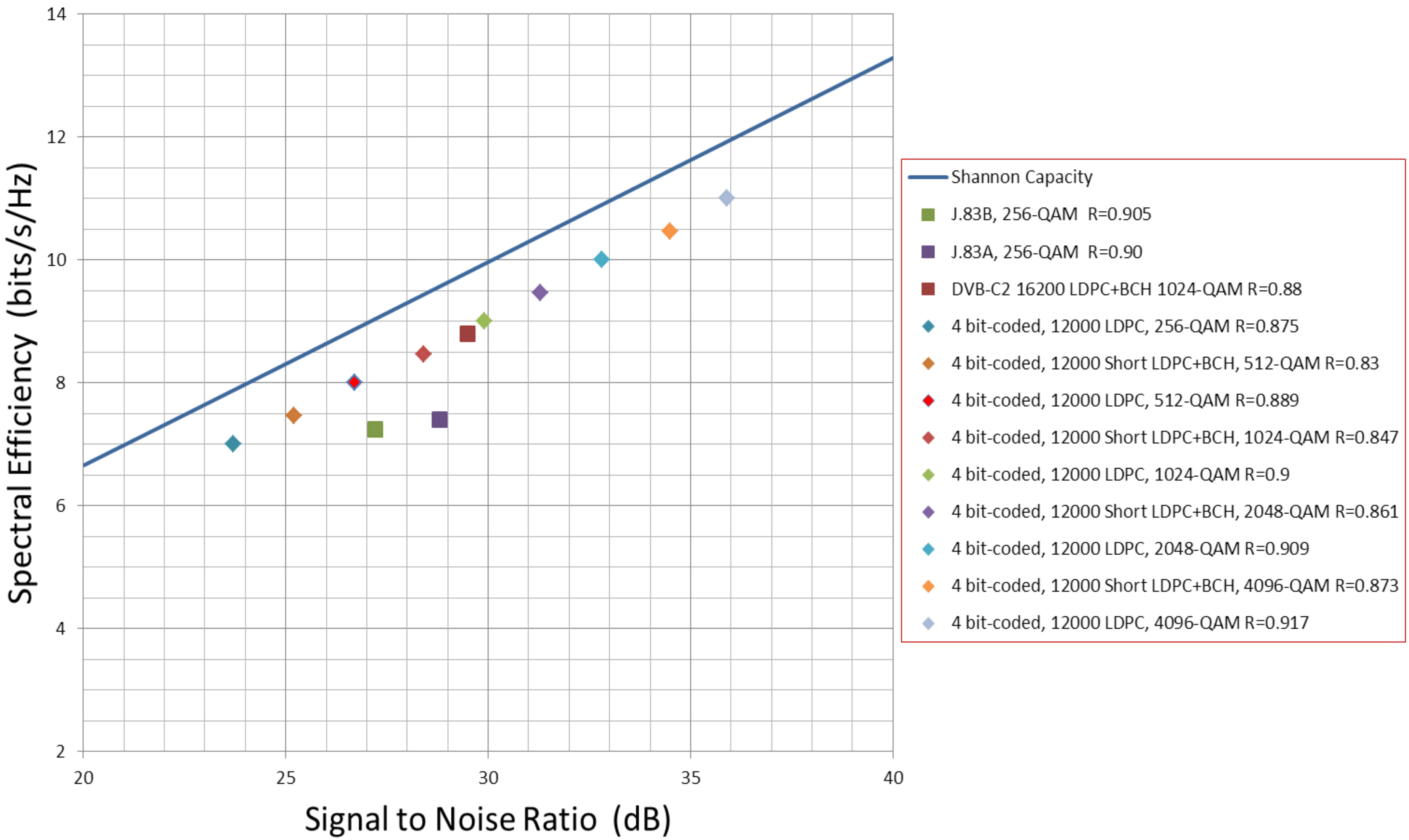
QAM symbol size	coded bits	uncoded bits	Shorten size	BCH correction t	BCH codeword size	BCH check bits	# Max iterations	Overall rate	Bits/ symbol	b/s distance to the previous one	SNR @10^{-8} BER (dB)	SNR distance to the previous one
8	4	4	0	0	0	0	15	0.875	7		23.7	
9	4	5	4000	6	15000	90	15	0.828	7.46	0.46	25.2	1.5
9	4	5	0	0	0	0	15	0.889	8	0.54	26.7	1.5
10	4	6	4000	6	17000	90	15	0.846	8.46	0.46	28.4	1.7
10	4	6	0	0	0	0	15	0.9	9	0.54	29.9	1.5
11	4	7	4000	6	19000	90	15	0.86	9.46	0.46	31.3	1.4
11	4	7	0	0	0	0	15	0.909	10	0.54	32.8	1.5
12	4	8	4000	46	21000	90	15	0.871	10.46	0.46	34.5	1.7
12	4	8	0	0	0	0	15	0.917	11	0.54	35.9	1.4

256 TO 4096-QAM AND SHORTENING WITH BCH T=6 PERFORMANCE CURVES



Max 15 iterations on Full and Shortened LDPC code

SPECTRAL EFFICIENCY OF QAM WITH FEC



CONCLUSIONS

- An LDPC Forward Error Correction approach is proposed with partial bit coding using set partitioned coded modulation
- Even and Odd QAM constellations supported for finer SNR Threshold granularity
- Codeword shortening supports variable code rates with a single LDPC code for finer spectral efficiency granularity
- Reduced decoder memory size with 12000 bit LDPC code
- Reduced decoder rate with 4-bit per QAM symbol partial bit coding
- Reduced decoder complexity with a single LDPC code
- Spectral Efficiency granularity in 0.5 bits/symbol increments
- SNR Threshold granularity in ~1.5 dB increments
- Better performance with lower complexity and greater flexibility

THANK YOU