FORWARD ERROR CORRECTION PROPOSAL FOR EPOC PHY LAYER

IEEE 802.3bn EPoC - SEPTEMBER 2012



Broadcom

BROADCOM

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

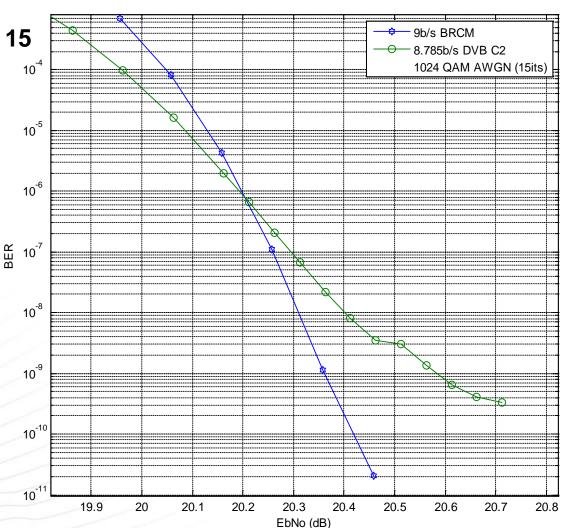
Difference: 0.09dB

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	00001	00011	00010	00000	00001	00011	00010	10000	10001	10011	10010	10000	10001	10011	10010		-		
				-		-	-	1010 00000	_		1010 00010				1010 10010	1110 10000	-		11110				-
				1111	1111	1111	1111	1011	1011	1011	1011	1011	1011	1011	1011	1111	1111		1111				
9				00000 1101			00010 1101	00000 1001	00001 1001		00010 1001		10001 1001	10011 1001	10010 1001	10000 1101	10001 1101	10011 1101	10010 1101			5 4	
				00000 1100				00000 1000		00011 1000	00010 1000		10001 1000			10000 1100		10011 1100					
								01000 1010					11001 1010		11010 1010				11110 1010				10110 1010
00100 1011	00101 1011			01100 1011			01110 1011	01000 1011		01011 1011	01010 1011		11001 1011	11011 1011	11010 1011	11100 1011	11101 1011		11110 1011	10100 1011	10101		10110 1011
		00111 1001					01110 1001	01000 1001		01011 1001	01010 1001		11001 1001	11011 1001	11010 1001	11100 1001	11101 1001	11111 1001	11110 1001	10100 1001	10101 1001		10110 1001
	00101 1000			01100 1000				01000 1000				11000 1000			11010 1000				11110 1000	10100 1000			10110 1000
								01000 1110							11010 1110	11100 1110			11110 1110				10110
	00101 1111			01100 1111				01000 1111						11011 1111	11010 1111	11100 1111	11101 1111			10100 1111	10101	10111 1111	10110
00100 1101		00111 1101						01000 1101					11001 1101	11011 1101	11010 1101	11100 1101	11101 1101	11111 1101	11110 1101	10100 1101	10101 1101	10111 1101	
															11010 1100								10110 1100
		00111 0110						01000 0110					11001 0110		11010 0110				11110 0110				
00100 0111		00111 0111	00110 0111				01110 0111	01000 0111	01001 0111		01010 0111			11011 0111	11010 0111	11100 0111	11101 0111	11111 0111		10100 0111	10101 0111	10111 0111	
	00101 0101				01101 0101		01110 0101	01000 0101	01001 0101		01010 0101			11011 0101	11010 0101	11100 0101	11101 0101	11111 0101	11110 0101	10100 0101	10101 0101	10111 0101	10110 0101
00100 0100								01000 0100			01010 0100		11001 0100	11011 0100					11110 0100	10100 0100	10101 0100		10110 0100
		00111 0010						01000 0010		01011 0010	01010 0010		11001 0010	11011 0010		11100 0010	11101 0010	11111 0010	11110 0010	10100 0010			10110 0010
00100 0011	00101 0011		00110 0011		1		01110 0011	01000 0011	01001 0011		01010 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		01111 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						01110 0000	01000 0000		01011 0000	01010 0000	11000 0000		11011 0000	11010 0000	11100 0000	11101 0000		11110 0000	10100 0000			10110 0000
		3		00000 0110		00011 0110	00010 0110			00011 0010	00010 0010		10001 0010	10011 0010		10000 0110	10001 0110	10011 0110	10010 0110				
				00000 0111	00001 0111	00011 0111			00001 0011	00011 0011	00010 0011	10000 0011	10001 0011	10011 0011	10010 0011	10000 0111	10001 0111	10011 0111	10010 0111			(c)	
				00000 0101	00001 0101	00011 0101	00010 0101		00001 0001	00011 0001	00010 0001	10000 0001	10001 0001	10011 0001	10010 0001	10000 0101	10001 0101	10011 0101	10010 0101				
No sol				00000 0100				00000 0000				10000 0000	10001 0000		10010 0000	10000 0100			10010 0100			100	

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 shorting: 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(2¹⁵)

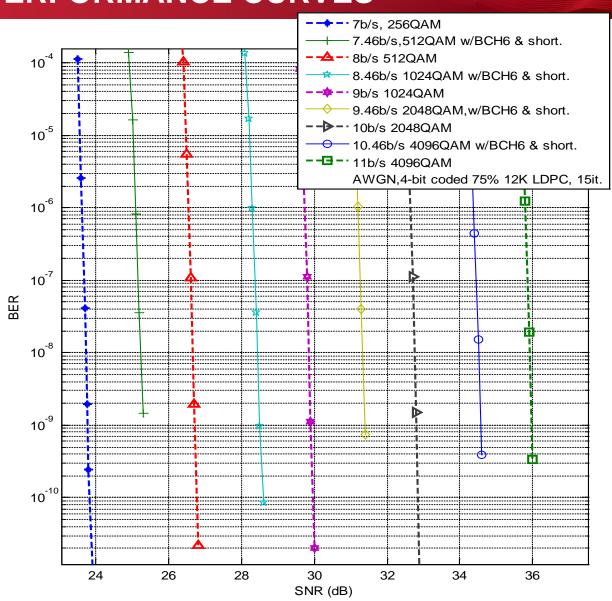
	QAM S	Symbols	BCH outer code						
Constellation	Symbol size	Number of coded bits	Number of uncoded bits	BCH codeword size	Number of correctable bits	Number of redundancy bits			
512	9	4	5	15000	6	90			
1024	10	4	6	17000	6	90			
2048	11	4	7	19000	6	90			
4096	12	4	8	21000	6	90			

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

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

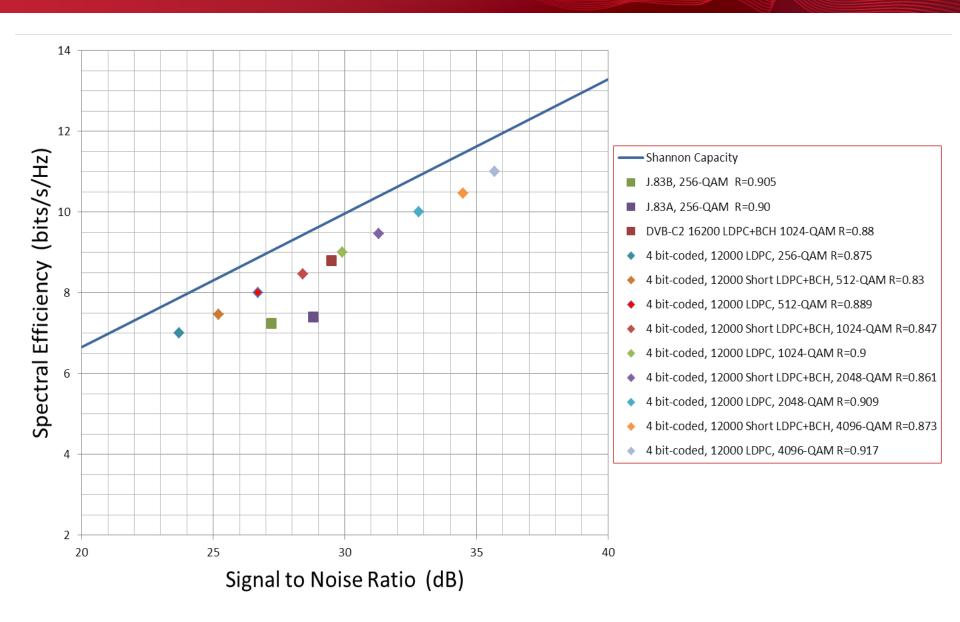




Max 15 iterations on Full and Shortened LDPC code

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



