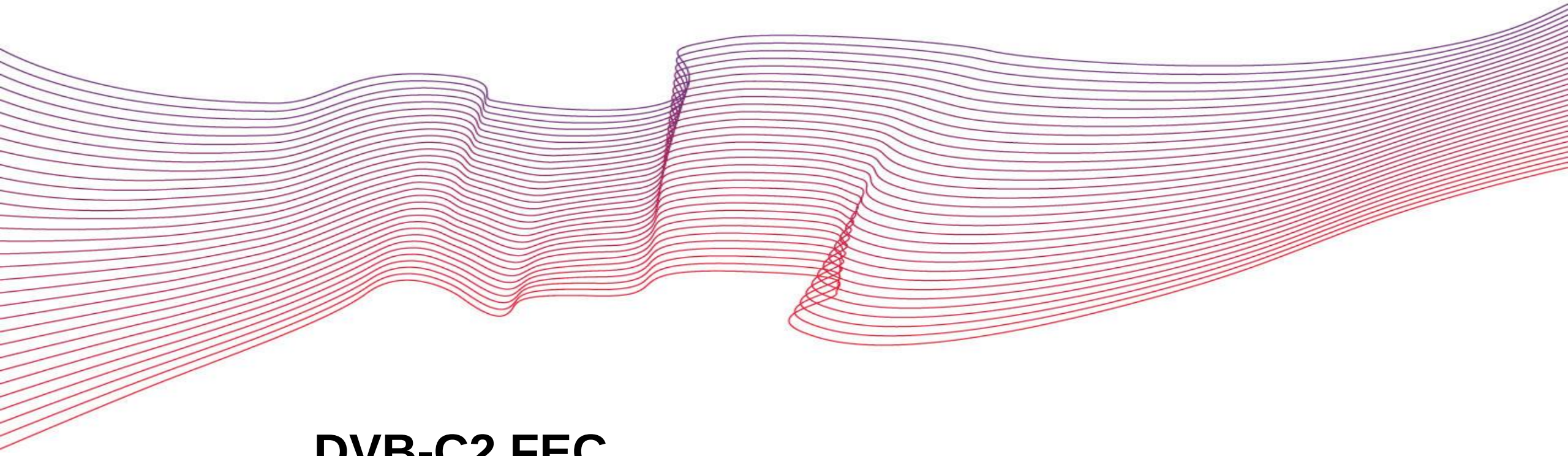
LDPC FEC PROPOSAL FOR EPOC

Broadcom Corporation

LDPC FEC CODES

- **Single rate long LDPC code for all constellations**
  - No outer code
  - No bit interleaver
  - Codeword size: 15800 bits
    - 2.5% reduction from DVB C2 16,200 bits LDPC code
  - 90% Code Rate
    - Widely used and hardware friendly structure
  - QC-LDPC structure

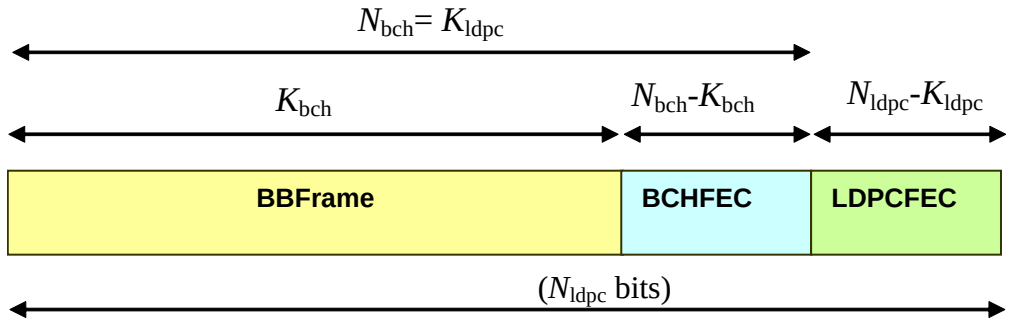
- **Single rate short LDPC code for all constellations**
  - No outer code
  - No bit interleaver
  - Codeword size: 4950 bits
    - 20% reduction from DVB C2 16,200 bits LDPC code
  - 85% Code Rate
  - QC-LDPC structure
    - Widely used and hardware friendly structure



DVB-C2 FEC

DVB-C2 FEC

- **Two layers coding**
  - Inner: 16,200 LDPC
  - Outer: BCH to mitigate error floor
  - 88% Code Rate



- **6 LDPC codes for spectral efficiency**

LDPC code Rate	LDPC Coded Block Nldpc	BCH t-error correction	BCH overhead
4/9	16 200	12	168
2/3	16 200	12	168
11/15	16 200	12	168
7/9	16 200	12	168
37/45	16 200	12	168
8/9	16 200	12	168

- **Designed by Hughes Network System (now a subsidiary of EchoStar) for DVB-S2 in 2002**

DVB-C2 FEC STRUCTURE

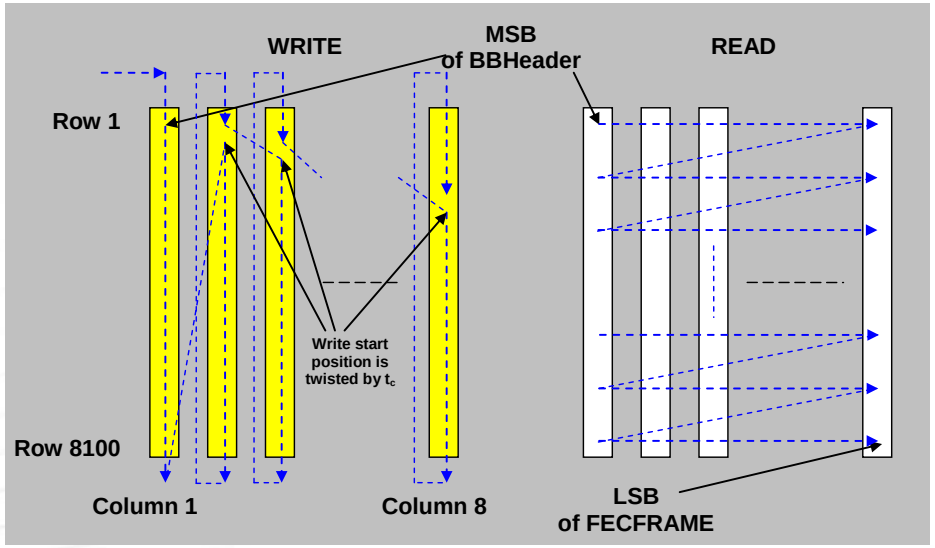
- **LDPC codes**
  - Not belong to the popular used and hardware friendly QC (quasi cyclic) LDPC
  - Converting the parity check matrices to QC type matrices will introduce sub-matrices of column degree 2 or more
  - Need x times decoders for x-channel bonding
- **Need two bit-interleaver before mapping to QAM constellations**
  - Parity interleaving
  - Column-twist interleaving (per 2^m QAM)

$$u_i = \lambda_i \text{ for } 0 \le i < K_{ldpc}$$ (information bits are not interleaved);

$$u_{K_{ldpc}+360t+s} = \lambda_{K_{ldpc}+Q_{ldpc}\cdot s+t} \text{ for } 0 \le s < 360,\ 0 \le t < Q_{ldpc}$$

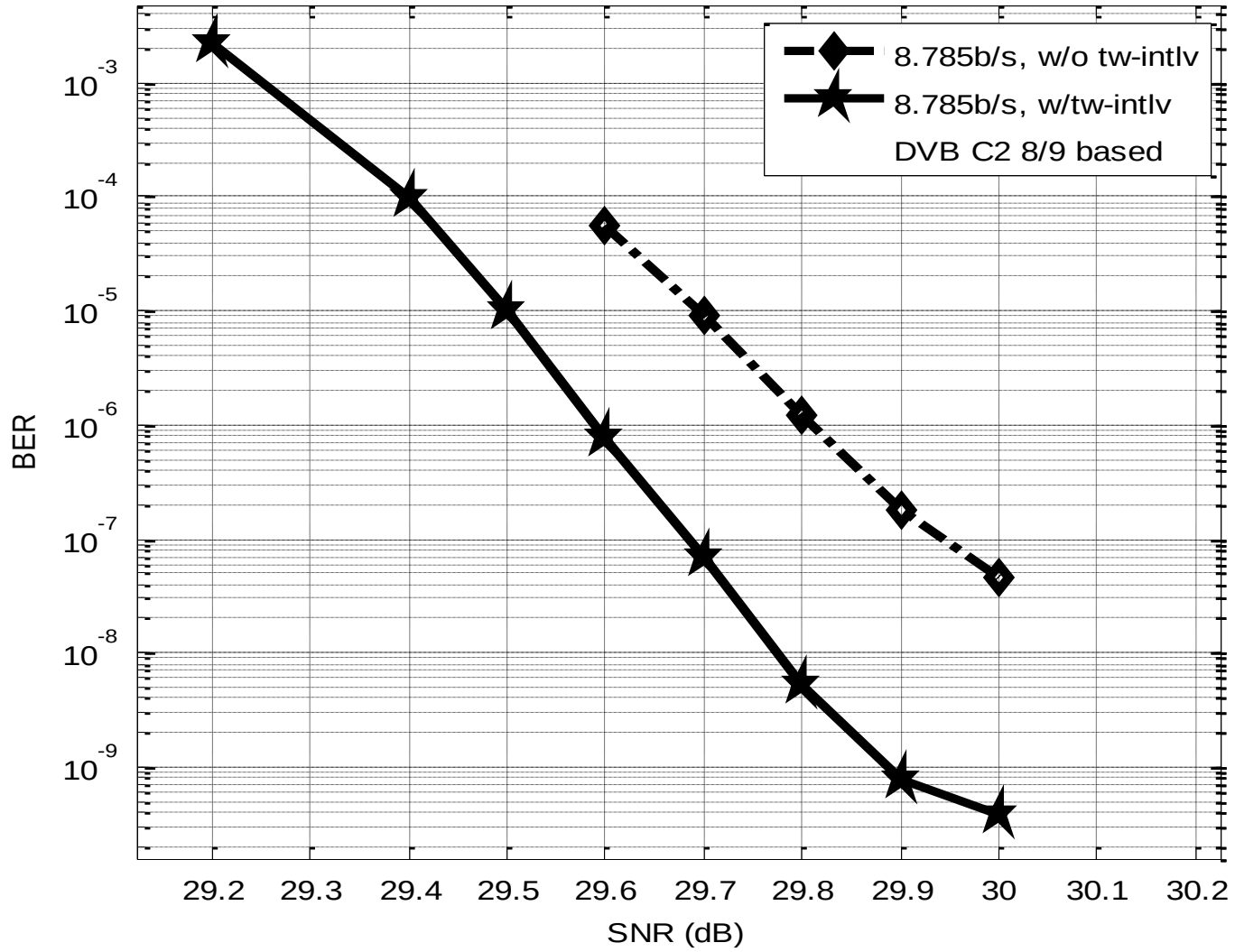
Code Rate	Q_{LDPC}
1/2	25
2/3	15
3/4	12
4/5	10
5/6	8
8/9	5

Parity bit interleaving



Bit interleaving scheme for normal FEC Frame length and 16QAM

DVB C2 RATE 8/9 CODE ON 1024QAM AWGN



IMPROVED CODES

Part I: Higher spectral efficiency

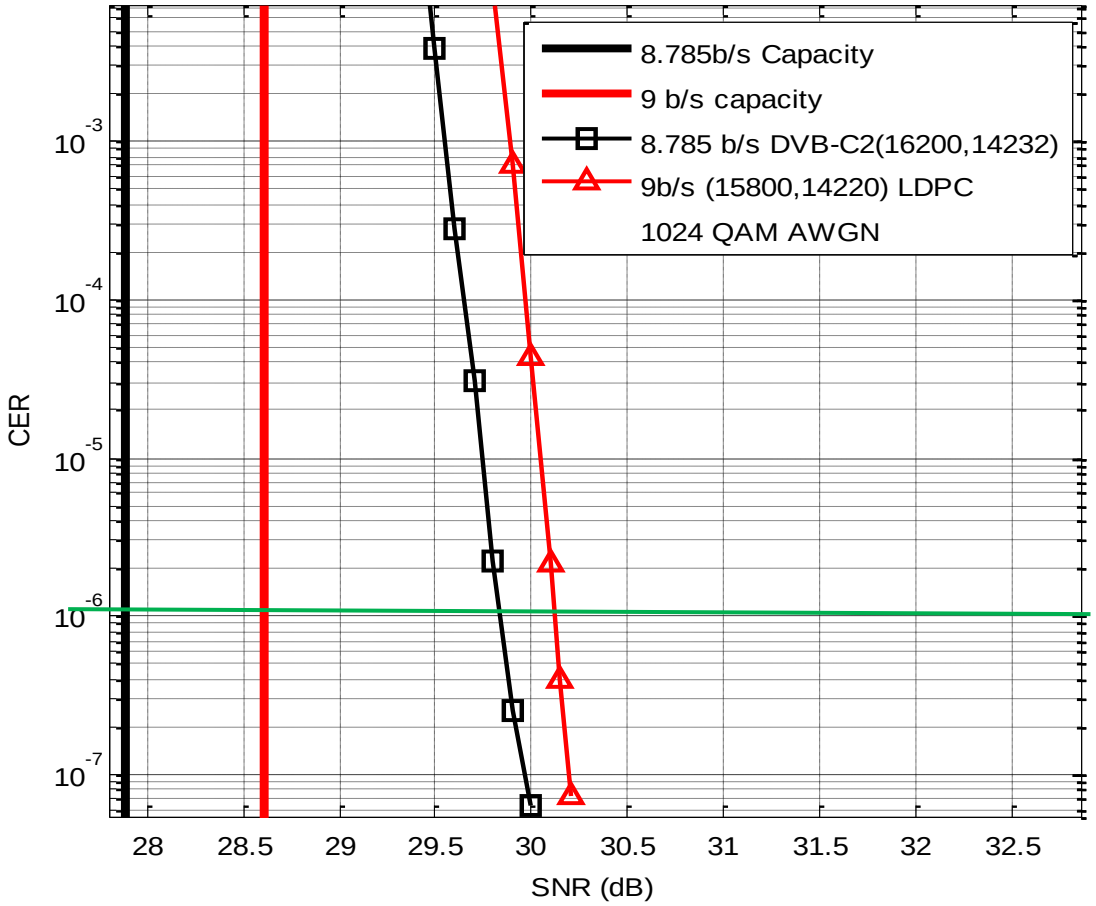
Code	Rate	Outer code	Inter-leave	1024QAM Capacity (dB)	SNR @CER=1e-6 (1024QAM) dB	Distance to capacity (1024QAM)	Spectral efficiency SNR gain compare to DVB C2	Information size (bits)	Codeword size (bits)	No. of check equations
DVB-C2 8/9 based	0.8785	BCH	Twisted	27.89	29.84	1.95dB	.	14232	16200	1,800
Improved long size II	0.9	No	No	28.61	30.1	1.48dB	0.53dB	14220	15800	1,580

Part II: Lower complexity

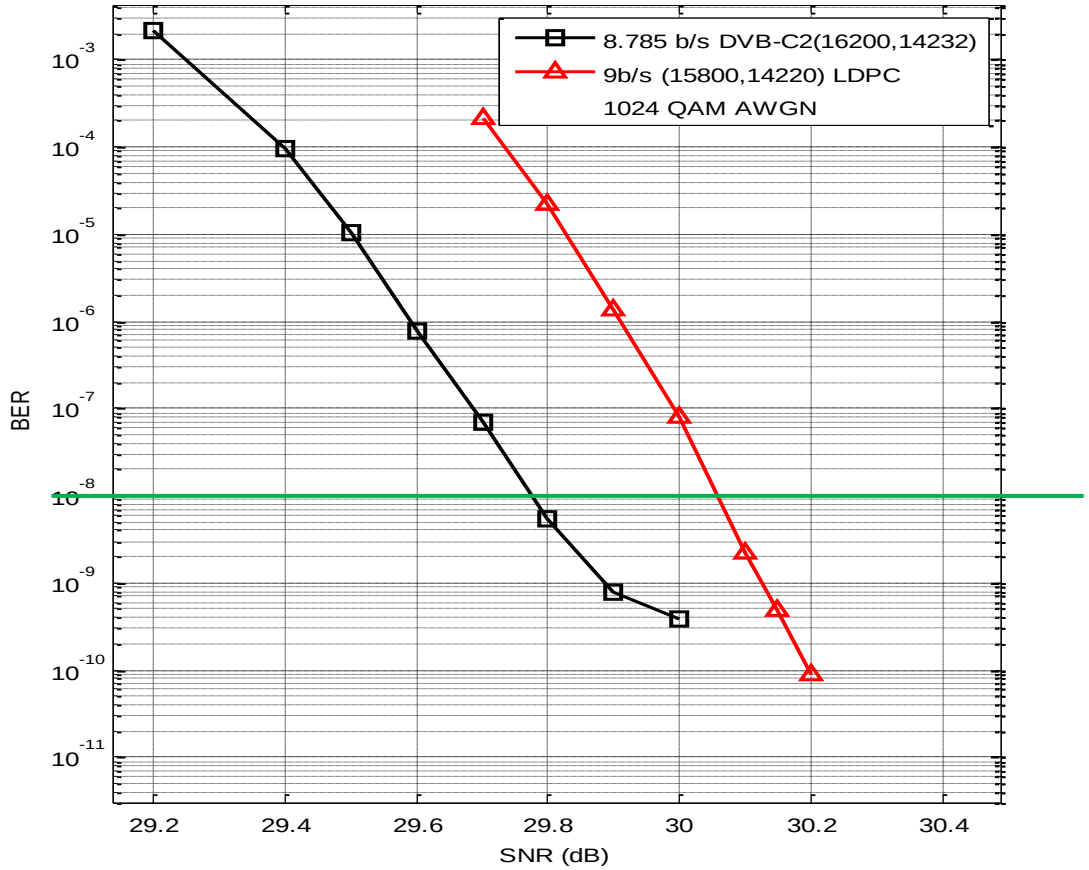
Code	Rate	Outer code	Inter-leave	1024QAM Capacity (dB)	SNR @CER=1e-6 (1024QAM) dB	Distance to capacity (1024QAM)	Spectral efficiency SNR loss compare to DVB C2	Information size (bits)	Codeword size (bits)	No. of check equations
DVB-C2 8/9 base	0.8785	BCH	Twisted	27.89	29.84	1.95dB	.	14232	16200	1,800
MoCA 2.0	0.848	No	No	26.92	29.96	3.04dB	(1.09dB)	3900	4600	700
Improved MoCA 2.0	0.848	No	No	26.92	29.27	2.35dB	(0.4dB)	4200	4950	750

CODES PERFORMANCE CURVES (PART I)

CER(codeword error rate)

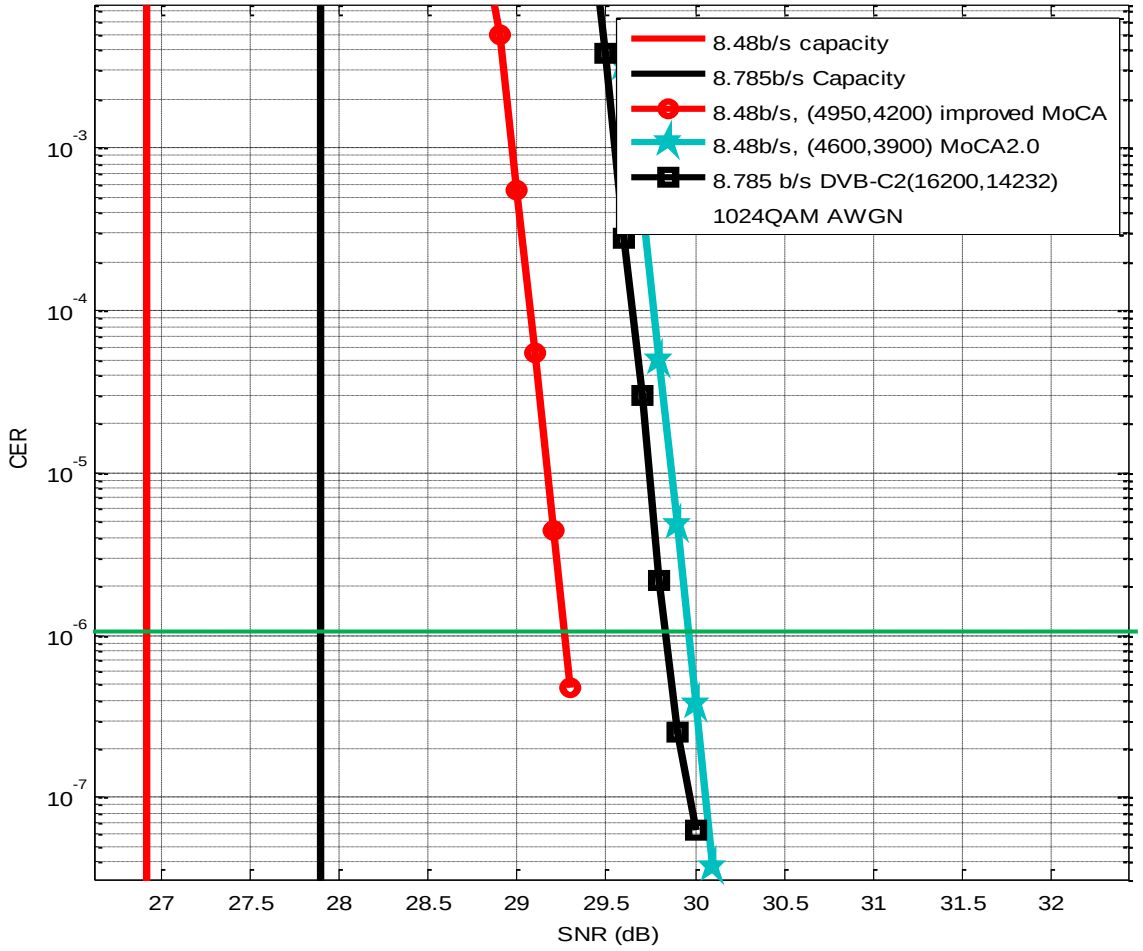


BER (bit error rate)

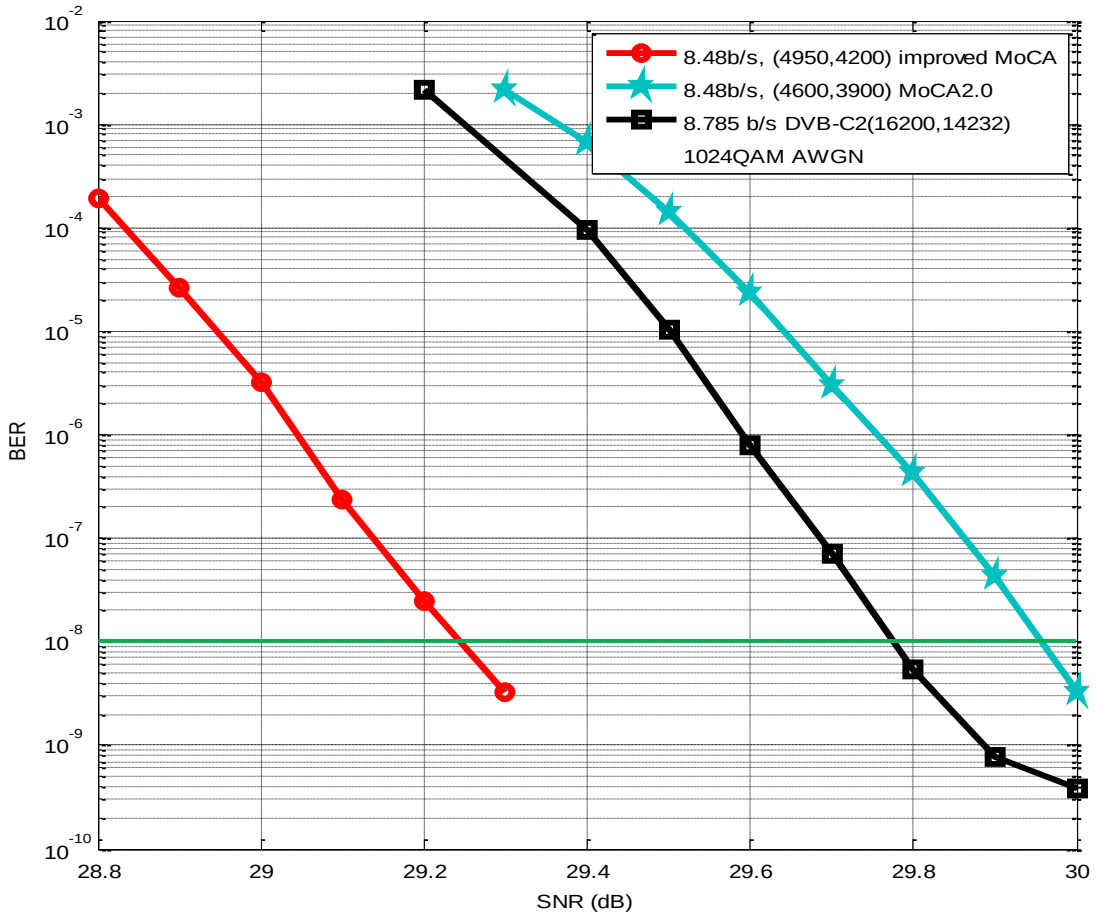


CODES PERFORMANCE CURVES (PART II)

CER(codeword error rate)

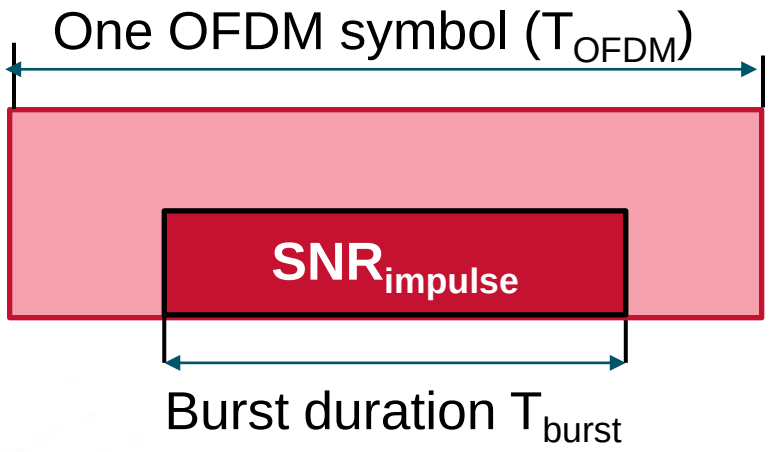


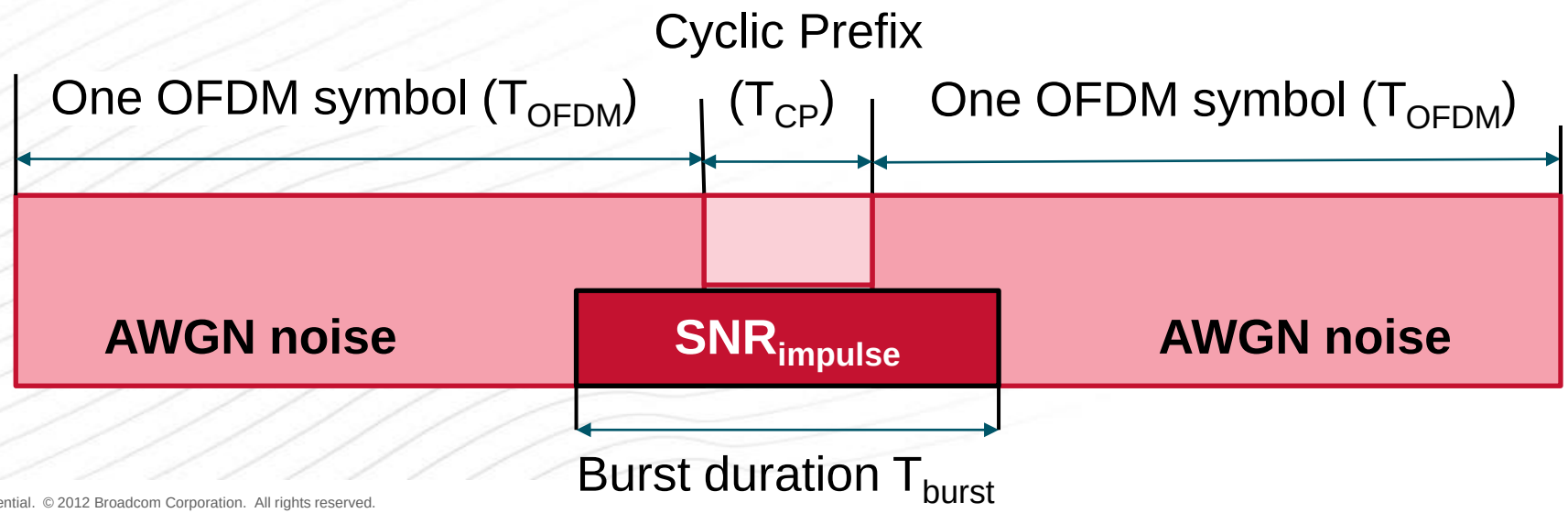
BER (bit error rate)



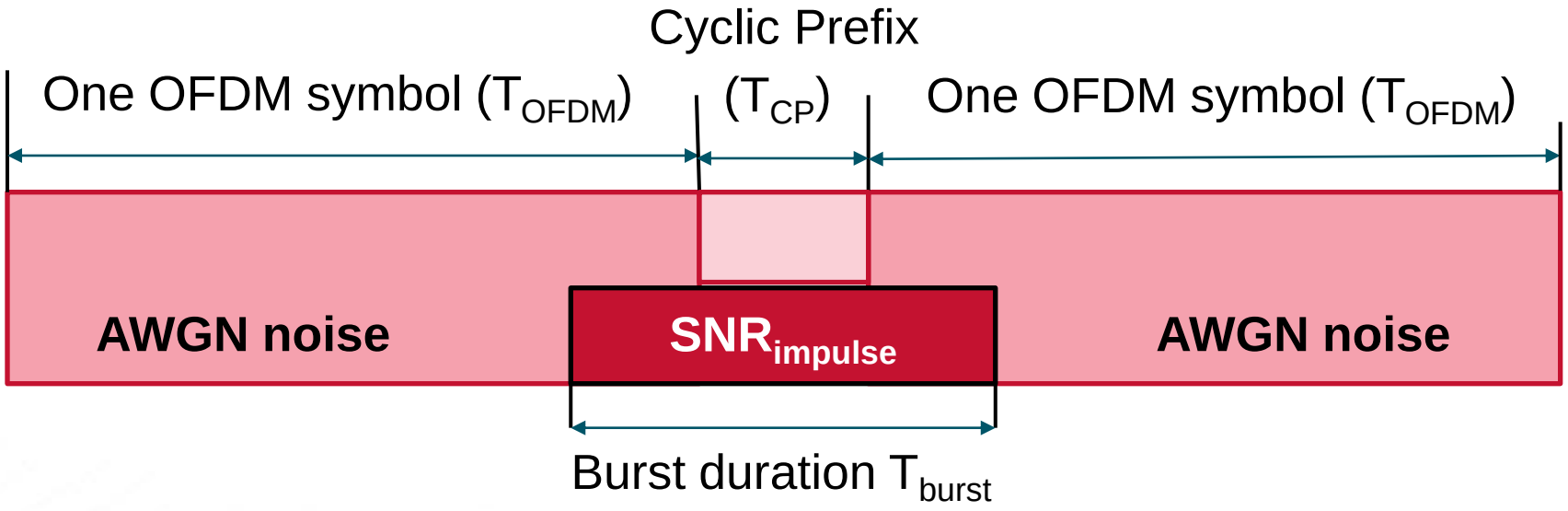
BURST PROTECTION

- **SNR on the burst noise impacted subcarrier**
  - LDPC decoder can take advantage of this known SNR





SNR CALCULATION



- **Case II: the burst hits two consecutive OFDM symbols equally**
  - SNR experienced by all sub-carriers in the two OFDM symbols is

$$SNR_{sub\text{-}carrier} = SNR_{impulse} - 10 \log (0.5 * (T_{burst} - T_{CP}) / T_{OFDM})$$

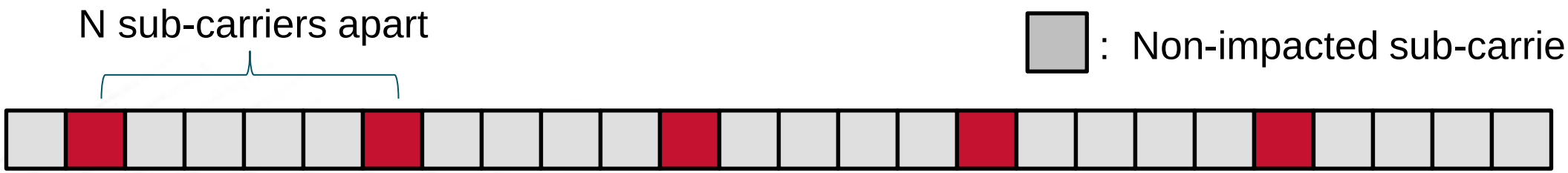
T_{OFDM}:	OFDM symbol duration without cyclic prefix
T_{CP} :	duration of cyclic prefix
T_{burst}:	burst duration
SNR_{impuls}:	impulse SNR

MINIMUM INTERLEAVER DEPTH

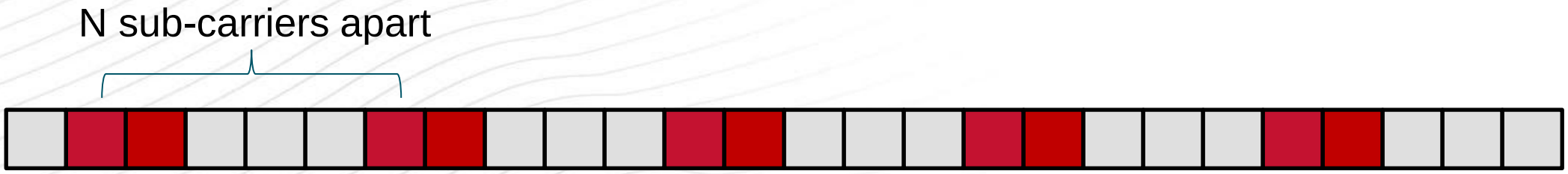
- **Our simulations show the minimum value for interleave depth N in order for BER to reach 1e-8**
- **Simulated cases**
  - Case 1: one OFDM symbol is impacted:

: Burst impacted sub-carriers

: Non-impacted sub-carriers



  - Case 2 two consecutive OFDM symbols are impacted equally:



PERFORMANCE IN MODERATE IMPULSE NOISE

- **10µs burst @ 10 dB SNR**

- **Two cases**
  - Size 4K OFDM symbol
    - Impact on one or two symbols
    - 20 µs each
  - Size 8K OFDM symbol
    - Impact on one or two symbols
    - 40 µs each

Impulse noise SNR		10 dB					
Interleave depth		5		10		15	
OFDM size		4K	8K	4K	8K	4K	8K
87.9%	**DVBC2**	**N**	**N**	**N**	**N**	**35.2dB**	**32.7dB**
84.8%	(4600,3900) MoCA 2.0	N	N	N	N	35.5dB	33dB
84.8%	(4950,4200) Improved	N	N	N	**33.1dB**	32.1dB	31.3dB
90%	(15800,14220)	N	N	N	N	35.2dB	32.8dB

Threshold BER : 1e-8

N: error floor above threshold

number: SNR (dB) when pass the threshold

OFDM symbol impacted: one and two

PERFORMANCE IN STRONG IMPULSE NOISE

- **10µs burst @ 0 dB SNR**
- **Two cases**
  - Size 4K OFDM symbol
    - Impact on one or two symbols
    - 20 µs each
  - Size 8K OFDM symbol
    - Impact on one or two symbols
    - 40 µs each

Impulse noise SNR		0 dB							
Interleave depth		5		10		15		20	
OFDM size		4K	8K	4K	8K	4K	8K	4K	8K
87.9%	**DVBC2**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
84.8%	(4600,3900) MoCA 2.0	N	N	N	N	N	N	N	N
84.8%	(4950,4200) Improved	N	N	N	N	N	N	**32.9dB**	**32.2dB**
90%	(15800,14220)	N	N	N	N	N	N	N	N

Threshold BER : 1e-8

N: error floor above threshold

number: SNR (dB) when pass the threshold

OFDM symbol impacted: one and two

HARDWARE COMPLEXITY

- **On LDPC codeword sizes**
  - DVB C2: 16,200 bits
  - Improved MoCA 2: 4,950 bits
  - Improved MoCA 2 scheme is about 70% smaller than DVB C2 scheme
- **On code structure**
  - a) LDPC number of parity check equations matrix
    - DVB C2 FEC (the least among 6 LDPC codes): 1800 (rate 8/9 code) [rate 6/9 code has 5400]
    - Improved MoCA 2: 750
    - Improved MoCA 2 structure is about 86% smaller than DVB C2 structure
  - b) Outer code and bit-interleave
    - DVB-C2:
      - 12 bits correction BCH
      - Parity bits permutation
      - Column twist interleave
    - Improved MoCA 2: None → another 5% saving
- **Improved MoCA 2 FEC gives very substantial hardware saving!**

MOCA IMPLEMENTATION

- **DVB C2 designed for 150 Mbps throughput**
- **MoCA 2.0 currently supports speeds up to 1 Gbps throughput**
- **MoCA silicon providers**
  - Broadcom
  - Entropic
  - ST Micro
  - Intel (planned – just elected to the MoCA Board of Directors)
  - …
- **Licensing**
  - LOA from Broadcom in progress
  - DVB C2 IP status not yet determined
- **Suitable for use in Downstream or Upstream**
  - Substantial reduction in implementation complexity, testing scope, and time to market
  - Based on commercially deployed, highly successful industry standard