Lower Error Floors for NASA LDPC Codes

Jon Hamkins

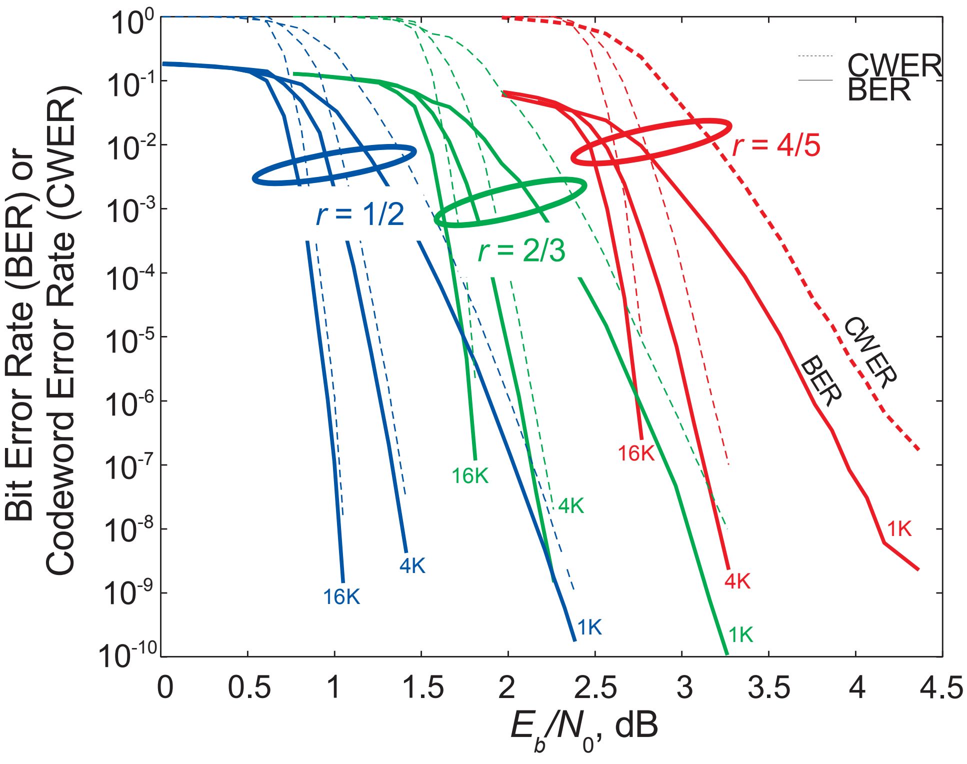
Jet Propulsion Laboratory
California Institute of Technology

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Previously Reported Performance

Performance previously reported:

- AR4JA codes were simulated to below
  - CWER = 10^{-6}
  - BER = 10^{-7}
- Some codes simulated longer
  - AR4JA (1024,1/2) down to BER = 10^{-10}
  - C2, down to BER = 10^{-11}
- Performance presented in Sep. 2007 Orange Book



Error Floors:

- No error floors found, except for:
- AR4JA (1024, 4/5) code
  - Orange Book showed possible floor just below CWER = 10^{-6}
  - Some other decoders created an error floor as high as CWER = 10^{-4}
  - This suggests care should be taken to implement decoder
  - Is the floor at CWER = 10^{-6} inherent?

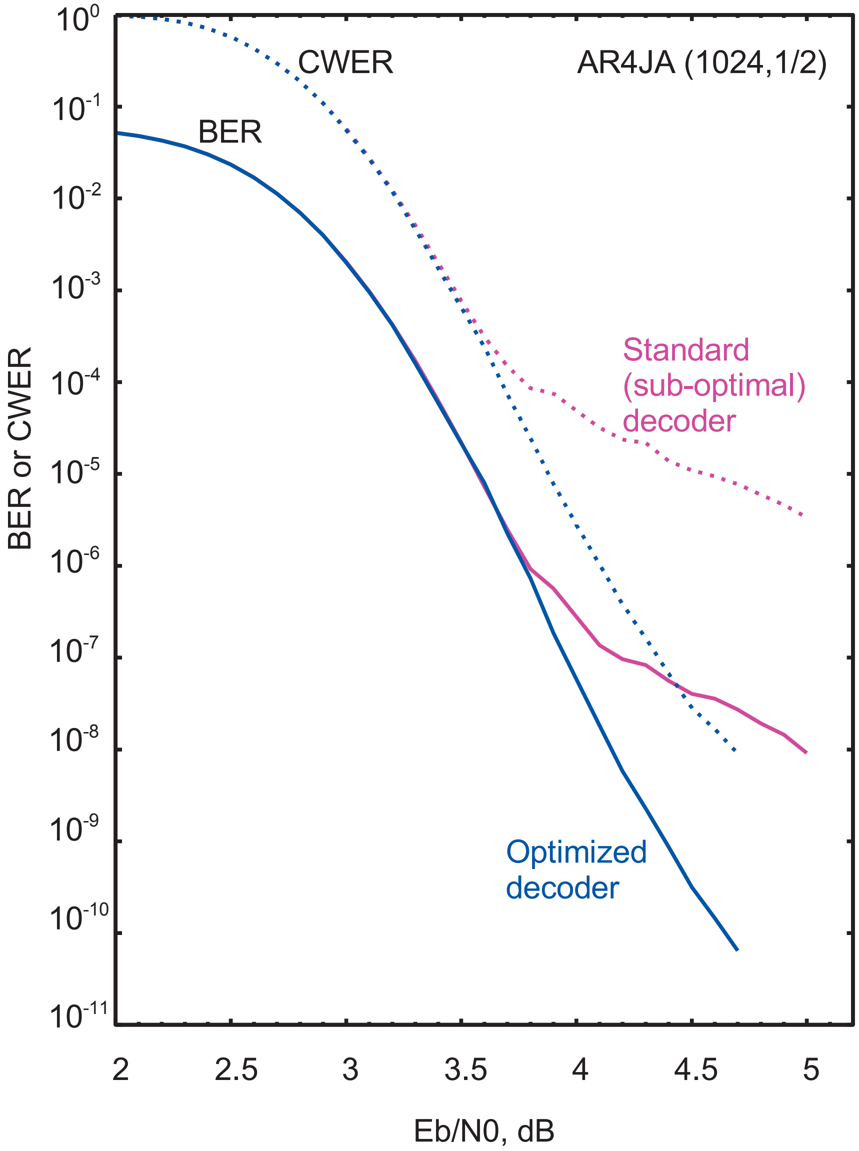
Lower Error Floor for AR4JA (1024,1/2) Code

Standard vs. optimized decoders

- Standard decoder (magenta)
  - Does not properly limit deg-1 variable nodes
  - Does not add-clip-subtract-clip (“Jones clip”) at the variable nodes
  - Performs standard processing at check nodes
- Optimized decoder (blue)
  - Fixes oversights above
  - Incorporates a partial hard-limiter at check nodes: this amplifies correct check node messages
  - Complexity is about the same as standard decoder
  - Details are contained in a publicly available report (http://ipnpr.jpl.nasa.gov)

New, lower floor for AR4JA (1024,1/2) code

- Optimized decoder lowers the floor, down to below CWER = 3x10^{-8} and BER = 10^{-10}, about 2 decades lower than that reported in Orange Book
- This indicates that
  - The code has good distance properties, and no inherently high error floor
  - Care should be taken in implementing decoder, following guidance in the published report



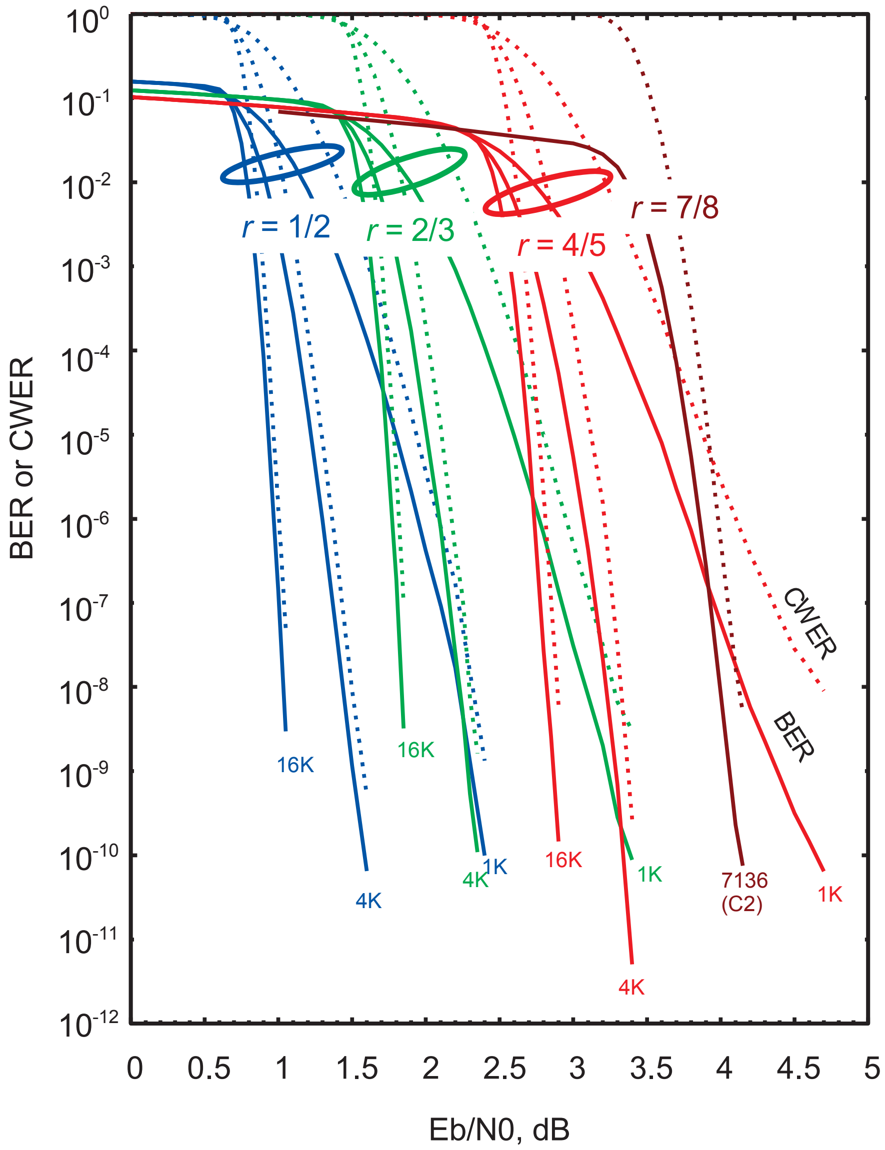
Extended Simulation Results

Longer software simulations were conducted

- This verifies absence of error floors to lower regime
- For speed:
  - Implemented in C
  - Care taken for efficient encoding, decoding
  - Simulations run on a cluster of 19 CPUs
- For performance:
  - Optimized decoder, discussed above, was used

Performance

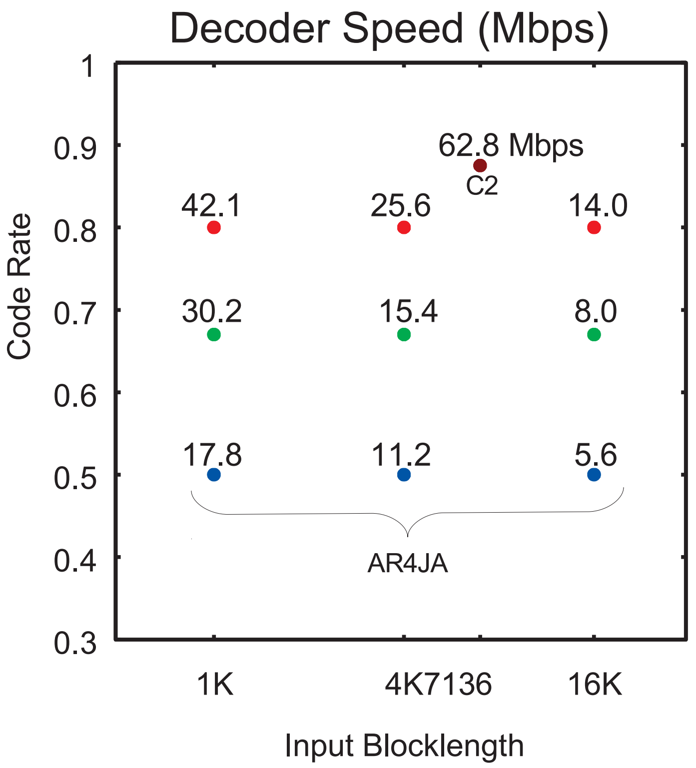
- Performance curves were extended in most cases to
  - CWER = 10^{-8}
  - BER = 10^{-10}
- No floors seen, down to BER = 10^{-10}



Decoding Speed

Software speed was measured

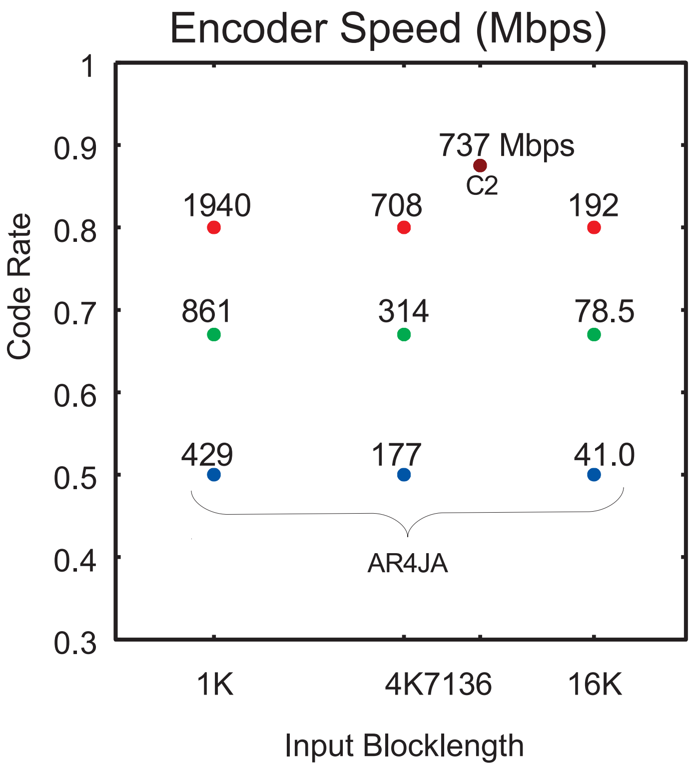
- Software language: C
- Simulation Platform:
  - Cluster of 19 CPUs
  - Each with 3 GHz quad-Xeon or similar
- Operating point: CWER=10^{-8}
- Decoder speed ranged from 6 to 63 Mbps



Encoding Speed

Software speed was measured

- Software language: C
- Simulation Platform:
  - Cluster of 19 CPUs
  - Each with 3 GHz quad-Xeon or similar
- Operating point: CWER=10^{-8}
- Encoder speed ranged from 41 Mbps to 1.9 Gbps



Variable Coded Modulation (VCM) with NASA LDPC Codes

Jon Hamkins

Jet Propulsion Laboratory
California Institute of Technology

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Bandwidth Efficiency vs. Power Efficiency

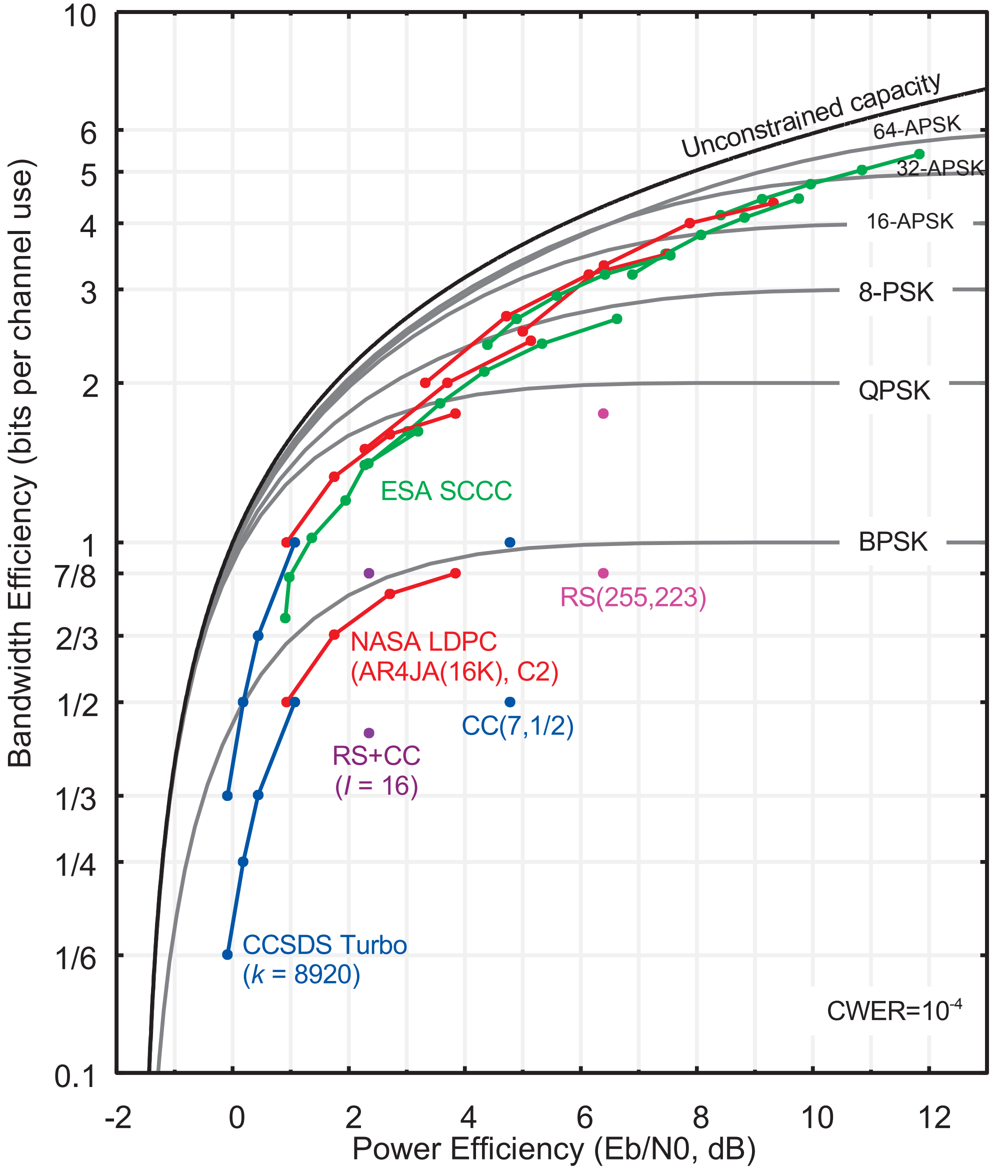
Shown on plot:

- Constrained and unconstrained capacity
- Coded modulation, plotted at CWER=10^{-4}:
  - CCSDS codes(blue, magenta, purple) [1]
  - NASA LDPC [2]
  - ESA SCCC [3]

Observations

- The LDPC codes are natural extension of Turbo codes to higher bandwidth efficiencies
- The SCCC and LDPC codes heavily overlap in their utility (achievable operating point in the trade-space)
- The LDPC codes outperform the SCCC codes, by up to 0.75 dB (e.g., at 2 b/c.u.), despite their shorter length

Based on this, we expect LDPC and SCCC to perform similarly when used with Variable Coded Modulation (VCM)



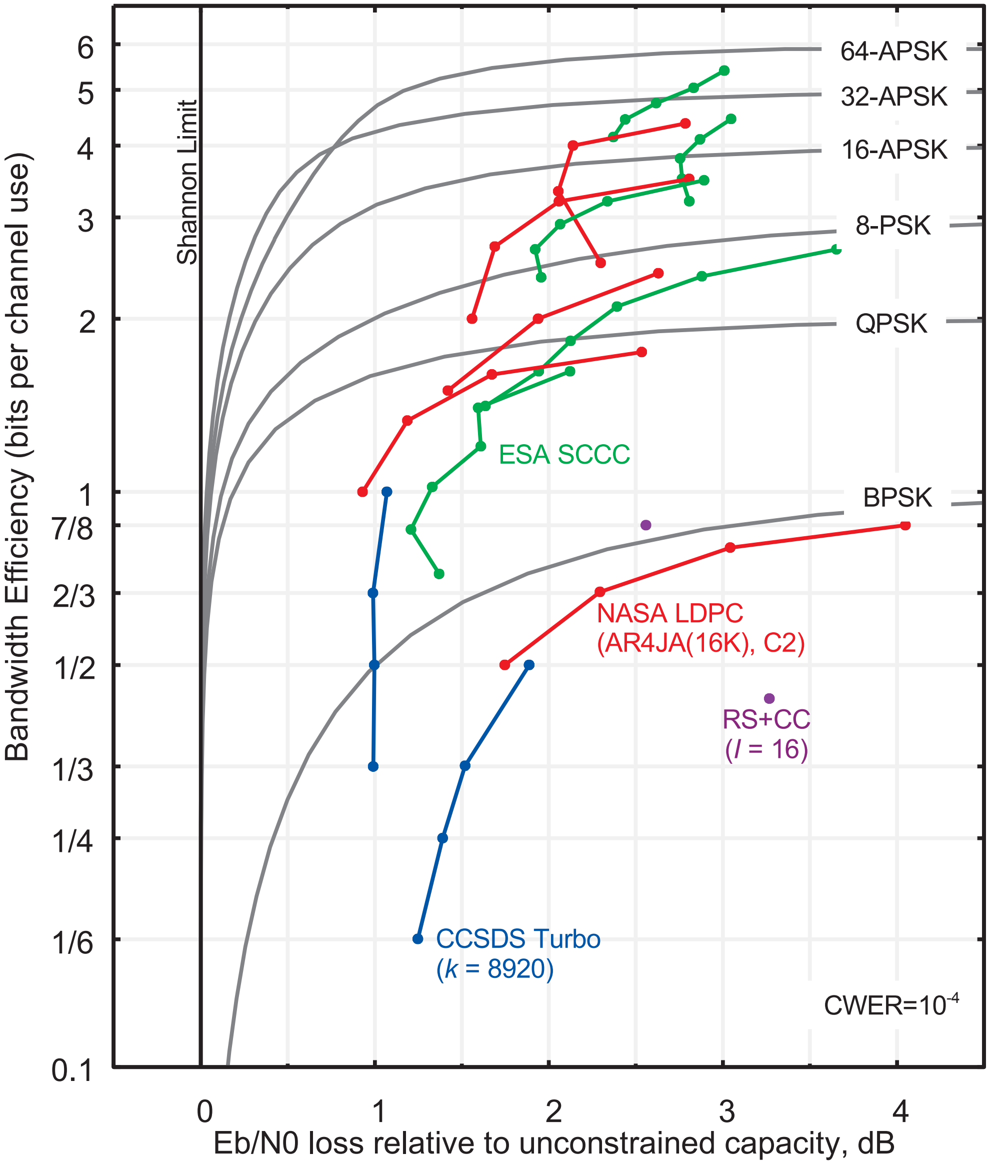
Gap to Capacity: Code Imperfectness

Same data, shown as “gap” to capacity

- Shows the additional Eb/N0 the coded modulations need relative to perfect, unbounded-length coding and unconstrained modulation.

Observations

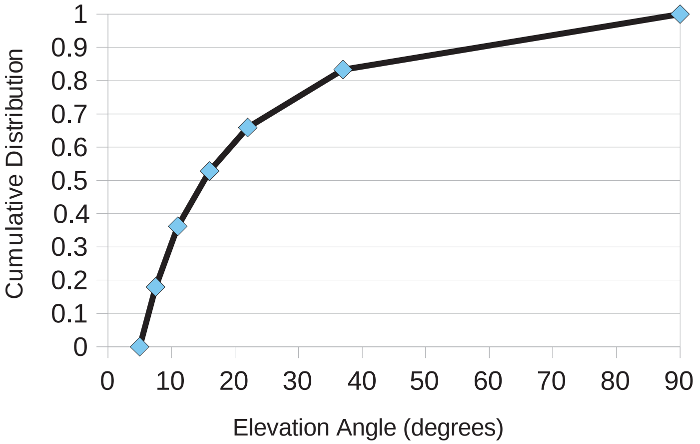
- On modulation capacities (gray):
  - BPSK has >1 dB loss for rates > 1/2
  - All have brick wall at 0 dB – they are optimal at asymptotically low rate
  - 64-APSK has design flaw – it's worse than 32-APSK below 4 b/c.u.
- On coded modulations (colored)
  - Turbo+QPSK gap: about 1.0 dB
  - SCCCs with 16/32/64-APSK have a capacity gap of 2+ dB; the 32-APSK performance appears to have a design problem
  - NASA LDPC is better, but only by about 0.5 dB at 16-APSK, and by about 1.5 dB at 32-APSK.
  - At >1.5 b/c.u., all codes have >1.5 dB gap!



Variable Coded Modulation (VCM) Example

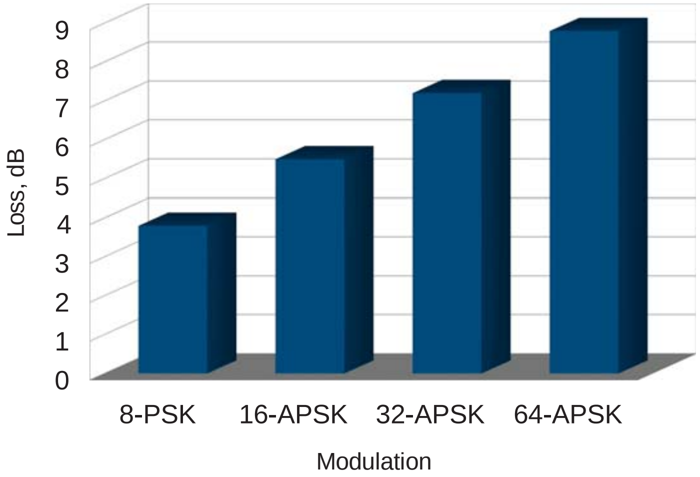
ESA described a practical scenario [4]:

- LEO satellite
  - Polar orbit at 693 km
  - Elevation profile:



  - Pointing antenna, gain 23 dBi
  - 60W TWTA – 27 GHz
  - TX power: 27.5W
  - Constant baud rate: 400 Msps
- Ground:
  - 6m antenna
  - ***G/T varies by elevation profile***

- Impairments:
  - Non-linear distortion: TWTA
  - Group delay distortion
  - Filter losses
  - Phase noise, I/Q imbalance
- Total losses, by modulation:



3 dB margin required

VCM Example: with SCCC

VCM with SCCC [4]:

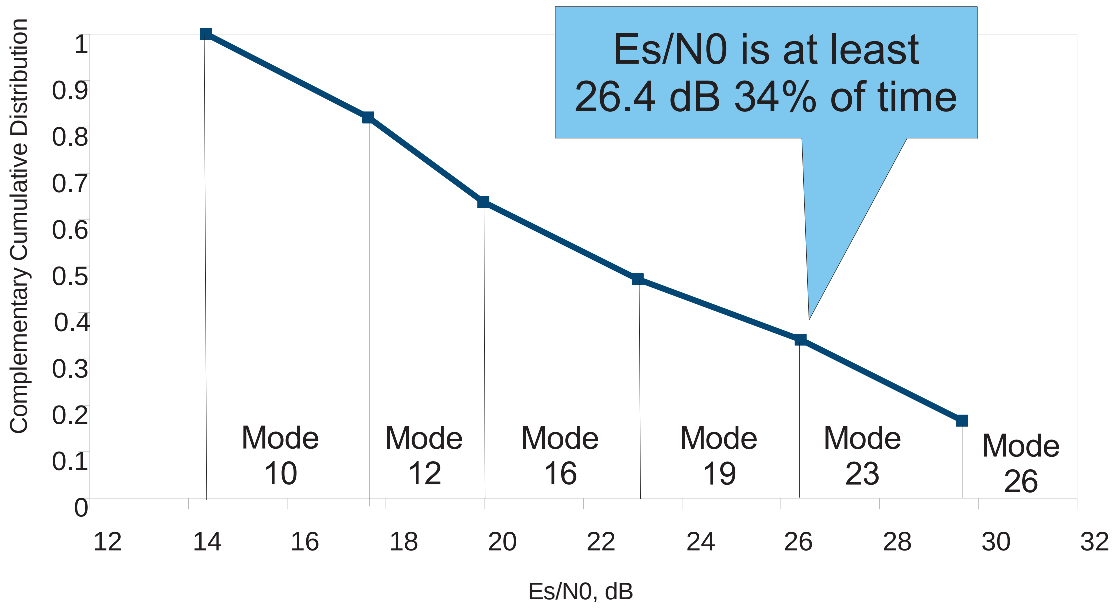
Section	Mode	Modulation	Bits per Channel use	Data Rate (Mbps)	Ideal Required Eb/N0 (dB) @CWER=1e-4	Ideal Required Es/N0 (dB) @CWER=1e-4	Margin (dB)	Losses (dB)	Required Es/N0 (dB), With margin And losses	Percent Time
1	10	8-PSK	2.10	841	4.33	7.56	3	3.8	14.36	17.96%
2	12	8-PSK	2.64	1055	6.63	10.84	3	3.8	17.64	18.21%
3	16	16-APSK	3.20	1280	6.42	11.47	3	5.5	19.97	16.65%
4	19	32-APSK	3.50	1398	7.46	12.90	3	7.2	23.10	13.06%
5	23	64-APSK	4.12	1647	8.47	14.62	3	8.8	26.42	17.45%
6	26	64-APSK	5.07	2027	10.82	17.87	3	8.8	29.67	16.67%

Average throughput: 1.364 Gbps

This is the corresponding Es/N0 profile:

E.g., SCCC mode 23:

Required Es/N0: 14.6 dB
(ideal, @ CWER=10^{-4})
Impairments: 8.8 dB
Margin: 3.0 dB
Required Es/N0: 26.4 dB



Es/N0 is at least 26.4 dB 34% of time

VCM Example: SCCC vs. NASA LDPC Codes

VCM with SCCC [4]:

Section	Mode	Modulation	Bits per Channel use	Data Rate (Mbps)	Ideal Required Eb/N0 (dB) @CWER=1e-4	Ideal Required Es/N0 (dB) @CWER=1e-4	Margin (dB)	Losses (dB)	Required Es/N0 (dB), With margin And losses	Percent Time
1	10	8-PSK	2.10	841	4.33	7.56	3	3.8	14.36	17.96%
2	12	8-PSK	2.64	1055	6.63	10.84	3	3.8	17.64	18.21%
3	16	16-APSK	3.20	1280	6.42	11.47	3	5.5	19.97	16.65%
4	19	32-APSK	3.50	1398	7.46	12.90	3	7.2	23.10	13.06%
5	23	64-APSK	4.12	1647	8.47	14.62	3	8.8	26.42	17.45%
6	26	64-APSK	5.07	2027	10.82	17.87	3	8.8	29.67	16.67%

Average throughput: 1.364 Gbps

VCM with NASA LDPC codes, using same Es/N0 profile:

Section	Mode	Code	Modulation	Bits per Channel use	Data Rate (Mbps)	Ideal Required Eb/N0 (dB) @CWER=1e-4	Ideal Required Es/N0 (dB) @CWER=1e-4	Margin (dB)	Losses (dB)	Required Es/N0 (dB), With margin And losses	Percent Time
1	10	AR4JA(16K,2/3)	8-PSK	2.00	800	3.70	6.71	3	3.8	13.51	7.57%
2	11	AR4JA(16K,4/5)	8-PSK	2.40	960	5.14	8.94	3	3.8	15.74	9.53%
3	14	AR4JA(16K,2/3)	16-APSK	2.67	1067	4.72	8.98	3	5.5	17.48	16.89%
4	15	AR4JA(16K,4/5)	16-APSK	3.20	1280	6.14	11.19	3	5.5	19.69	10.00%
5	16	C2	16-APSK	3.50	1399	7.50	12.94	3	5.5	21.44	12.78%
6	19	AR4JA(16K,4/5)	32-APSK	4.00	1600	7.88	13.90	3	7.2	24.10	7.18%
7	20	C2	32-APSK	4.37	1749	9.32	15.73	3	7.2	25.93	36.06%

Average throughput: 1.384 Gbps

Conclusions

Conclusions

- SCCC and LDPC are similar in many practical ways:
  - Code rates (SCCC 0.36 to 0.9, LDPC: 0.5 to 0.875)
  - Blocklengths (SCCC 5758 to 43678, LDPC: 1024 to 16384)
  - Both can be used with higher order modulations
  - Bandwidth/power efficiency performance (LDPC is a few tenths of a dB better)
- For a practical example, VCM+LDPC performs similar to VCM+SCCC

References

References

[1] "TM synchronization and channel coding – Summary of concept and rationale," CCSDS 130.1-G-1 Green Book, June 2006.

[2] J. Hamkins, "Performance of low-density parity-check coded modulation," Proceedings of the Aerospace Conference, Big Sky, MT, Mar. 2010.

[3] "Flexible advanced coding and modulation scheme for high rate telemetry applications," CCSDS 131.0-R draft Red Book, September 2009.

[4] M. Bertinelli, N. Toptsidis, P.-D. Arapoglu, "VCM performance for LEO satellites at 26 GHz," CCSDS presentation, May 3-7, 2010.

Backup

SCCC Performance Details

Mode	Modulation	Bits per Channel use	Data Rate (Mbps)	Ideal Required Eb/N0 (dB) @CWER=1e-4	Ideal Required Es/N0 (dB) @CWER=1e-4	Margin (dB)	Losses (dB)	Required Es/N0 (dB), With margin And losses
1	QPSK	0.71	284	0.96	-0.52	3	3	5.48
2	QPSK	0.86	344	0.98	0.32	3	3	6.32
3	QPSK	1.04	415	1.29	1.45	3	3	7.45
4	QPSK	1.21	486	1.90	2.74	3	3	8.74
5	QPSK	1.39	557	2.30	3.74	3	3	9.74
7	8-PSK	1.39	557	2.39	3.83	3	3.8	10.63
6	QPSK	1.63	652	3.17	5.29	3	3	11.29
8	8-PSK	1.63	652	2.99	5.11	3	3.8	11.91
9	8-PSK	1.84	735	3.56	6.20	3	3.8	13.00
10	8-PSK	2.10	841	4.33	7.56	3	3.8	14.36
11	8-PSK	2.37	948	5.33	9.08	3	3.8	15.88
13	16-APSK	2.37	948	4.37	8.12	3	5.5	16.62
14	16-APSK	2.64	1055	4.90	9.11	3	5.5	17.61
12	8-PSK	2.64	1055	6.63	10.84	3	3.8	17.64
15	16-APSK	2.90	1161	5.61	10.24	3	5.5	18.74
16	16-APSK	3.20	1280	6.42	11.47	3	5.5	19.97
17	16-APSK	3.50	1398	7.52	12.96	3	5.5	21.46
18	32-APSK	3.20	1280	6.89	11.94	3	7.2	22.14
19	32-APSK	3.50	1398	7.46	12.90	3	7.2	23.10
20	32-APSK	3.82	1529	8.04	13.87	3	7.2	24.07
21	32-APSK	4.12	1647	8.81	14.95	3	7.2	25.15
23	64-APSK	4.12	1647	8.47	14.62	3	8.8	26.42
22	32-APSK	4.44	1778	9.76	16.24	3	7.2	26.44
24	64-APSK	4.44	1778	9.13	15.61	3	8.8	27.41
25	64-APSK	4.77	1908	9.93	16.72	3	8.8	28.52
26	64-APSK	5.07	2027	10.82	17.87	3	8.8	29.67
27	64-APSK	5.39	2157	11.85	19.16	3	8.8	30.96

NASA LDPC Performance Details

Code	Modulation	Bits per Channel use	Data Rate (Mbps)	Ideal Required Eb/N0 (dB) @CWER=1e-4	Ideal Required Es/N0 (dB) @CWER=1e-4	Margin (dB)	Losses (dB)	Required Es/N0 (dB), With margin And losses
AR4JA(16K,1/2)	BPSK	0.50	200	0.93	-2.08	3	2.2	3.12
AR4JA(16K,2/3)	BPSK	0.67	267	1.75	-0.01	3	2.2	5.19
AR4JA(16K,4/5)	BPSK	0.80	320	2.71	1.74	3	2.2	6.94
C2	BPSK	0.87	350	3.84	3.26	3	2.2	8.46
AR4JA(16K,1/2)	QPSK	1.00	400	0.93	0.93	3	3	6.93
AR4JA(16K,2/3)	QPSK	1.33	533	1.75	3.00	3	3	9.00
AR4JA(16K,4/5)	QPSK	1.60	640	2.71	4.75	3	3	10.75
C2	QPSK	1.75	700	3.84	6.27	3	3	12.27
AR4JA(16K,1/2)	8-PSK	1.50	600	2.28	4.04	3	3.8	10.84
AR4JA(16K,2/3)	8-PSK	2.00	800	3.70	6.71	3	3.8	13.51
AR4JA(16K,4/5)	8-PSK	2.40	960	5.14	8.94	3	3.8	15.74
C2	8-PSK	2.62	1049	6.60	10.79	3	3.8	17.59
AR4JA(16K,1/2)	16-APSK	2.00	800	3.32	6.33	3	5.5	14.83
AR4JA(16K,2/3)	16-APSK	2.67	1067	4.72	8.98	3	5.5	17.48
AR4JA(16K,4/5)	16-APSK	3.20	1280	6.14	11.19	3	5.5	19.69
C2	16-APSK	3.50	1399	7.50	12.94	3	5.5	21.44
AR4JA(16K,1/2)	32-APSK	2.50	1000	5.00	8.98	3	7.2	19.18
AR4JA(16K,2/3)	32-APSK	3.33	1333	6.40	11.63	3	7.2	21.83
AR4JA(16K,4/5)	32-APSK	4.00	1600	7.88	13.90	3	7.2	24.10
C2	32-APSK	4.37	1749	9.32	15.73	3	7.2	25.93