Closing the Gap to the Capacity of APSK: Constellation Shaping and Degree Distributions

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Outline

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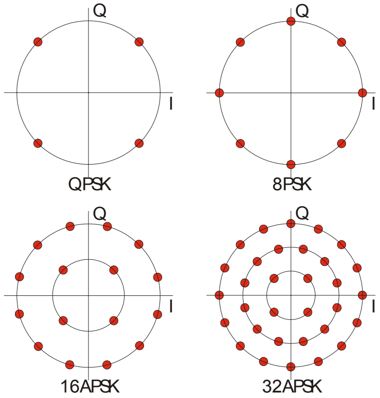
DVB-S2 Standard

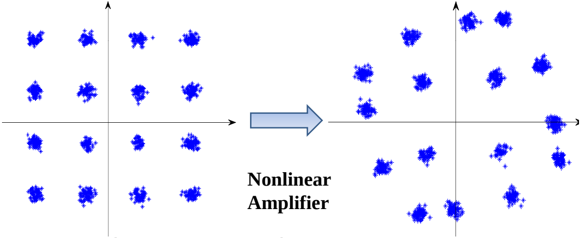
Features of Digital Video Broadcasting - Satellite - Second Generation:



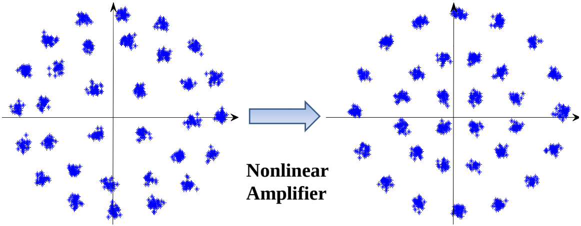
- LDPC Coding with two lengths and several rates.
- Amplitude-phase shift keying (APSK) up to $M = 32$.
- Variable and adaptive coding to support interactive services.

APSK vs. QAM for Nonlinear Channels

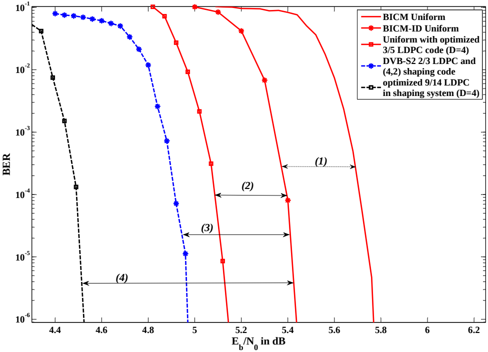
- Due to the use of TWTA, satellite channels are nonlinear.
- QAM constellations become highly distorted.



- APSK maintains distinct rings despite nonlinearity.



Contributions of This Paper



- Baseline system:
  - 32-APSK.
  - $R = 3$ bits/symbol.
  - AWGN channel.
- Performance improvements:
  1. BICM-ID decoder: *0.3 dB gain*.
  2. Optimized LDPC code's degree distribution: *0.3 dB gain*.
  3. Constellation shaping: *0.5 dB gain*.
  4. Both code optimization *and* constellation shaping: *0.9 dB gain*.

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Constellation Shaping

The energy efficiency can be improved by transmitting lower-energy signals more frequently than higher-energy signals.

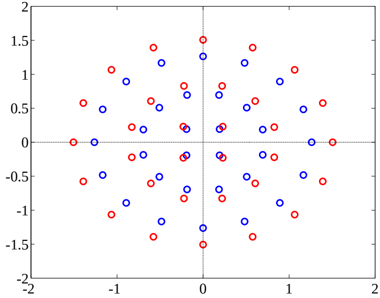


Figure : Uniform 32APSK vs. shaped 32APSK. Both constellations have the same energy.

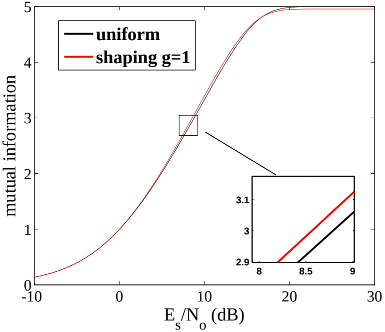
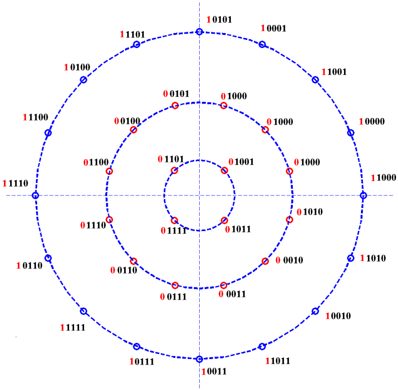


Figure : The capacity of shaped 32APSK is about 0.3 dB better than uniform 32APSK.

Shaping Through Signal Set Partitioning

- Partition the constellation into **two** equal-sized sub-constellations.
- Use a **shaping bit** to select between the two sub-constellations.
    - The lower-energy sub-constellation is selected more frequently.
    - Requires the shaping bit to be encoded so that it is not uniform.
- The remaining bits select from among the $M/2$ symbols in the selected sub-constellation with equal probabability.



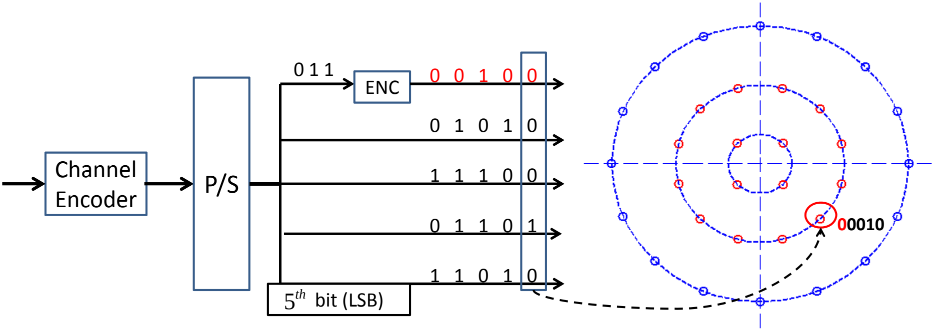
Shaping Encoder

- Shaping encoder maps k_s bits to a n_s bit shaping codeword.
- Code is designed with the goal of having more zeros than ones.
- Example $(k_s = 3, n_s = 5)$ code:

3 input data bits	5 output codeword bits
0 0 0	0 0 0 0 0
0 0 1	0 0 0 0 1
0 1 0	0 0 0 1 0
0 1 1	0 0 1 0 0
1 0 0	0 1 0 0 0
1 0 1	1 0 0 0 0
1 1 0	0 0 0 1 1
1 1 1	1 0 1 0 0

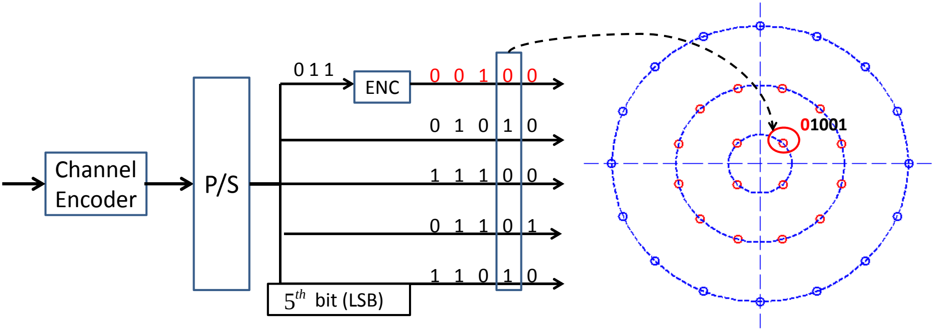
- $p_0 = 31/40$ is the probability of 0.
- $p_1 = 9/40$ is the probability of 1.

Shaping Operation



- Here, the $(5,3)$ shaping code is used as an example.
- The P/S block segments groups of 23 bits.
- Three bits delivered to the shaping encoder.

Shaping Operation



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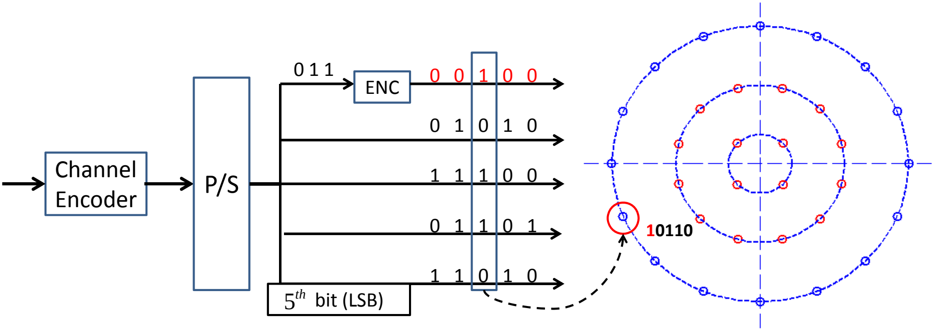

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DVB-S2 standardized LDPC code

Key features of the DVB-S2 LDPC code:

- Variable rate: $R_c = \frac{k_c}{n_c} = \{\frac{1}{4}, \frac{1}{3}, \frac{1}{2}, \frac{3}{5}, \frac{2}{3}, \frac{3}{4}, \frac{4}{5}, \frac{5}{6}, \frac{8}{9}, \frac{9}{10}\}$.
- Two lengths: $n_c = 16,200$ (short) and $n_c = 64,800$ (long).
- Systematic encoding.
- Last $m_c = n_c - k_c$ columns of $\mathbf{H}$ are a *dual diagonal* submatrix, making it an *extended irregular repeat accumulate* (eIRA) code[1].

- Constant row weight; i.e., *check regular*.
- Variable column weight, with $D = 3$ different values[2].

[1] M. Yang, W. E. Ryan, and Y. Li, "Design of efficiently encodable moderate-length high-rate irregular LDPC codes," *IEEE Trans. Commun.*, vol. 52, pp. 564–571, Apr. 2004.

[2] Not including the last column, which has a weight of 1.

EXIT charts

The *convergence threshold* is the SNR value in which the bit error rate of an LDPC-coded system starts dropping sharply.

- The value of the threshold depends on the *degree distribution*.

EXIT charts[3]

- Predict the convergence threshold.
- Can be used to identify good candidate degree distributions.
- However, because it is just a prediction, the candidate codes still need to be simulated to determine which is best.

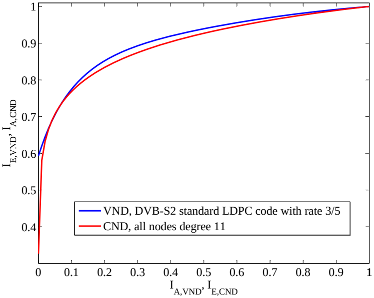

Figure : EXIT chart for the uniform system at $\mathcal{E}_b/N_0 = 4.93$ dB.

[3] S. ten Brink, G. Kramer, and A. Ashikhmin, "Design of low-density parity-check codes for modulation and detection," *IEEE Trans. Commun.*, vol. 52, pp. 670–678, Apr. 2004.

EXIT Charts with Constellation Shaping

When shaping is used, the variable-node decoder (VND) accounts for the effects of shaping.

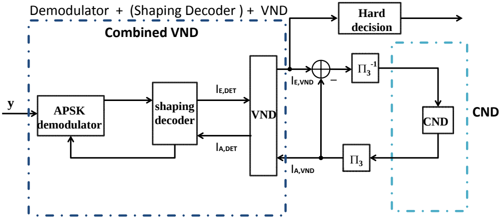

Figure : Model of decoder used for constructing EXIT charts.

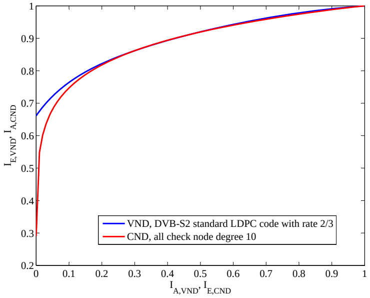

Figure : EXIT chart for the shaped system at $\mathcal{E}_b/N_0 = 4.53$ dB.

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Optimization Procedure

Common considerations:

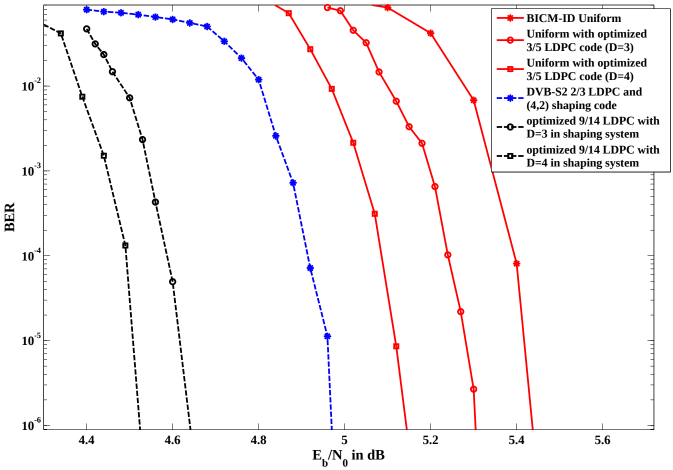
- Spectral efficiency set to $R = 3$ bits/symbol.
- Systematic eIRA code structure.
- Row-weights from DVB-S2 maintained.
- Either $D = 3$ or $D = 4$ distinct column weights.

Optimization steps:

- Optimize LDPC code for uniform modulation.
- Shaping with off-the-shelf DVB-S2 code.
- Jointly optimize the LDPC code and the shaping.

R_c	R_s	$\mathcal{E}_b/N_0$ in dB (BER $= 10^{-5}$)
3/5 (38880/64800)	1	standard: 5.42
		optimized (D=4) 5.13
2/3 (43200/64800)	2/4	standard: 4.96
9/14 (41661/64806)	2/3	optimized (D=4) 4.51

BER Comparison



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Conclusion

- Performance of LDPC-coded APSK can be improved by over 1 dB through the combination of:
  - BICM-ID instead of just BICM.
  - Constellation shaping.
  - Optimization of LDPC degree distributions.
- An extra 0.1 dB gain is achieved by using $D = 4$ distinct variable-node degrees, instead of just $D = 3$.
- Drawbacks:
  - Per-iteration complexity increase.
  - Slight increase in the PAPR.
- See journal version for more detail:
  M. C. Valenti and X. Xiang, "Constellation shaping for bit-interleaved LDPC coded APSK," *IEEE Trans. Commun.*, Oct. 2012.

Thank You.