Constellation Shaping for Bit-Interleaved Coded APSK

Dr. Matthew C. Valenti, **Xingyu Xiang**

Lane Department of Computer Science and Electrical Engineering
West Virginia University

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Outline

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Two Definitions

Constellation Shaping

- Idea: transmit constellation signal points with lower energy more frequently than those with higher energy
- Goal: save transmit power, or achieve performance gain under the same transmit power
- How: we use non-linear short length shaping code in our paper

APSK (Amplitude phase-shift keying)

- Included in DVB-S2 (second generation of the Digital Video Broadcasting Satellite) and other communication standards
- both spectral and energy efficient, well suited for nonlinear channels

Background

Information–theoretic Optimization

“Modulation Optimization”

R. D. Gaudenzi, K. Liolis in reference [2], [3], respectively

Practical Implementation

“System implementation”

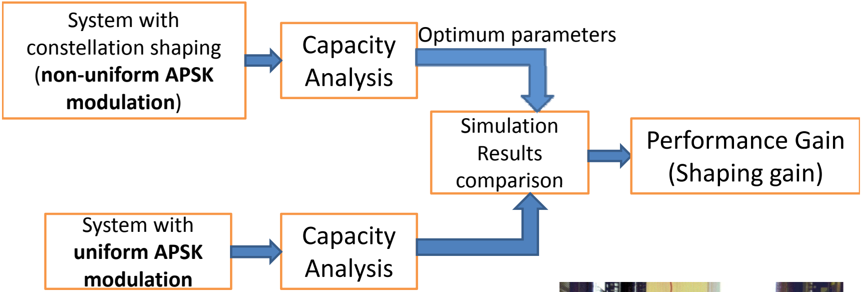
Stephane Y. Le Goff, et al. in reference [5, 6]

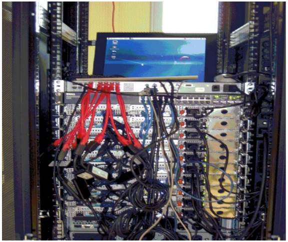
Joint optimization and actual system simulation

Our work

ICC 2011

General flowchart





Mutual Information(MI) and Channel Capacity

- MI between two random variables, X and Y is given by,

$$I(X;Y) = E\left[\log\left(\frac{p(Y|X)}{p(Y)}\right)\right]$$

- Channel Capacity is the highest rate at which information can be transmitted over the channel with low error probability. Given the channel and the receiver, capacity is defined as

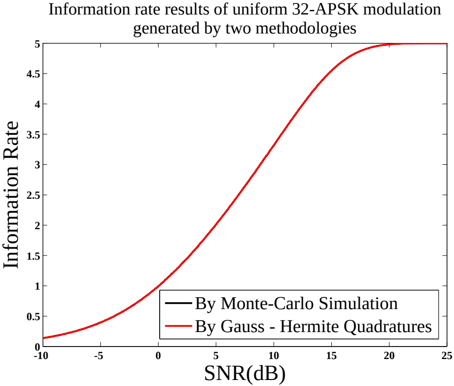
$$C = \max_{p(x)} I(X;Y)$$

The mutual information between output Y and input X is

$$I(X;Y) = \sum_{j=0}^{M-1} p(x_j) \int p(y|x_j) \log_2 \frac{p(y|x_j)}{p(y)} dy.$$

M - number of input symbols.

The integration can be solved using Gauss - Hermite Quadratures in AWGN channel.



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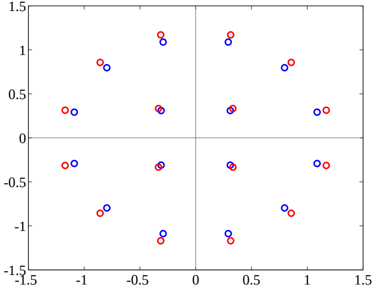
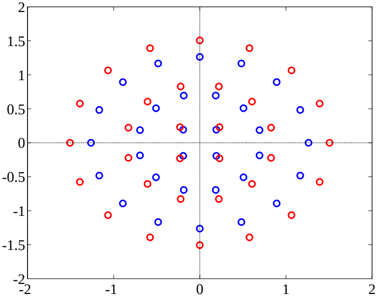
Constellation Shaping for APSK

- Our strategy is from S. LeGoff, IEEE T. Wireless, 2007.
- Use shaping code to choose low-energy symbols more frequently
- For a fixed average energy, shaping strategy spreads out the symbols



(a) 16apsk



(b) 32apsk

$$(\mathcal{E}_s = \Sigma_{i=0}^{M-1} p(x_i)\mathcal{E}_i = 1)$$

Shaping Encoder

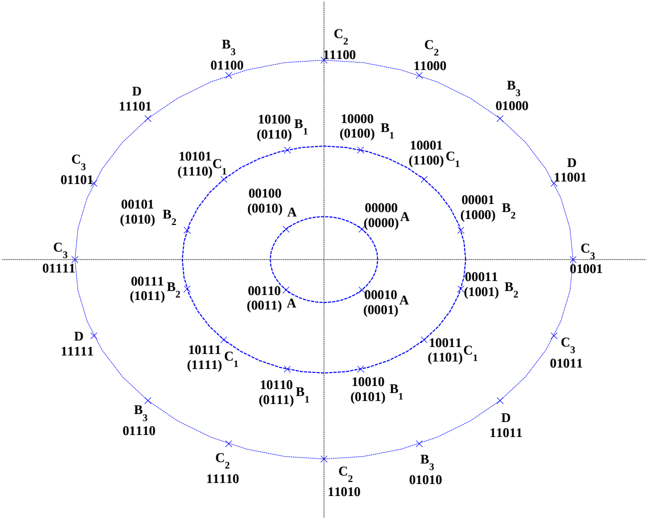
We design the shaping encoder to output more zeros than ones. One example is,

Table: (5,3) shaping code.

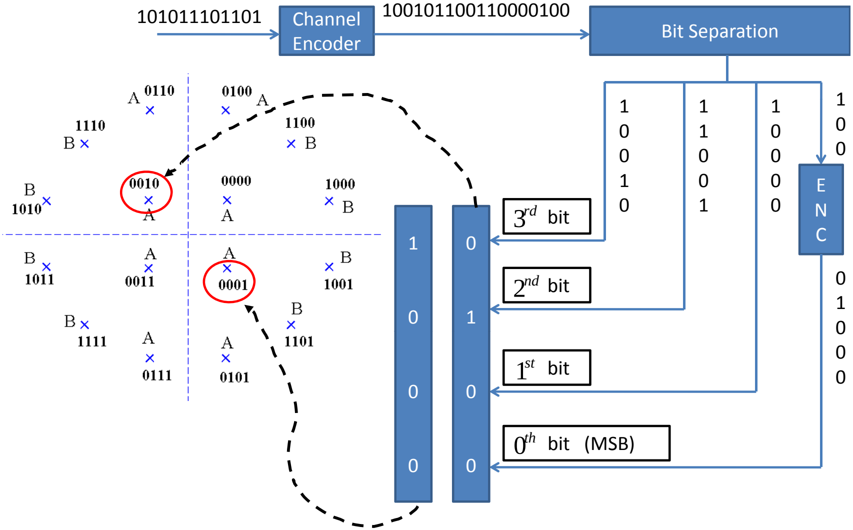
3 input data bits	5 output codeword bits
0 0 0	0 0 0 0 0
0 0 1	0 0 0 0 1
0 1 0	0 0 0 1 0
0 1 1	0 0 1 0 0
1 0 0	0 1 0 0 0
1 0 1	1 0 0 0 0
1 1 0	0 0 0 1 1
1 1 1	1 0 1 0 0

- p_0: the probability of 0 in the codeword table, ($p_0 = \frac{31}{40}$ above)
- p_1: the probability of 1 in the codeword table, ($p_1 = \frac{9}{40}$ above)

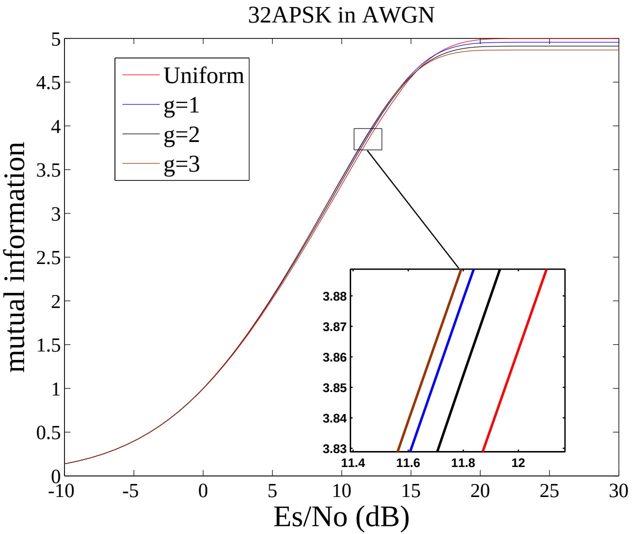
16/32 APSK symbol-labeling map based on DVB-S2 standard



Shaping Operation



32-APSK results with continuous output optimized over p_0



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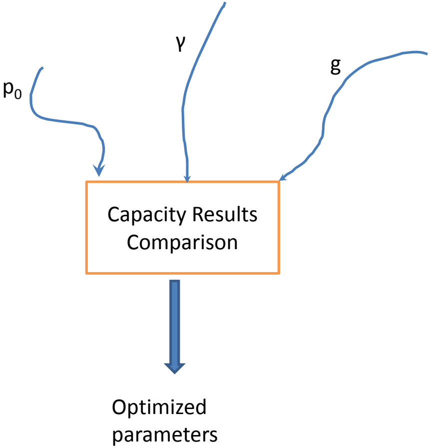
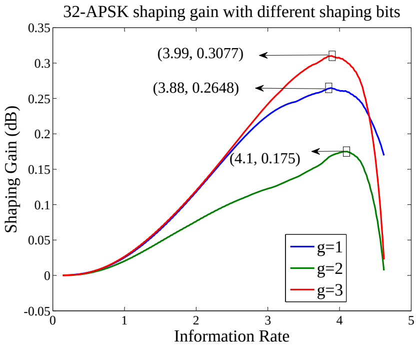
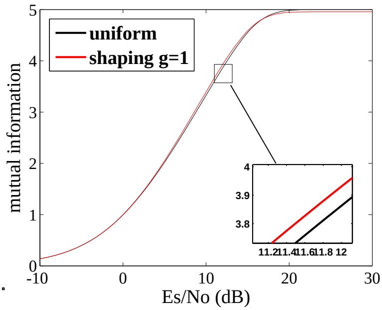
Algorithm used for jointly optimization



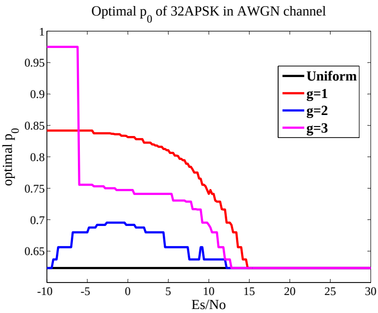
1. Fix the SNR, radius ratios γ, number of shaping bits(g).
2. Vary p_0 from 0.5 to 0.99 in increments of 0.005.
3. For each value of p_0, compute the corresponding information rate.
4. Go over the information rate array and find the highest information rate, record the values of p_0 and γ, g that produce it.

Shaping Gain and its evaluation

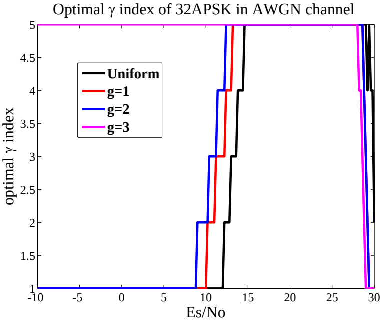




optimum p_0 and γ



(a) optimal p_0 of 32APSK



(b) optimal γ index of 32APSK

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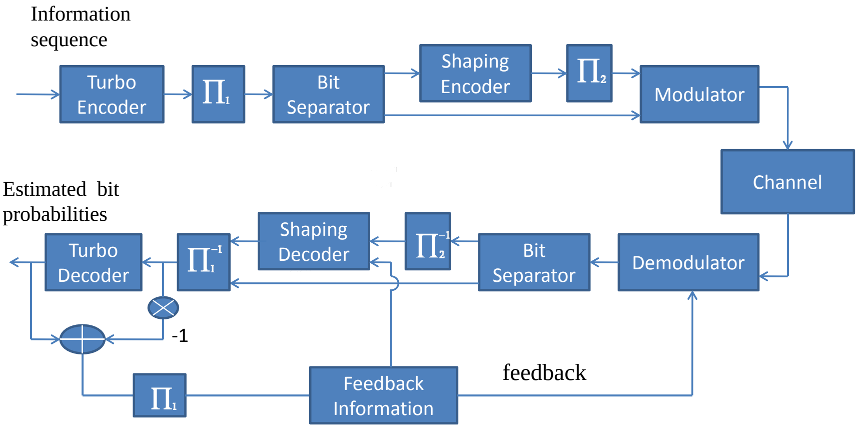
Implementation

BICM-ID (bit-interleaved coded-modulation with iterative decoding) System



Optimum Parameters

Maximum shaping gain achieved in AWGN for M-APSK with g shaping bits. The optimized p_0 and γ are shown. The related information rate and SNR value(in dB) are also listed.

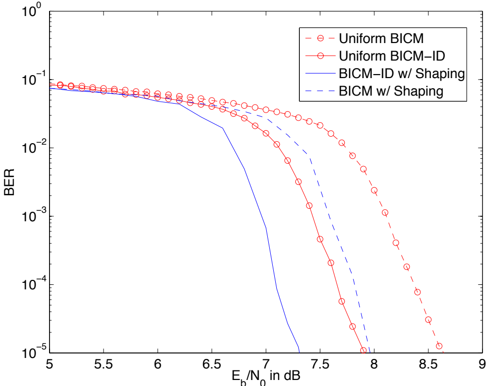
M	g	R	$\mathcal{E}_b/N_0$ (capacity value)	gain	p_0	γ
16	1	3.09	4.714 dB	0.091 dB	0.623	2.70
	2	2.95	4.077 dB	0.322 dB	0.688	2.57
32	1	3.88	5.915 dB	0.265 dB	0.716	{2.64,4.64}
	2	4.06	6.517 dB	0.175 dB	0.623	{2.53,4.30}
	3	3.89	5.898 dB	0.310 dB	0.656	{2.53,4.30}

BER Curves

Parameters used for the 32-APSK simulation

γ	R	R_c	R_s	$\mathcal{E}_b/N_0$ (capacity value)
{2.64,4.64}	3.849	5000/6491	1	6.092 dB
	3.858	5000/6190	7/9	5.834 dB

BER curves of 32-APSK in AWGN at rate R=3.85 bits/symbol



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Conclusion

- The simple constellation-shaping strategy considered in this paper can achieve shaping gains of about 0.6 dB.
- This work can be further extended to include LDPC code, which will make the system fully compatible with DVB-S2 standard
- Extrinsic information transfer chart (EXIT chart) can be used to optimize the parameter of the error correction code