Performance of Variable Coded Modulations over a Nonlinear Channel for VCM Protocol Red Book

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• Goal
  – Evaluate the performance of the Recommended Standard’s codes and modulations specified in the “Variable Coded Modulation Protocol” Red Book (CCSDS 431.1-R-0.1), over a nonlinear channel.

• Objectives:
  – Perform simulations that identifies the operating Eb/No required to achieve a CWER of 1e-4 over a nonlinear channel for a subset of the following MODCOD combinations:
    • Channel Codes:
      – AR4JA (Rate 1/2, 2/3, 4/5) LDPC codes (K=16384), C2 LDPC codes
    • Modulations:
      – BPSK, QPSK, 8-PSK, 16-APSK, 32-APSK, 64-APSK
  – Compare against performance over an ideal AWGN channel with simulation results presented in input paper, SLS-CS_18-09.
End-to-End Simulation

Transmit

Binary Data Source

Encoder

Digital Modulator

Pulse Shaper

Power Amplifier

Phase Noise

Channel Model

Ka-Band TWTA:
- Memoryless Lookup Table (AM/AM, AM/PM)

SRRC:
- Roll-off: 0.35
- Length: 16 sym

AWGN

Matched Filter

Soft Decision Baseband Demodulator

Decoder

Receive

Carrier Phase Recovery:
- Decision-Directed Costas Loop
- 2nd Order
- Norm. Loop BW: 1e-5

Symbol Timing Recovery:
- Gardner’s Algorithm
- 2nd Order
- Norm. Loop BW: 1e-5

LLR Calculation:
- Floating Point

MATLAB Built-in LDPC Decoder:
- 200 Iterations

LDPC Codes:
- AR4JA Rate 1/2
- AR4JA Rate 2/3
- AR4JA Rate 4/5
- C2 Rate 7/8

Mod Symbol Rate:
- 100Mmps

Modulations:
- BPSK
- QPSK
- 8-PSK
- 16-APSK
- 32-APSK
- 64-APSK

SRRC:
- Roll-off: 0.35
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MATLAB Built-in LDPC Decoder:
- 200 Iterations

Transmit

Receive

4 Samples/Symbol

4 Samples/Symbol

4 Samples/Symbol

4 Samples/Symbol

Transmit

Receive

4 Samples/Symbol
## Signal Constellations

**BPSK**

**QPSK, Gray Mapping**

**8-PSK, Gray Mapping**

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Code Rate</th>
<th>Constellation Ratio Specification</th>
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<tbody>
<tr>
<td>16-APSK</td>
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<td>$r_2/r_1 = 3.15$</td>
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<td>2/3</td>
<td>$r_2/r_1 = 3.15$</td>
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<tr>
<td></td>
<td>4/5</td>
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<td></td>
<td>7/8</td>
<td>$r_2/r_1 = 2.63$</td>
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<td>32-APSK</td>
<td>1/2</td>
<td>$r_2/r_1 = 4.00$, $r_3/r_1 = 8.00$</td>
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<tr>
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<td>2/3</td>
<td>$r_2/r_1 = 3.15$, $r_3/r_1 = 6.25$</td>
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<td>4/5</td>
<td>$r_2/r_1 = 2.72$, $r_3/r_1 = 4.87$</td>
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<td>7/8</td>
<td>$r_2/r_1 = 2.57$, $r_3/r_1 = 4.41$</td>
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<td>64-APSK</td>
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<td>$r_2/r_1 = 2.73$, $r_3/r_1 = 6.31$</td>
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<td>7/8</td>
<td>$r_2/r_1 = 2.73$, $r_3/r_1 = 6.31$</td>
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</table>

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Details of Channel Model

- **Power Amplifier**
  - TWTA model from SCCC Green Book CCSDS 130.11-G-0 is used.
  - AM/AM and AM/PM nonlinear distortions are modeled and applied as memoryless lookup tables.

- **Phase Noise**
  - Phase noise profile from input paper SLS-RFM_09-09 “ESA advanced coding and modulation performance under realistic channel conditions” is used.
Analysis Approach

- Adopted analysis approach applied in the SCCC Green Book CCSDS 130.11-G-0 using figure-of-merit (FOM) known as “Total Degradation” (TD).

\[ TD = \left( \frac{E_b}{N_0} \right)_{NL} - \left( \frac{E_b}{N_0} \right)_{AWGN} + OBO \ (dB) \]

- Amplifier output back-off that represents measured reduction in available power in the link.
- "Demodulation Loss" – Ratio between power needed at receiver to achieve CWER of 1e-4 over the non-linear channel and the linear AWGN channel.

\[ \frac{E_b}{N_0} \] required on a nonlinear channel to achieve CWER of 1e-4

\[ \frac{E_b}{N_0} \] required on ideal AWGN channel to achieve CWER of 1e-4

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Analysis Approach (Cont.)

• For each VCM mode:
  1. Perform IBO/OBO optimization by means of total degradation (TD).
  2. Report Eb/No required to achieve a CWER of 1e-4 over the specified nonlinear channel.
  3. Apply distortion mitigation to decrease TD and repeat steps 1-2.

• Mitigation techniques considered:
  1. Centroidal pre-distortion (Refer to “DVB-S2 modem algorithms design and performance over typical satellite channels” by Casini)
  2. Ideal sample-by-sample phase post-distortion de-rotation *
  3. Receiver mean phase de-rotation *

* We are currently analyzing these mitigation techniques, results are pending.
TD Optimization without Distortion Mitigation - Preliminary Simulation Results

VCM 9: QPSK, Rate 2/3 AR4JA LDPC
VCM 14: 8PSK, Rate 4/5 AR4JA LDPC
VCM 23: 32APSK, Rate 7/8 C2 LDPC

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# Optimum TD Simulation Results without Distortion Mitigation

<table>
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<tr>
<th>VCM Mode</th>
<th>Code</th>
<th>K</th>
<th>N</th>
<th>Modulation</th>
<th>Ideal Required (Eb/No)_{AWGN} [dB] @ CWER=1e-4</th>
<th>Required (Eb/No)_{AWGN} [dB] @ CWER=1e-4</th>
<th>IBO [dB]</th>
<th>OBO [dB]</th>
<th>TD [dB]</th>
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</tr>
</tbody>
</table>

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**With Phase Noise**
- 1 Frame Error
- 5 Frame Errors

**No Phase Noise**
- 30 Frame Errors
Summary

• We have verified that the LDPC VCM modes operate with non-linear distortions.
• The TD FOM is a useful measure to study the total end-to-end losses for non-linear channels but may not be relevant to an actual system.
• We are researching other methods of mitigation and will report when studies are completed.
Acronym List

• VCM – Variable Coded Modulation
• LDPC – Low Density Parity Check
• CWER – Codeword Error Rate
• IBO – Input Back-off
• OBO – Output Back-off
• TD – Total Degradation
• AWGN – Additive White Gaussian Noise
• SCCC – Serially Concatenated Convolutional Code
• TWTA – Traveling Wave Tube Amplifier
• Eb/No – Bit-Energy-to-Noise-Power-Density Ratio
• SRRC – Square Root Raised Cosine
• FOM – Figure of Merit