

# Joint Viterbi Detector/Decoder for Satellite Comms.

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# Outline

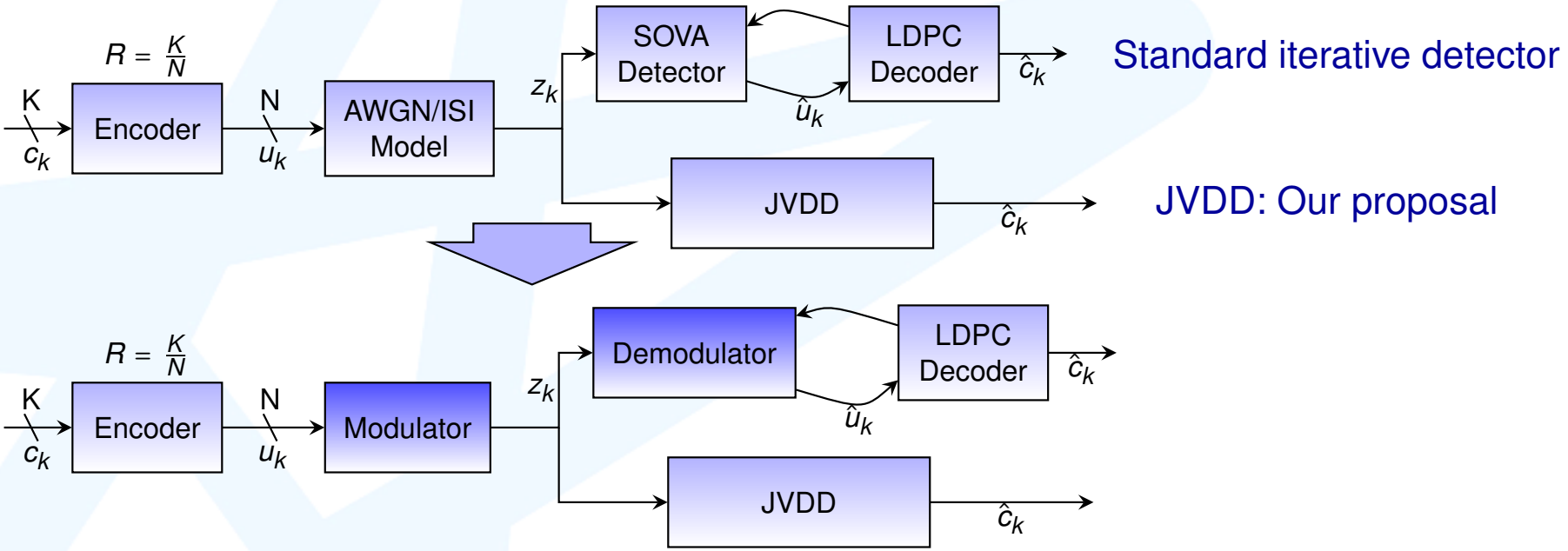

1. Introduction and Background
   - Satellite broadband DVB-S2
   - LDPC Encoder/Decoder
   - DVB-S2 Modulator/Demodulator
2. The JVDD
   - The JVDD Algorithm
   - JVDD Codes
3. JVDD vs iterative detector: Simulation Results
4. Conclusion

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# Communication channel model

This work is being carried out over a 3+ year project
Started: May 2014, ending: Aug 2017, funding: S$1m.
Our standard communication channel model uses iterative detection and LDPC codes to correct errors on the channel




Joint Viterbi Detector/Decoder (JVDD) is a higher performing alternative scheme to existing iterative detection schemes

The current work: apply JVDD to the satellite DVB-S2 standard

LDPC:Low Density Parity Check
AWGN:Additive White Gaussian Noise
SOVA:Soft-output Viterbi Algorithm
ISI:Intersymbol Interference
JVDD:Joint Viterbi Detector/Decoder
DVB-S2:Digital Video Broadcasting Satellite 2

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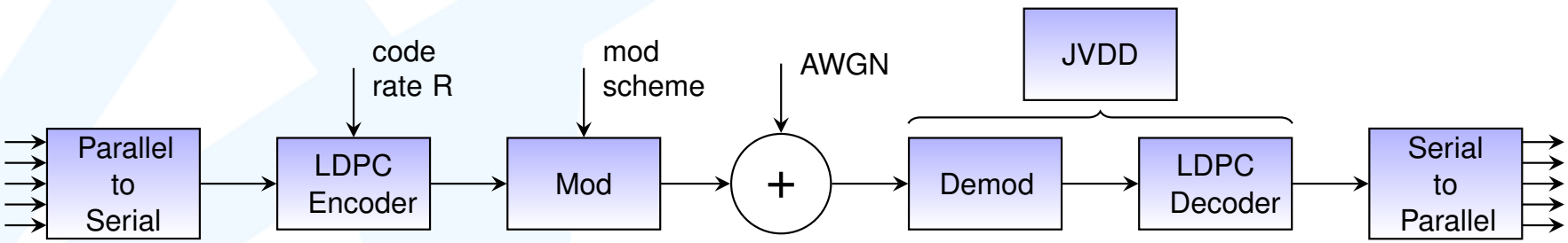
# Satellite broadband DVB-S2

Satellite broadband communication protocols defined by DVB-S2 standards

- DVB-S originally proposed in 1993 by Digital Video Broadcasting (DVB) consortium
- DVB-S2 second generation proposed in 2003.
- The DVB-S2 standard uses LDPC codes with rates
  - code rate R = $1/4, 1/3, 2/5, 1/2, 3/5, 4/5, 5/6, 8/9, 9/10$

  and PSK modulation schemes
  - QPSK, 8PSK, 16APSK and 32APSK

  for each frame, dependent on the channel conditions.




LDPC:Low Density Parity Check
APSK:Amplitude Phase Shift Keying

PSK: Phase Shift Keying
QPSK: Quadrature Phase Shift Keying

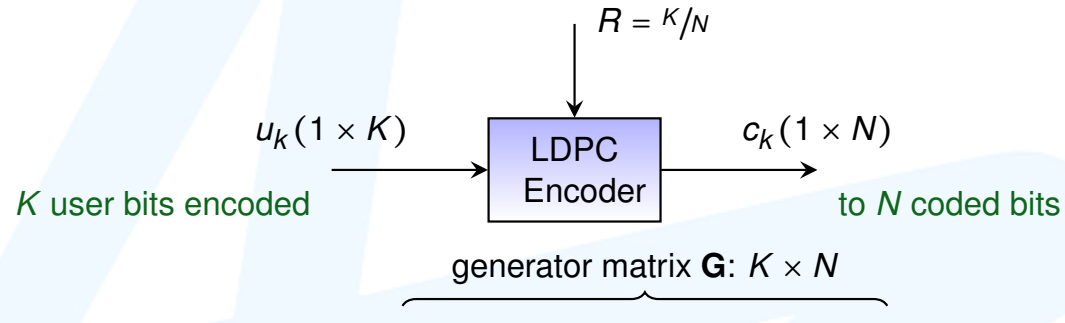
JVDD:Joint Viterbi Detector/Decoder
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# LDPC Encoder

The LDPC Encoder can be functionally depicted as matrix multiplication modulo 2 by the generator matrix.




generator matrix $\mathbf{G}$: $K \times N$

$$\mathbf{c} = \mathbf{uG} = \underbrace{[\,\mathbf{u}\,]}_{\text{user bits: } 1 \times K} \begin{bmatrix} 1 & & & \\ & 1 & & \\ & & \ddots & \\ & & & 1 \end{bmatrix} \begin{bmatrix} \\ \\ \mathbf{P} \\ \\ \end{bmatrix}_{M} = \underbrace{[\,\mathbf{u}}_{\text{Systematic bits}} \underbrace{|\,\mathbf{p}\,]}_{\substack{M \text{ Parity check bits} \\ M = N - K}}$$

- Systematic code has copy of the user bits in the codeword
- Parity check bits are modulo-2 summation of user bits
- Generator matrix **G** generates the codeword
- Parity check matrix **H** checks the codeword

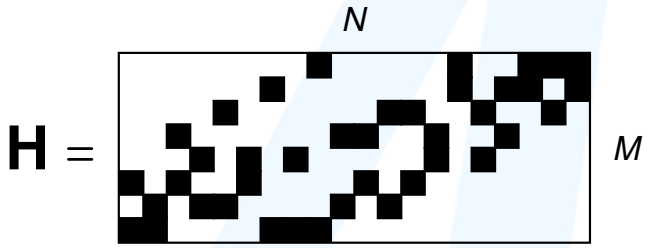


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# LDPC Decoder

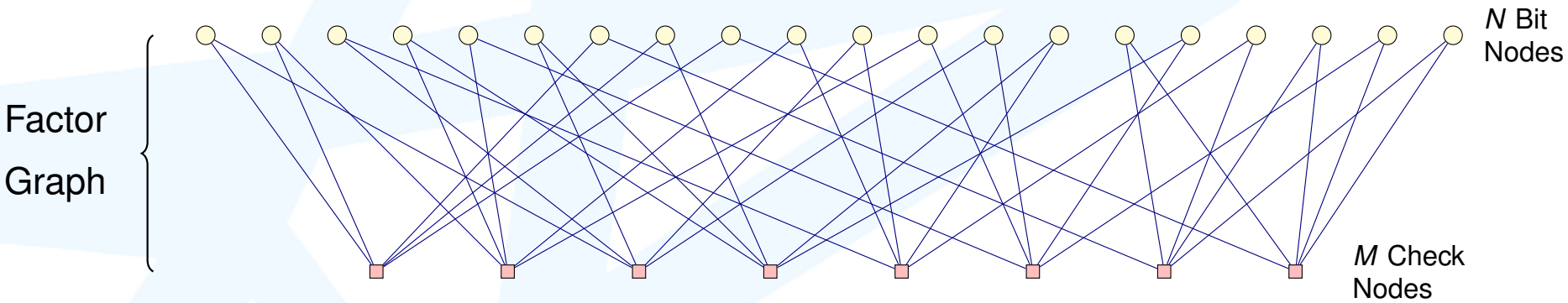
Parity check matrix **H**: $\mathbf{xH}^T = \mathbf{0}$ when **x** is a codeword

$\mathbf{xH}^T \neq \mathbf{0}$ when **x** is not a codeword




The *i*th check node in the factor graph is connected to the *j*th bit node

- If there is a 1 at $(i, j)$ in **H**



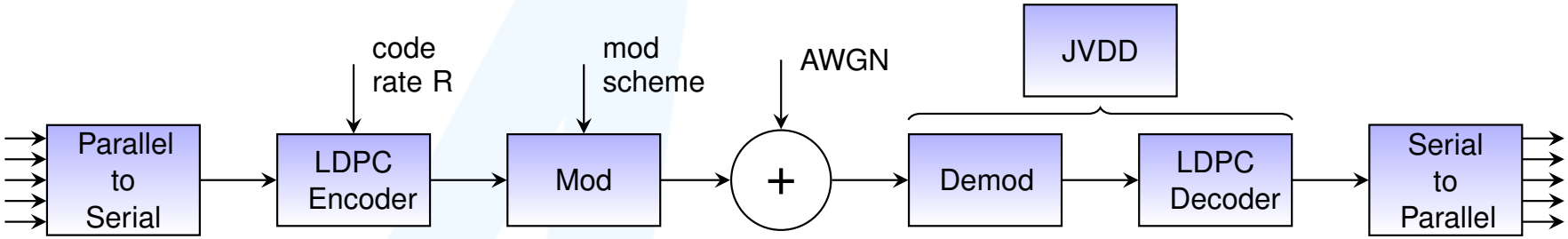

- Messages passed from bit-to-check and check-to-bit
  - Resulting in name: Message passing algorithm (MPA)
  - Also known as: Sum-product algorithm (SPA)
- Iterate bit-to-check and check-to-bit up to maximum iter
- DVB-S2: R = $^1/_4, ^1/_3, ^2/_5, ^1/_2, ^3/_5, ^4/_5, ^5/_6, ^8/_9, ^9/_{10}$
  - Depending on the channel conditions

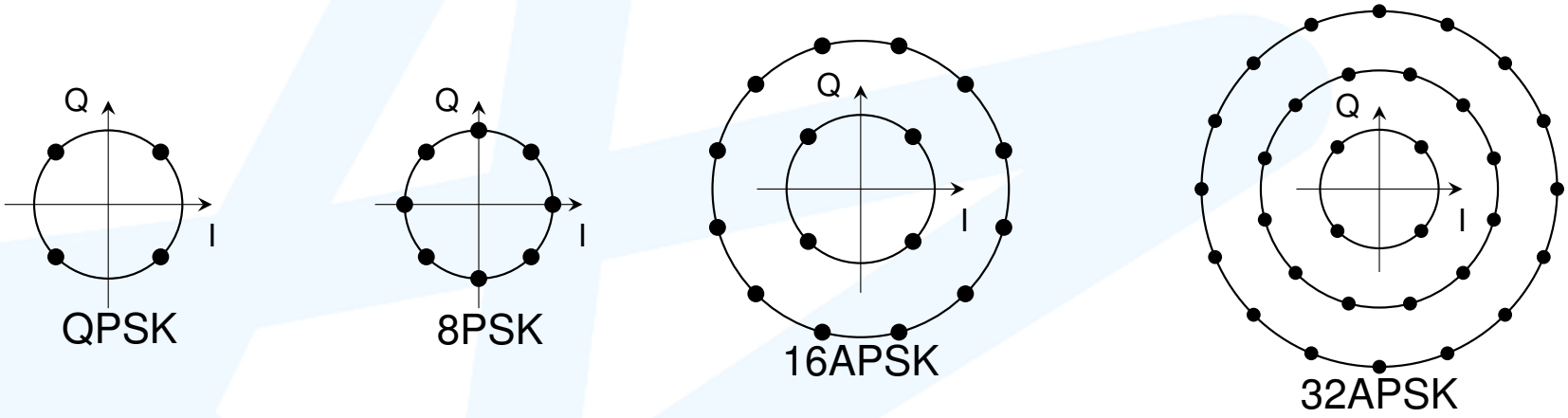
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# DVB-S2 Modulator/Demodulator




- Modulator maps sequences of bits onto the different constellation points for various schemes
- Demodulator computes probability of received constellation point given observed noisy readback
- Decoder uses information on code to correct errors.
- The JVDD does the demodulating and decoding jointly

LDPC:Low Density Parity Check
AWGN:Additive White Gaussian Noise
PSK: Phase Shift Keying
QPSK: Quadrature Phase Shift Keying
JVDD:Joint Viterbi Detector/Decoder
APSK: Amplitude/Phase Shift Keying

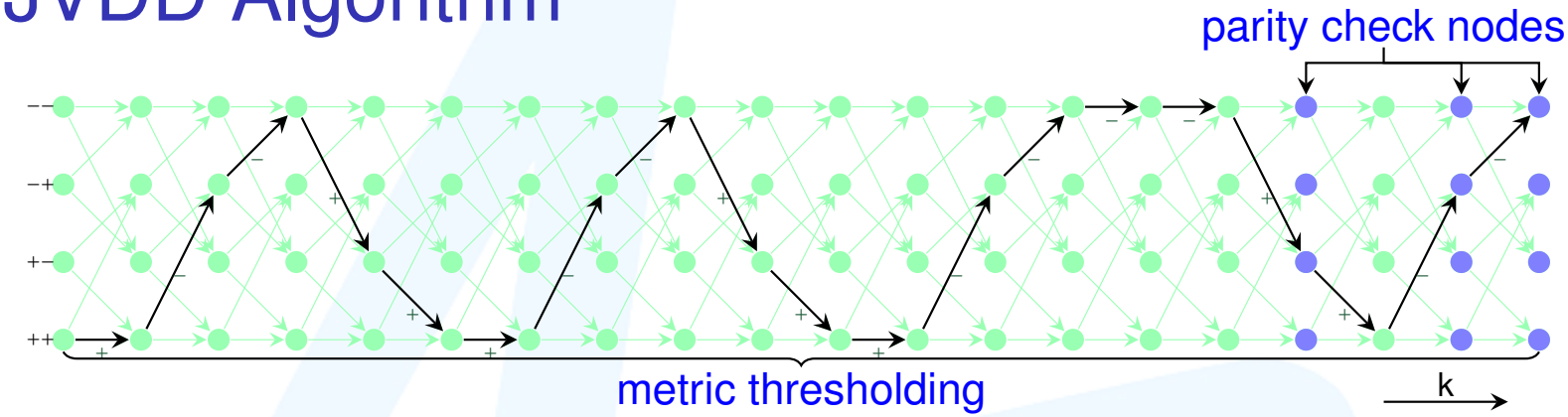
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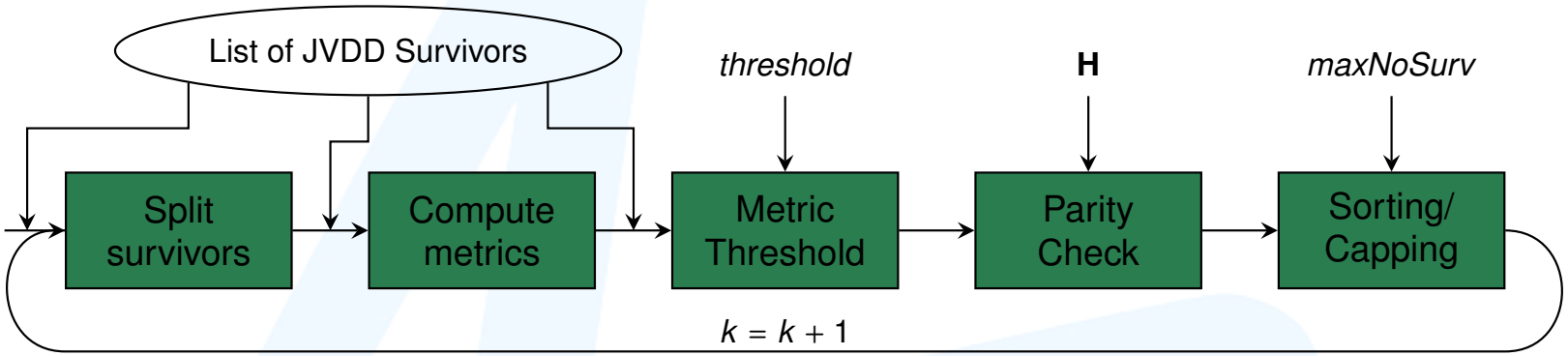
# The JVDD Algorithm




1. Metric thresholding (risky)
   - Metrics computed for each survivor (same as Viterbi)
   - Discard survivors where *metric* > *minMetric* + `threshold`
   - Number of surv grows as JVDD progresses
2. Parity checking (non-risky)
   - Discard survivors on certain nodes that fail parity check
   - Only retain survivors where: $\hat{\mathbf{c}}\mathbf{H}^T = \mathbf{0}$
   - Check occurs on last "1" of any row in the **H** matrix
3. Capping (risky)
   - Limit number of survivors to a given resource footprint
   - Order survivors and discard those with large metrics

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# JVDD Algorithm




- The number of survivors grows/shrinks as algorithm proceeds.
- Goal: manage number of survivors.
  - At a risk of losing the MMLC.
- The parity checking also brings down the number of survivors
  - No risk of losing the MMLC
  - Checking occurs at the position of the last ‘1’ of some row of the parity check matrix **H**.
- JVDD codes are designed with consideration to the position of the last ‘1’ in each row of **H**.

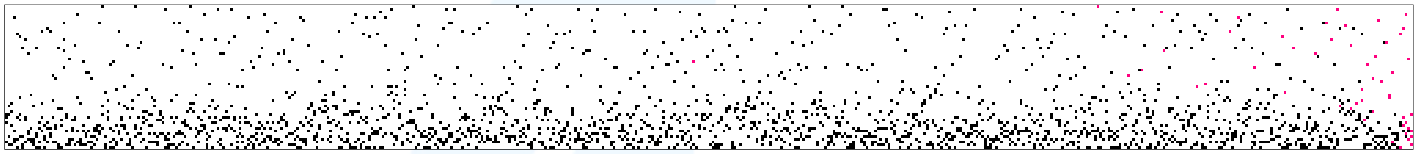
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# JVDD Codes

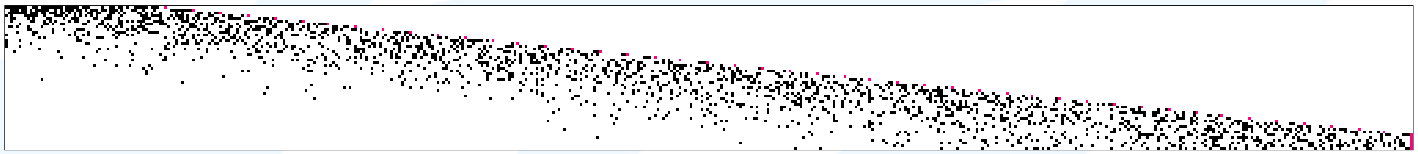
Random LDPC code



- Random codes with short-cycles removed → good for iterative detector
- Last 1 in each row clumped towards end → not good for JVDD

offset

JVDD code: GDLD

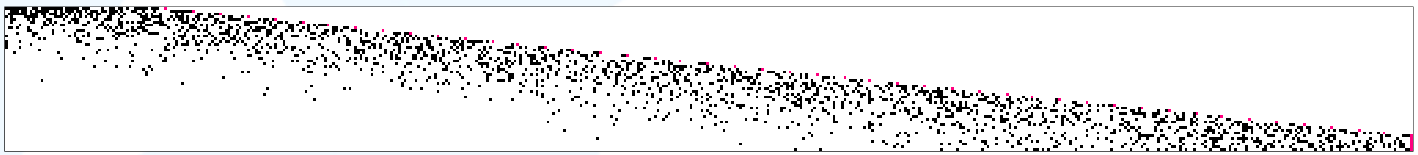


| Parameters | |
|---|---|
| $\sigma$ | std dev of Gaussian |
| $w_r$ | row weight |
| offset | horz offset of diag |

- JVDD codes → distribute last 1 in each row throughout trellis
- Parity checking operation occurs more evenly → fewer survivors

dx

JVDD code: VG-GDLD




| Parameters | |
|---|---|
| $\sigma$ | std dev of Gaussian |
| $w_r$ | row weight |
| dx | diagonal horz offset |
| dy | diagonal vert offset |

- Variable gradient code has 2 additional parameters: dx and dy
- More control over complexity and performance optimization

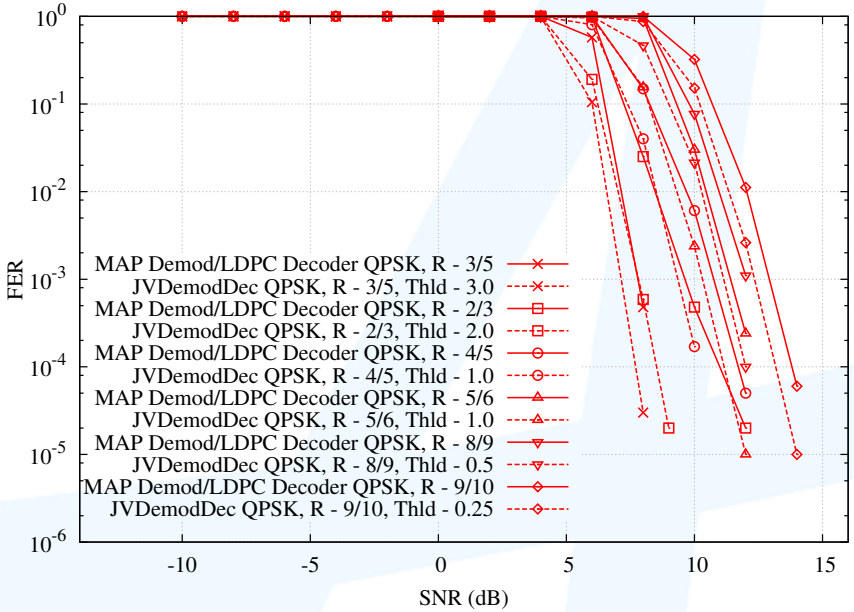
GDLD:Gaussian Distribution Linear Diagonal VG-GDLD: Variable Gradient GDLD.

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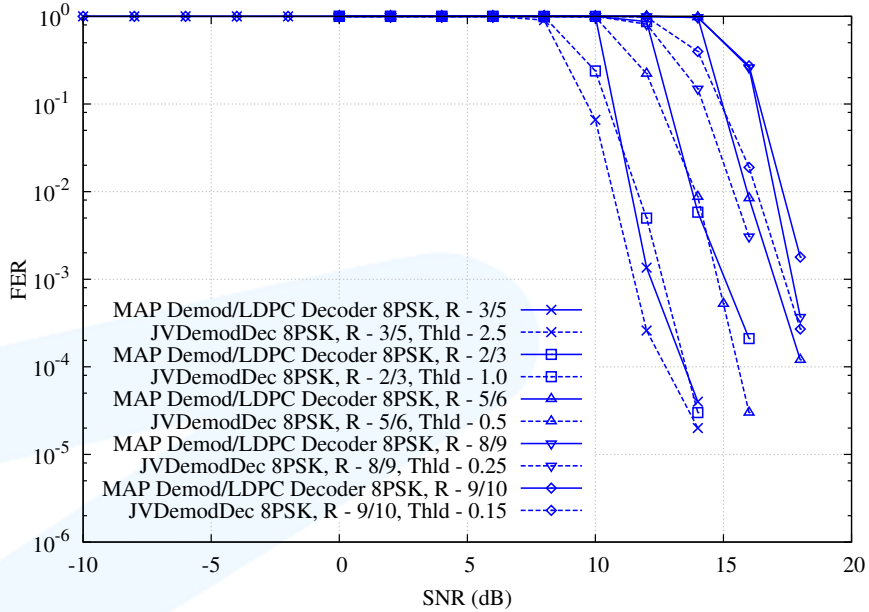

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# Simulation Results at CWL=1024

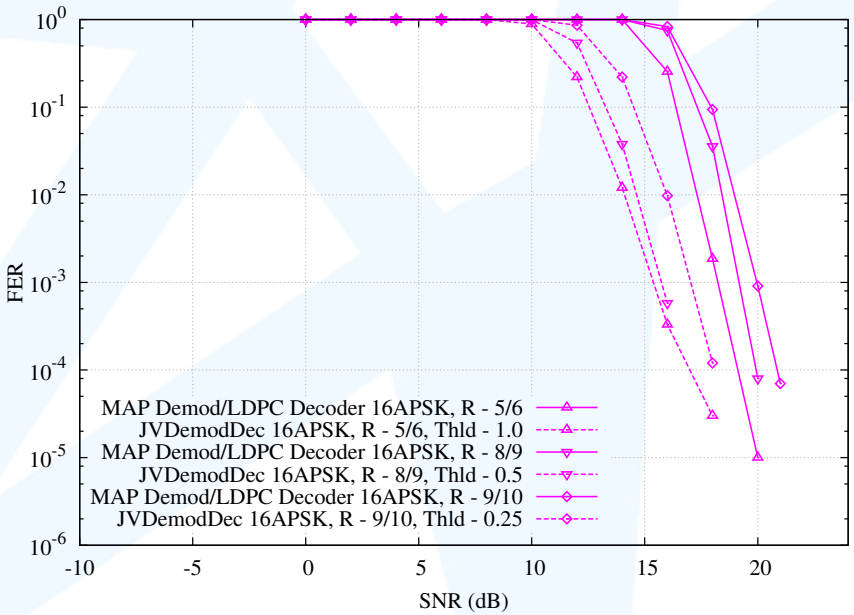
## QPSK



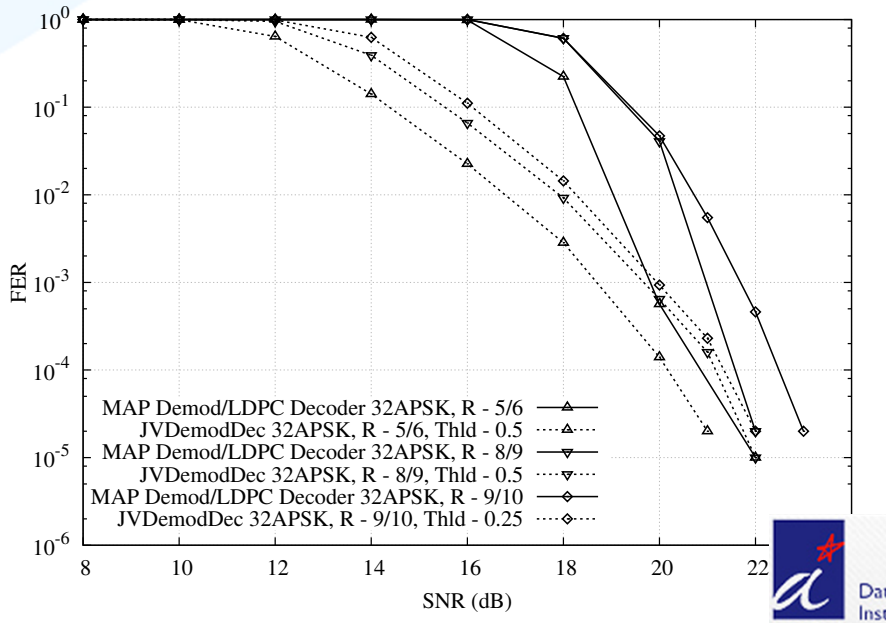

## 8PSK




## 16APSK



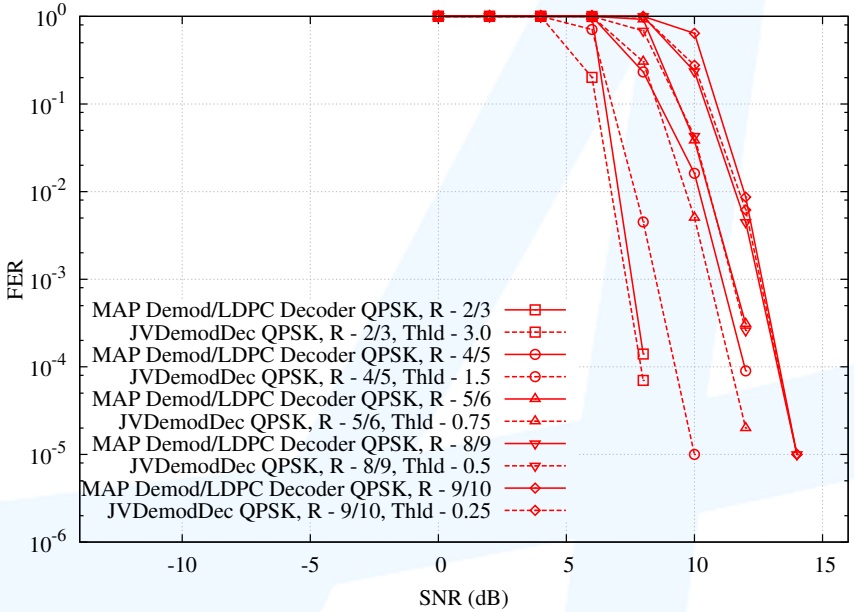

## 32APSK



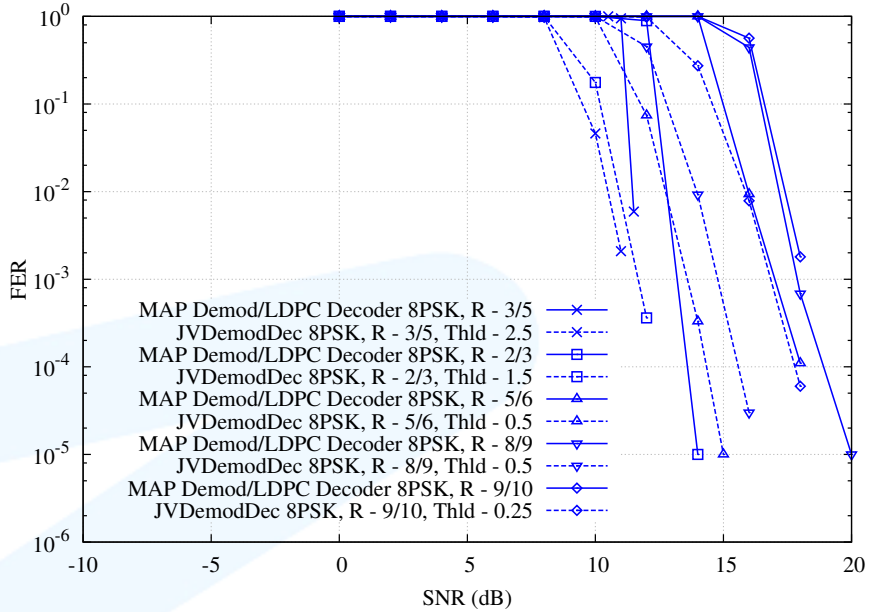

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# Simulation Results at CWL=2048

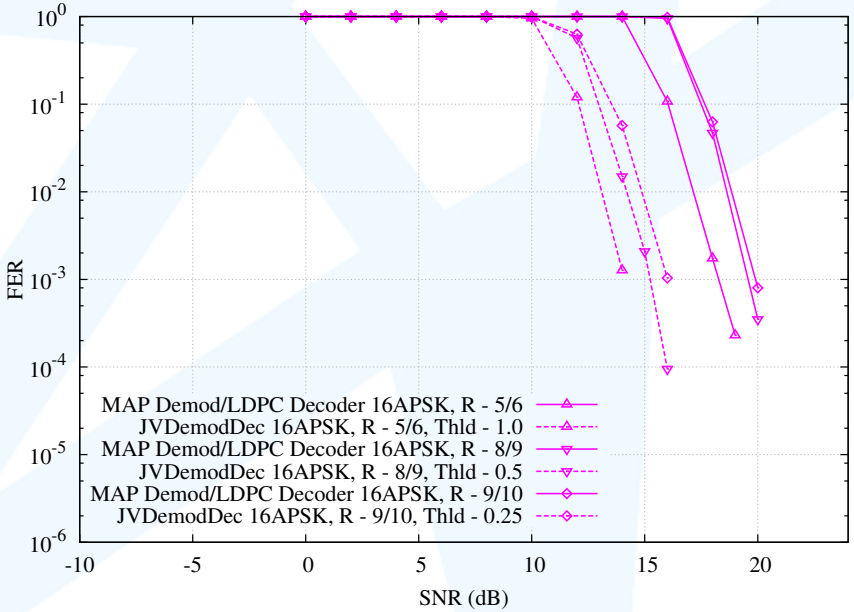
## QPSK




## 8PSK




## 16APSK




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# Conclusion and Further work

- We have gone over the DVB-S2 standard for satellite broadband communication
- The Joint Viterbi detector decoder is a novel scheme competing with existing demodulator/decoder
  - The JVDD has the potential to fit within the definitions of the DVB-S2 standard
  - To replace the demodulator/decoder structure therein
  - JVDD implemented at various parameters stipulated in the DVB-S2 standard:
    - Modulation: QPSK, 8PSK, 16APSK, 32APSK
    - Code rates varying from $\frac{1}{4}$ up to $\frac{9}{10}$.
- Simulation results show the JVDD outperforming the conventional iterative detector at CWL=1024 and 2048
- Main challenges remaining for JVDD:
  - Managing the complexity towards longer codeword lengths.