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Information Bottleneck Decoders for Message Passing Decoding with Coarse Quantization

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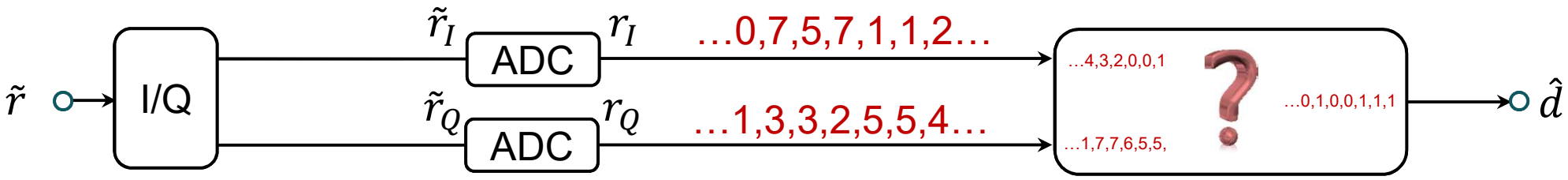
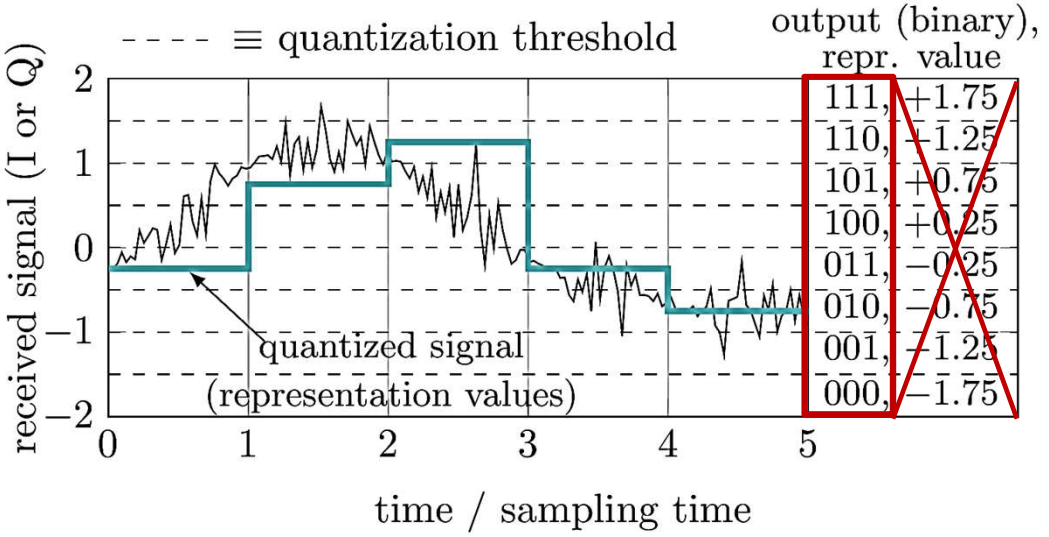
Outline

- Relevant information preserving discrete information processing
- The importance of coarse quantization in message passing decoding
- The *Information Bottleneck Method*
- Information bottleneck decoders for regular and irregular LDPC codes
- Information bottleneck receiver baseband processing
- Conclusions

Information Bottleneck Information Processing





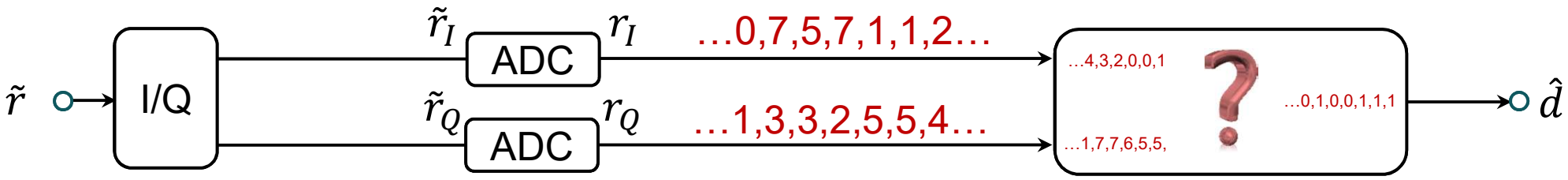
Coarse quantization → small bit width
Only process quantization indices?

Mutual information is independent of representation values:

$$I(X;Y) = \sum_x \sum_y p(x,y) \log \frac{p(x,y)}{p(x)\,p(y)}$$

Proposal: Information Bottleneck method

Information Bottleneck Information Processing

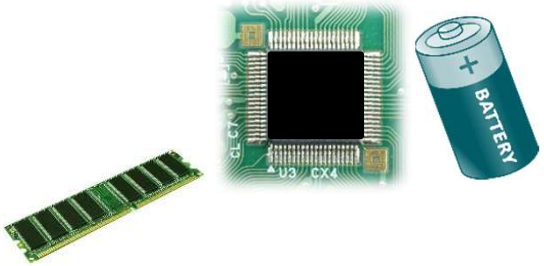


compact message representation

high throughput

chip area

simple ALUs (integer arithmetic)



power consumption

…

... with negligible performance degradation.

Implementation Aspects

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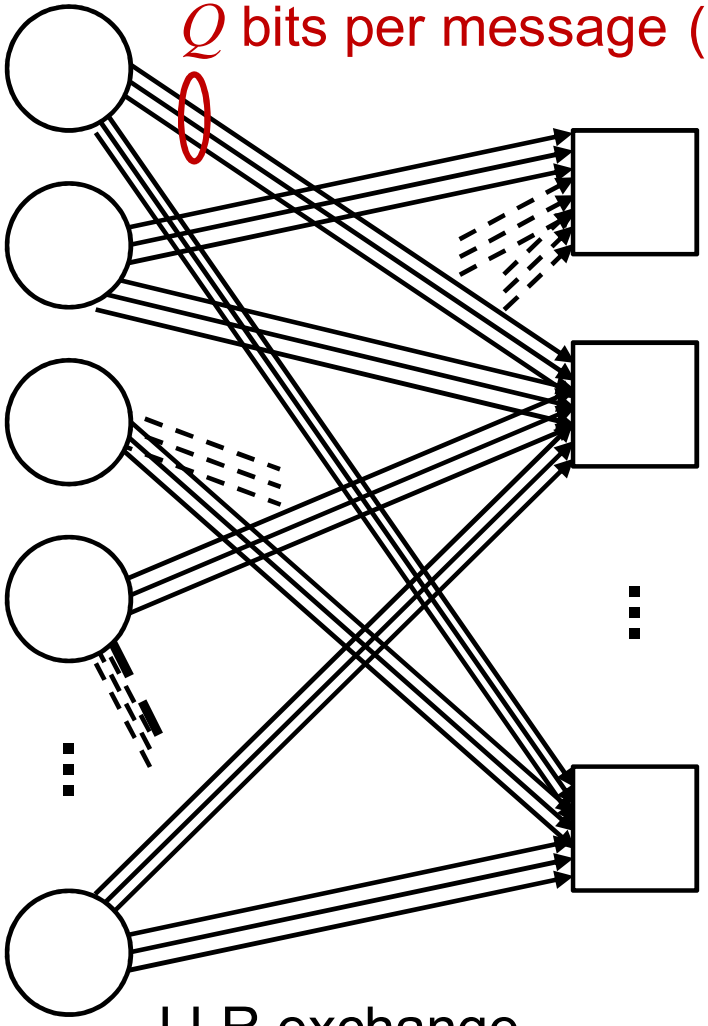

Wiring (routing) is the major problem !

(Especially for long codes and high node degrees.)

→ Unrolled architecture (pipeline)

→ Serial message transfer

Unrolled Architecture (Pipeline)

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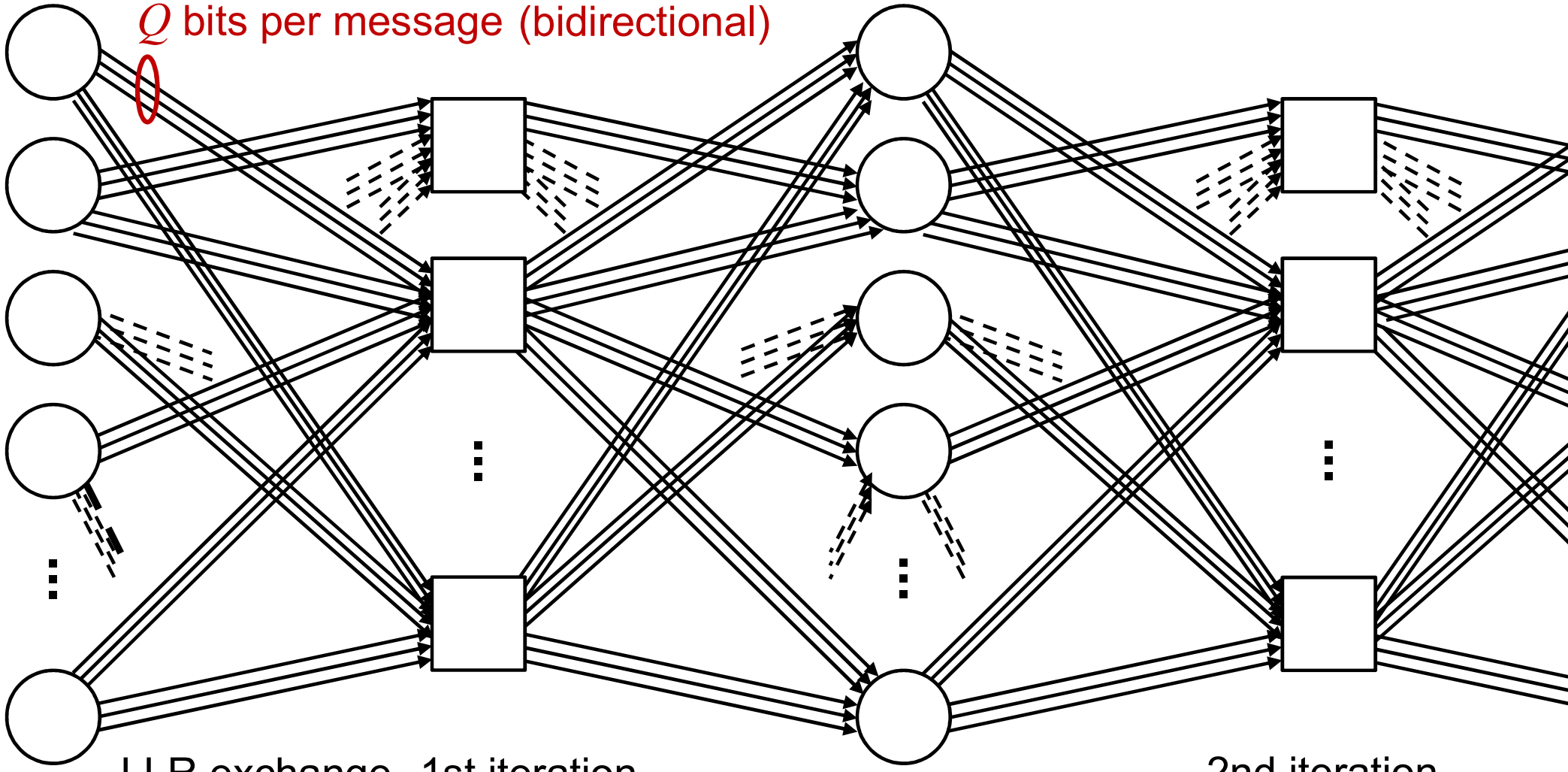
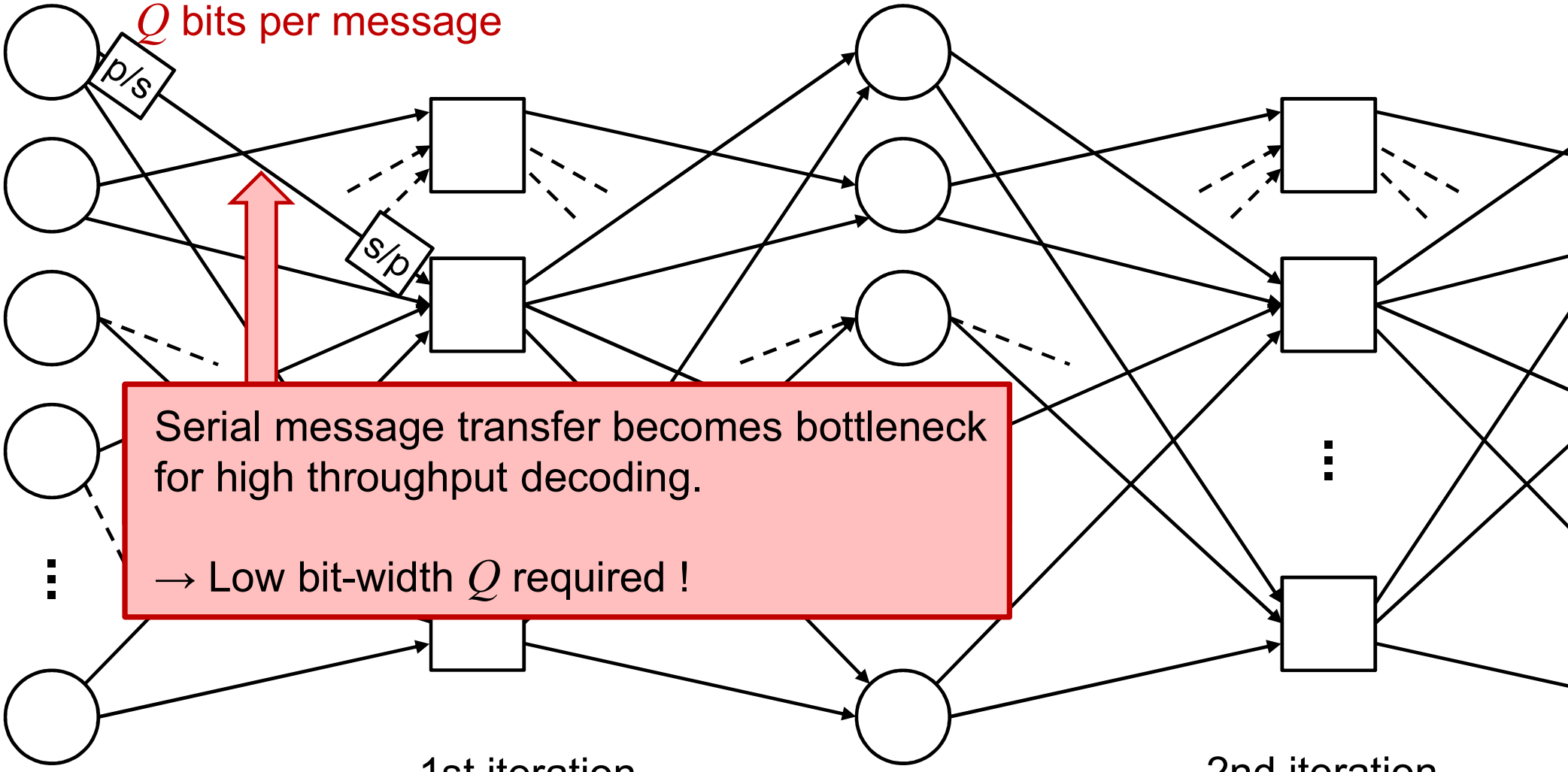
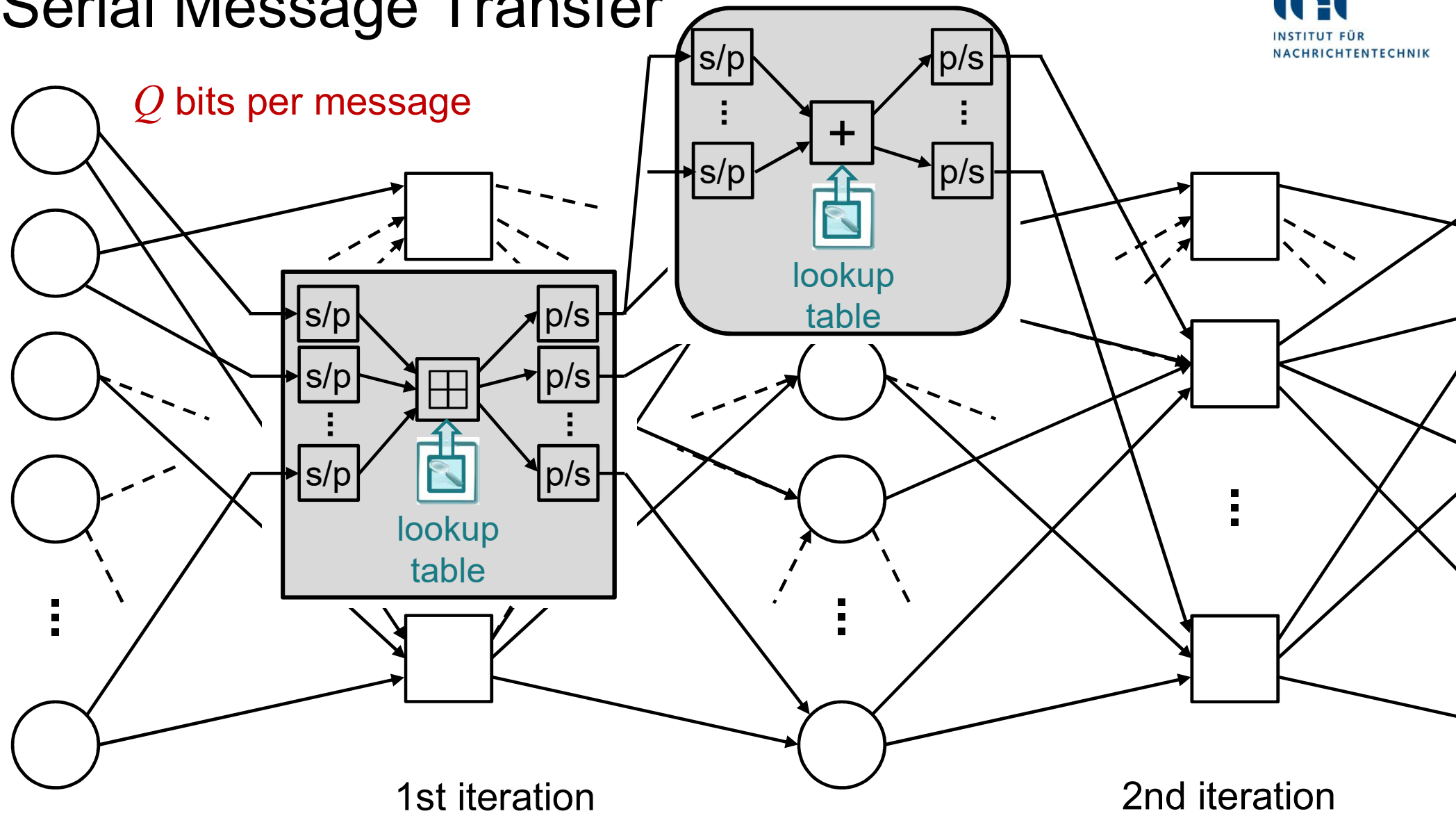


Serial Message Transfer

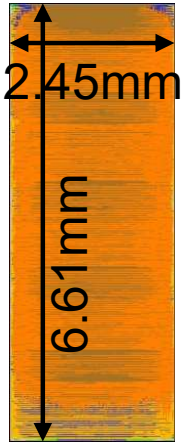


Serial Message Transfer



Ultra-High Throughput LDPC Decoder

reference min-sum decoder

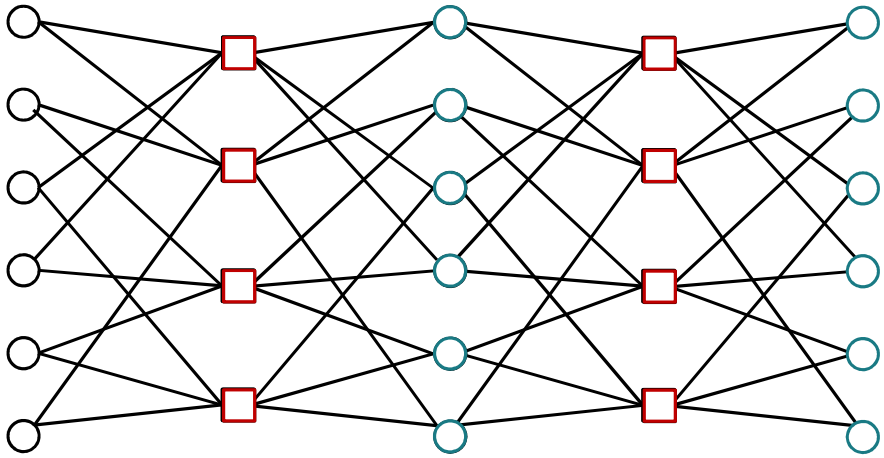


- Throughput: 588 Gbps
- Area: 16.2 mm^2 area
- Energy efficiency: 22.7 pJ per decoded bit

→ 2.2 × faster
→ 1.4 × smaller
→ 3.1 × more area efficient
→ 2 × better energy efficiency

compared to reference min-sum decoder

lookup tables only for variable nodes



min-approximation in check nodes

R. Ghanaatian, A. Balatsoukas-Stimming, C. Müller, M. Meidlinger, G. Matz, A. Teman, A. Burg: A 588-Gb/s LDPC decoder based on finite-alphabet message passing. IEEE Transactions on very large scale integration (VLSI) systems, Vol. 26, No. 2, February 2018

Contributions to Relevant Information Preserving Look-Up Table Based Decoding and Detection

- Application of the information bottleneck framework to the design of decoder look-up tables.
  → Information bottleneck algorithms can be applied for look-up table design and discrete density evolution.

- Decoder look-up table design that works for any irregular LDPC code irrespective of the degree distribution.

- Extension to non-binary LDPC codes.

- Extension to other detection stages such as QAM demapping and channel estimation.

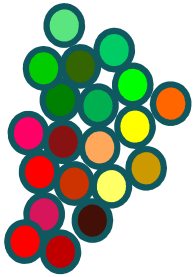
The Information Bottleneck Method: A Clustering Tool

observed random variable $Y, y \in \mathcal{Y}$

mutual information $I(X;Y)$

$p(x,y)$

relevant random variable $X, x \in \mathcal{X}$



N. Tishby, F. C. Pereira, and W. Bialek: The information bottleneck method. *37th annual Allerton Conference on Communication, Control, and Computing*, 1999, pp. 368–377.

The Information Bottleneck Method: A Clustering Tool

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observed random variable $Y, y \in \mathcal{Y}$

minimize $I(Y;T)$

$p(t \mid y)$

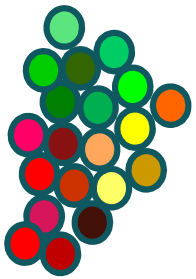
compressed random variable $T, t \in \mathcal{T}$

$|\mathcal{T}| \leq |\mathcal{Y}|$

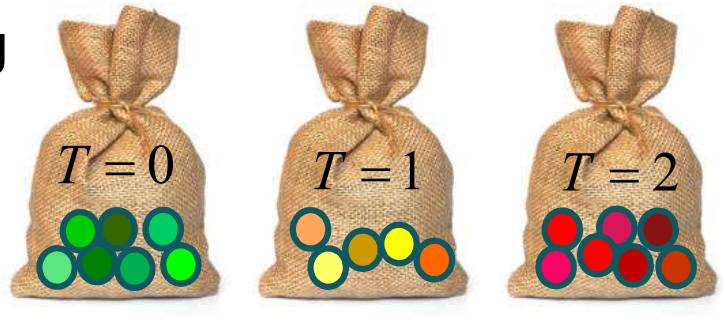
maximize $I(X;T)$

$p(x \mid t)$

relevant random variable $X, x \in \mathcal{X}$



clustering



N. Tishby, F. C. Pereira, and W. Bialek: The information bottleneck method. *37th annual Allerton Conference on Communication, Control, and Computing*, 1999, pp. 368–377.

The Information Bottleneck Method: A Clustering Tool

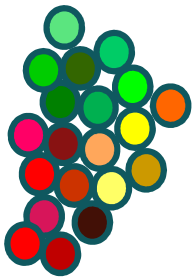
observed Y

minimize $I(Y;T)$ $p(t \mid y)$

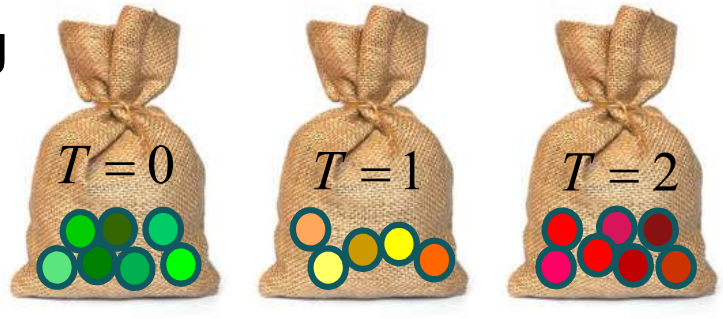
compressed T

maximize $I(X;T)$ $p(x \mid t)$

relevant X



clustering

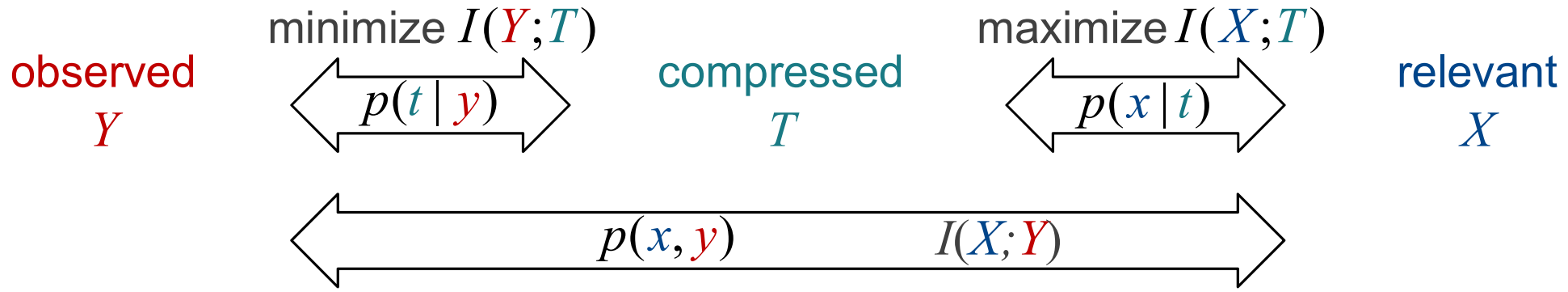


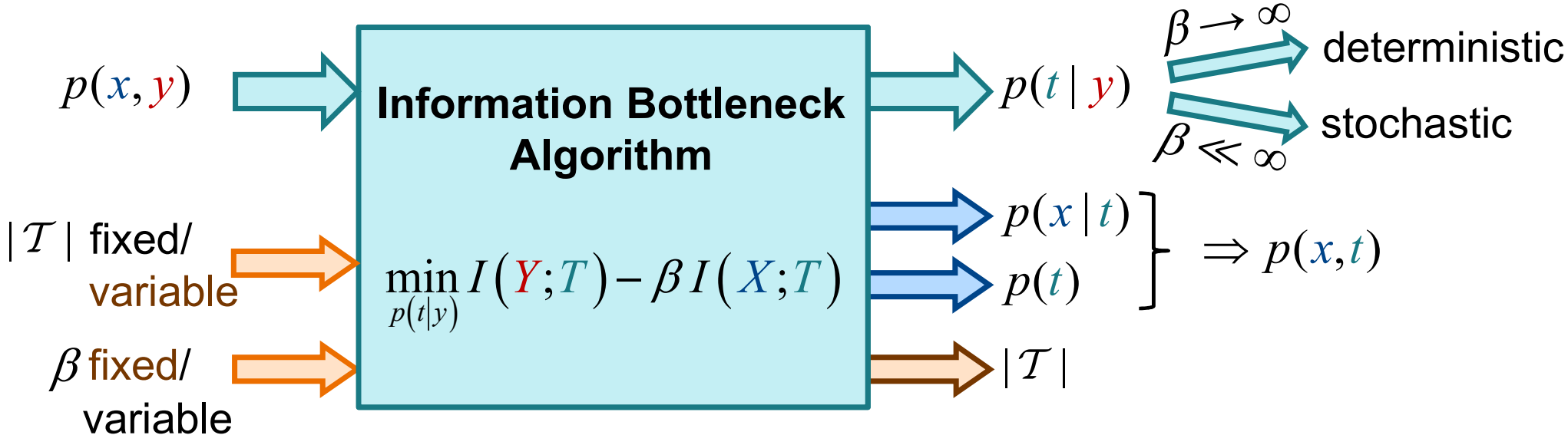
Clustering is described by $p(t|y)$

Deterministic clustering: $p(t|y) = 1$ or 0

Stochastic clustering: $0 \le p(t|y) \le 1$

Information Bottleneck Algorithms



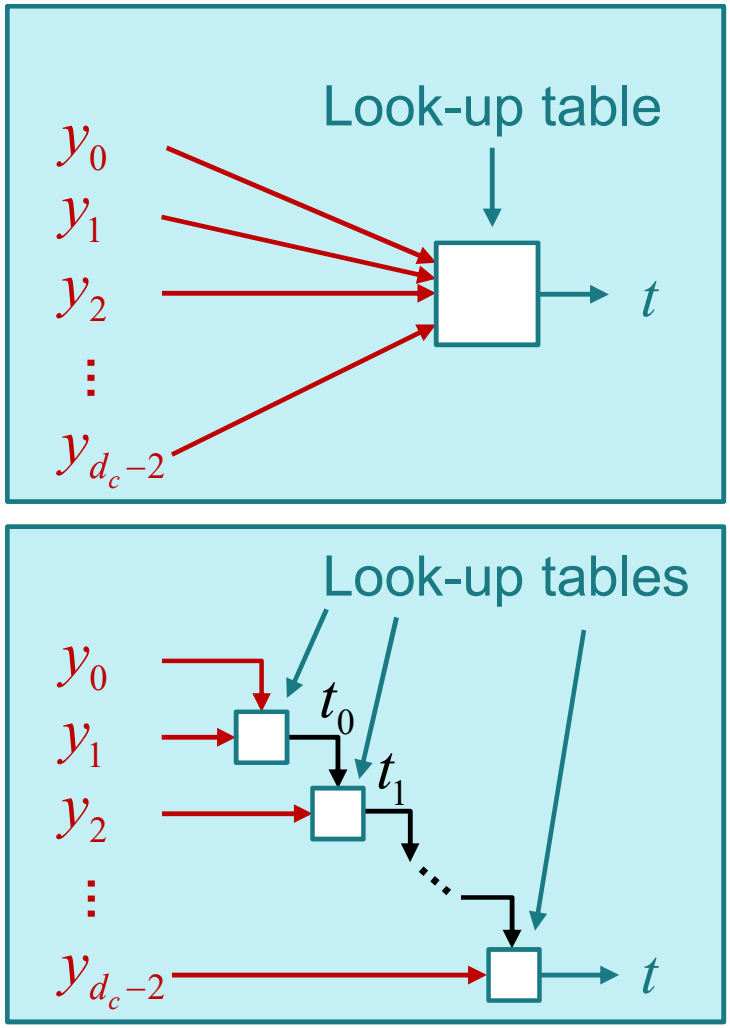


TUHH OpenSource Code Repositories

Information Bottleneck Algorithm Suite

https://goo.gl/FLgFej

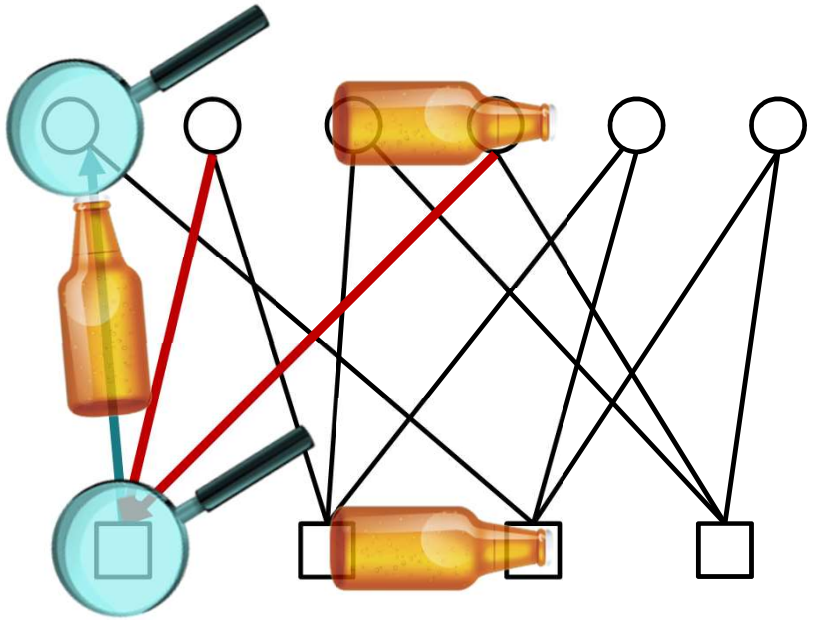
Information Bottleneck Message Passing Decoder



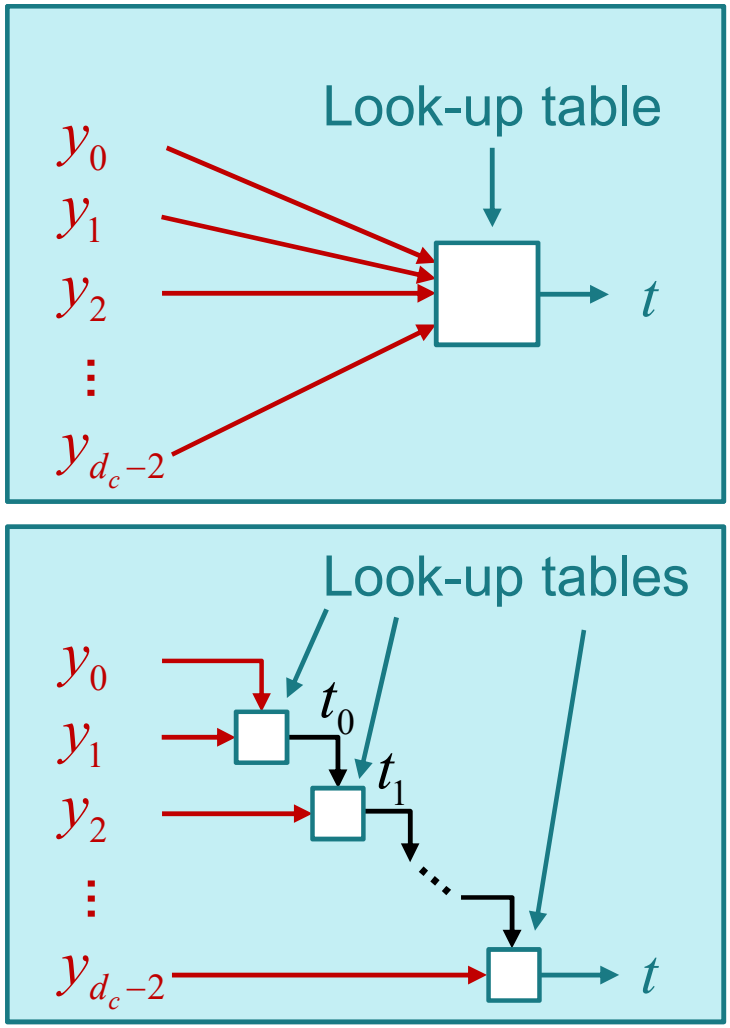
$|\mathcal{Y}|^{d_c-1}$ table entries ☹

→ split into concatenation of two-input tables

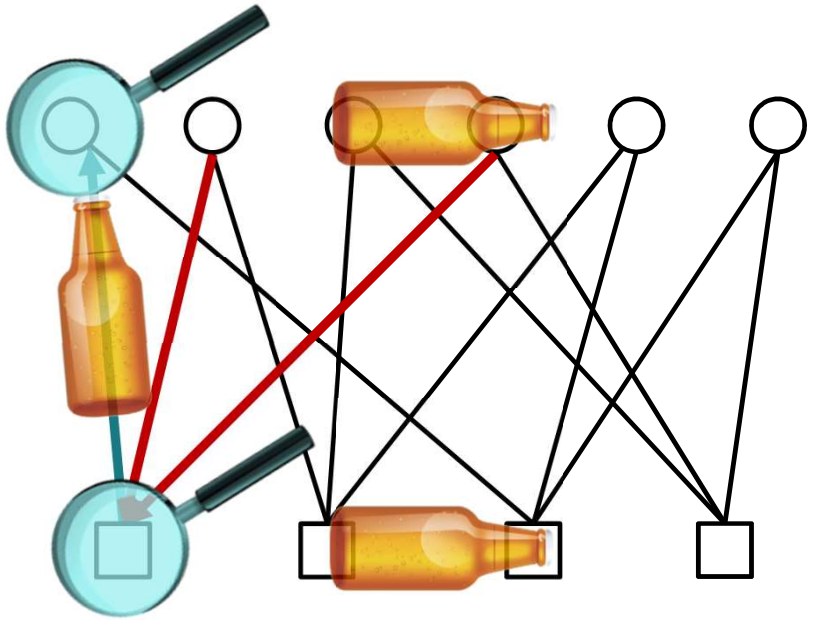
B. M. Kurkoski, K. Yamaguchi, K. Kobayashi: Noise thresholds for discrete LDPC decoding mappings. IEEE GLOBECOM, 2008.



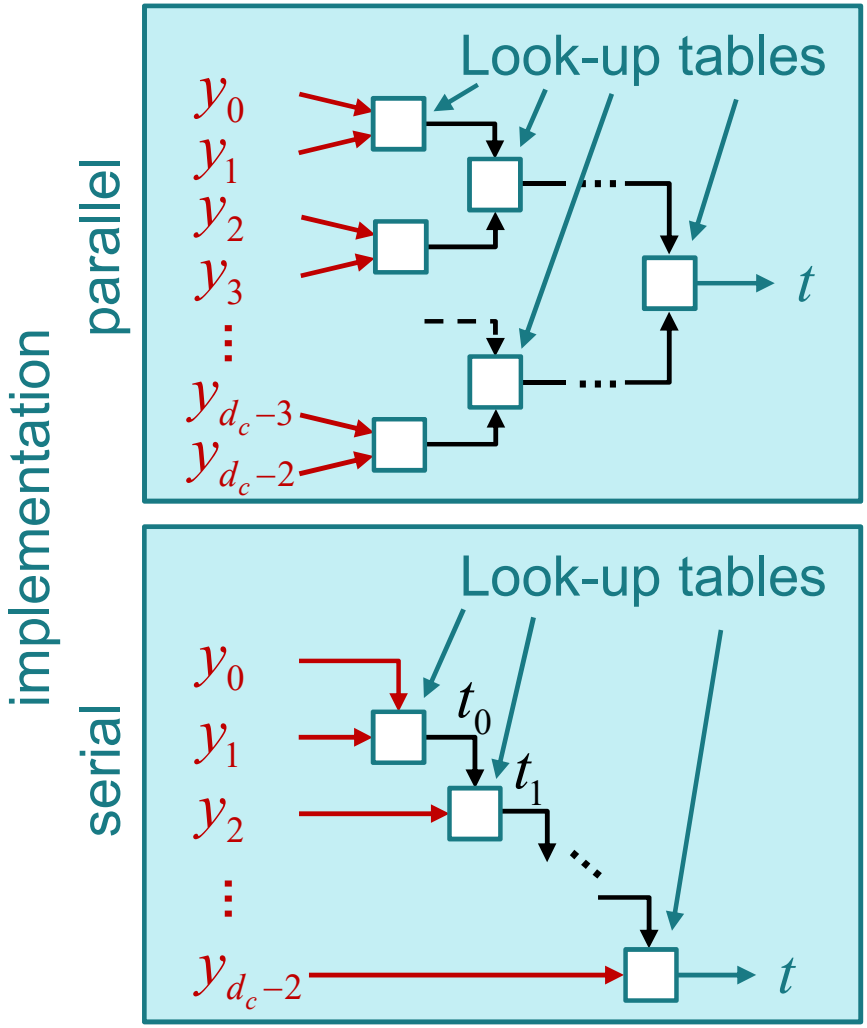
Information Bottleneck Message Passing Decoder



- All node operations are simple table look-ups.
- All table entries and passed messages are unsigned integers (indices).



Information Bottleneck Message Passing Decoder



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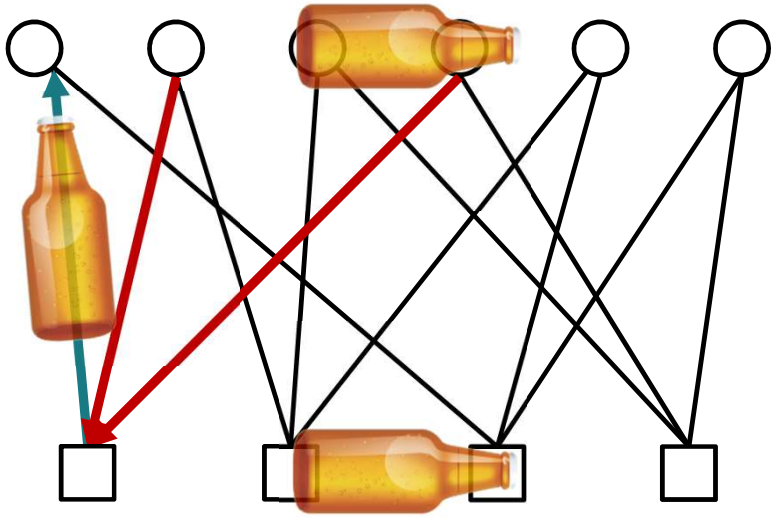
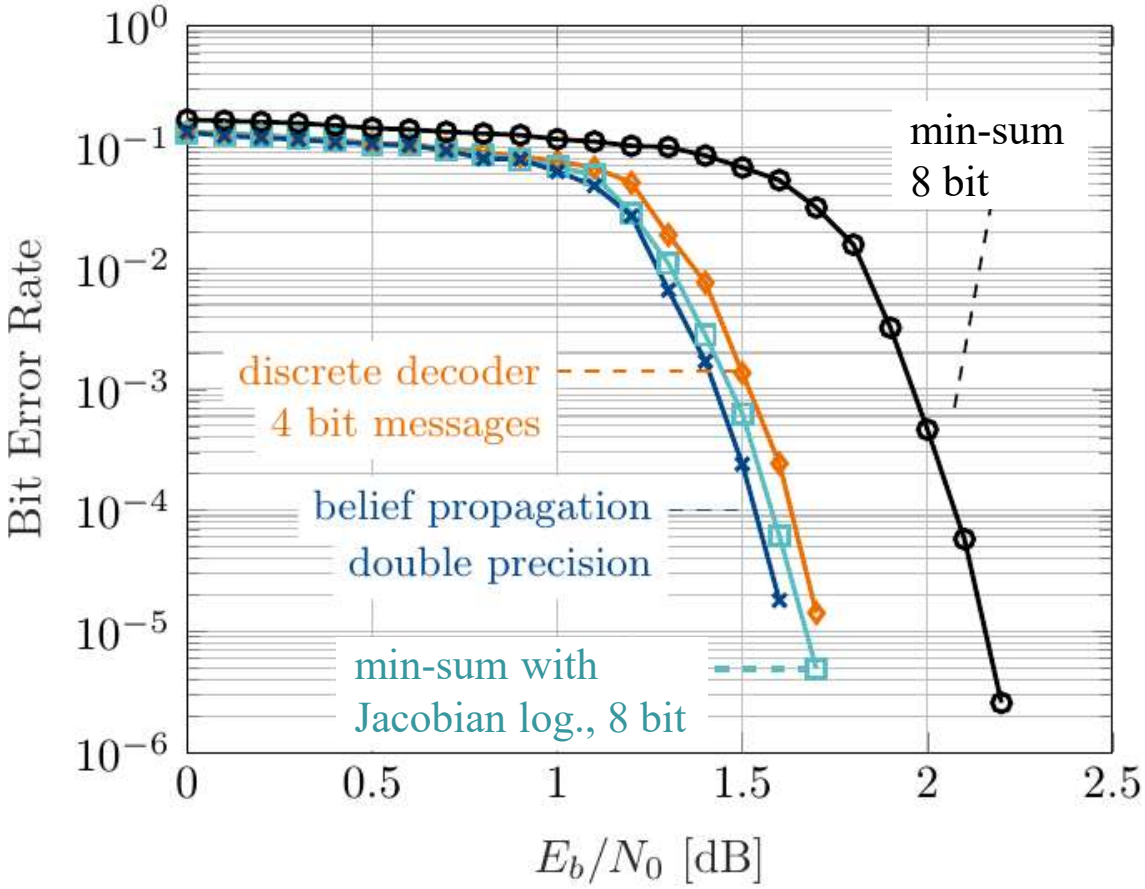
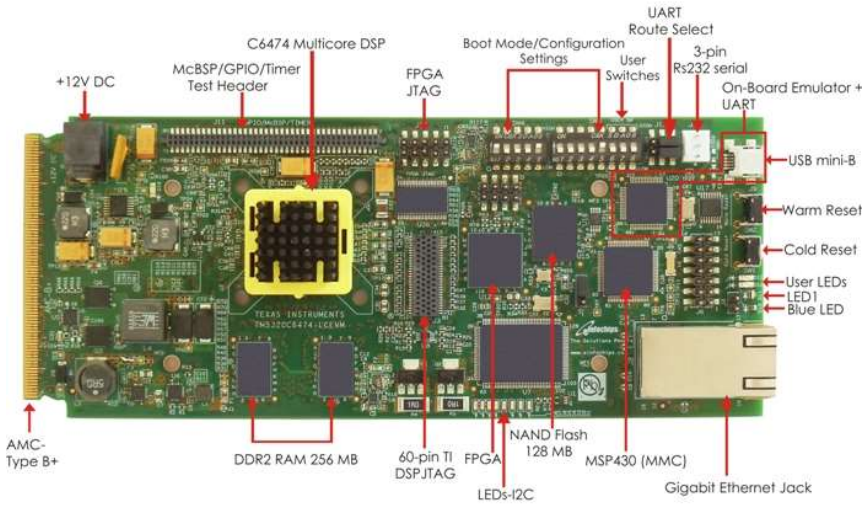


Discrete Decoder Implementation on a TMS320C6474 DSP

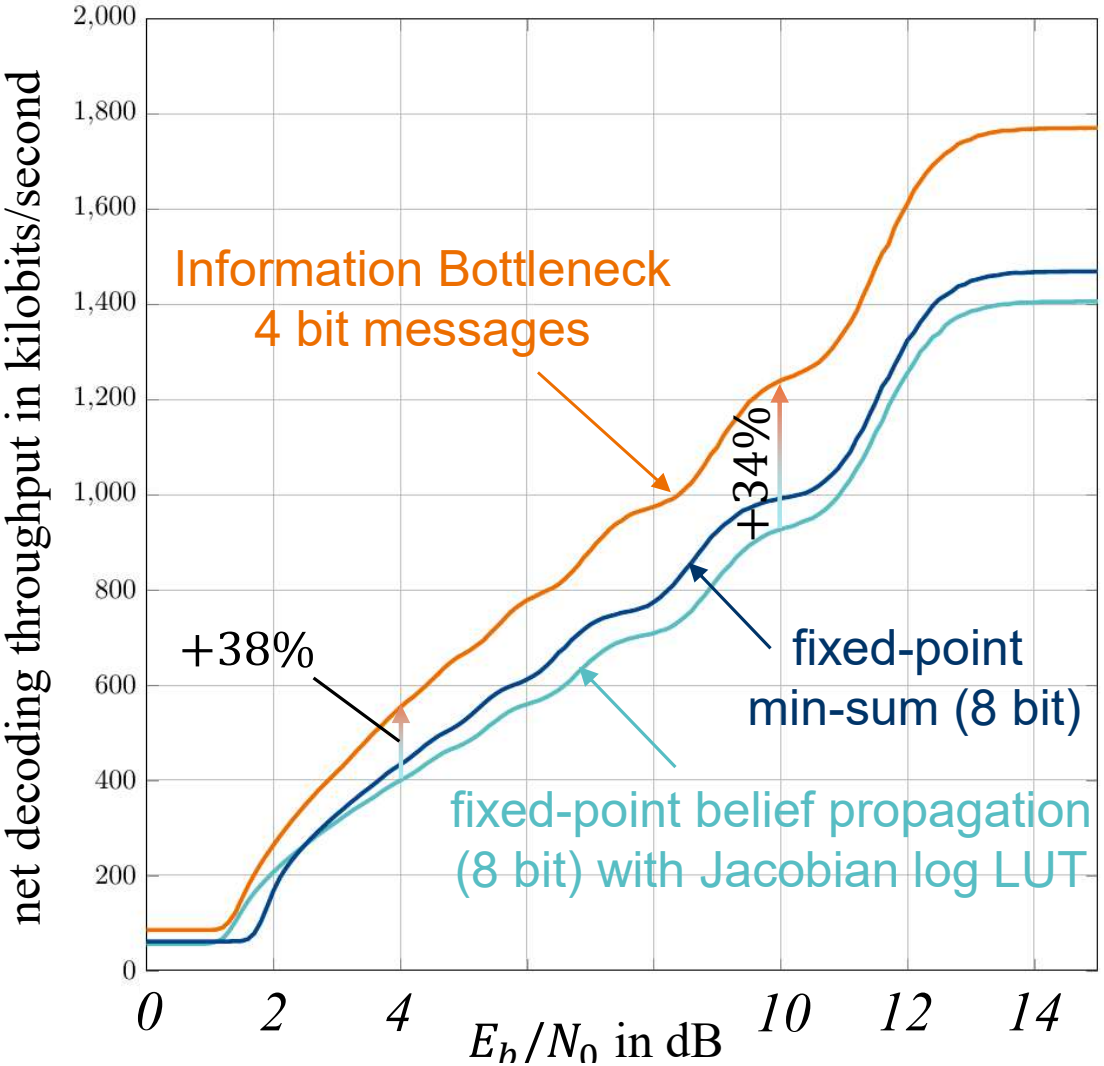


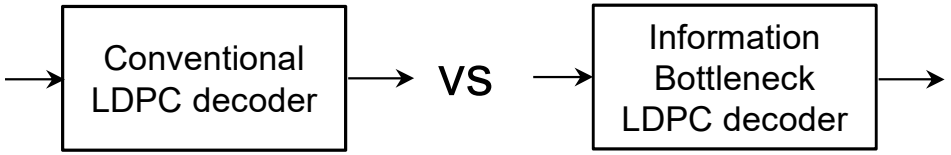


(3,6)-regular LDPC 8000.4000.3.483 from MacKay's database

Quantized output BI-AWGN channel with 16 output levels

Discrete Decoder Implementation on a TMS320C6474 DSP

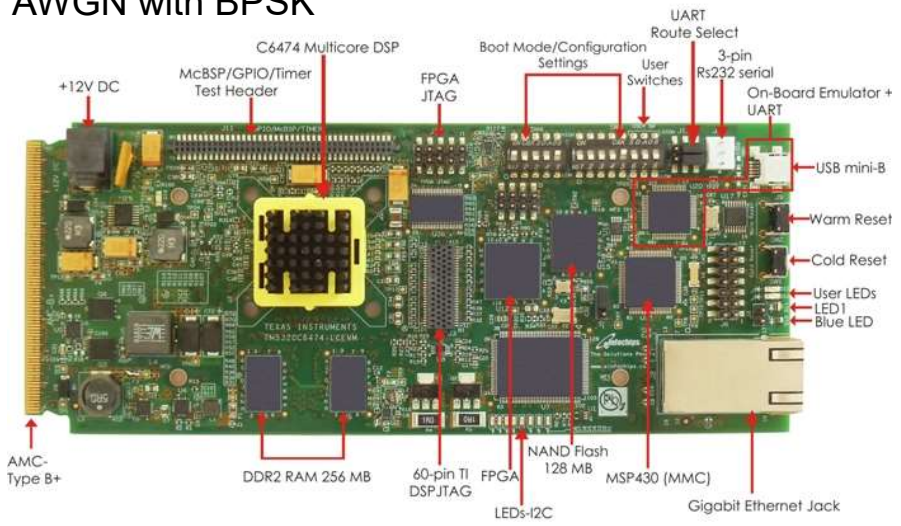




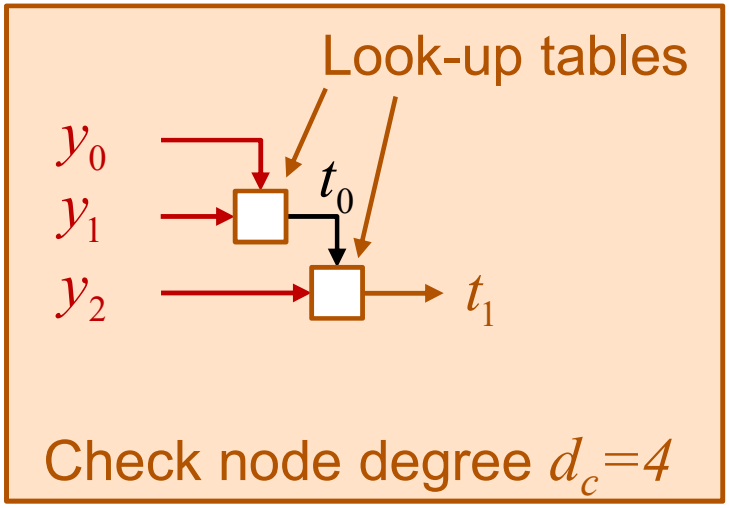
implementation on TI TMS320C6474 DSP for software defined radio application

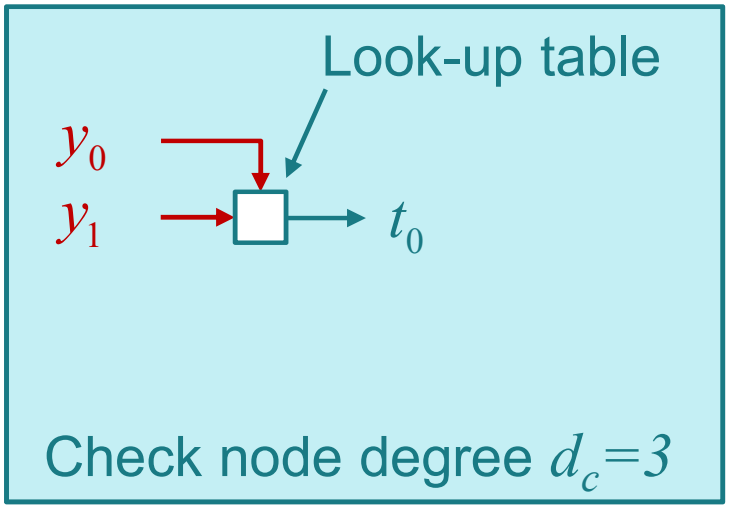
length 8000 $(3,6)$-regular LDPC (max. 50 iterations)

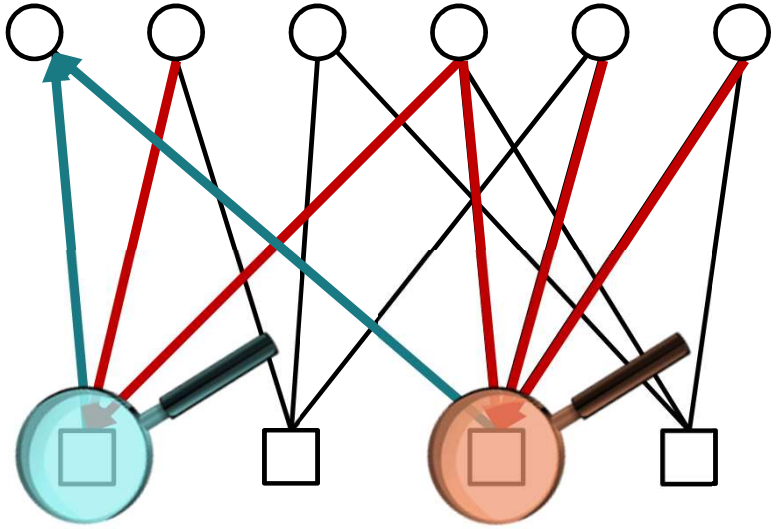
AWGN with BPSK



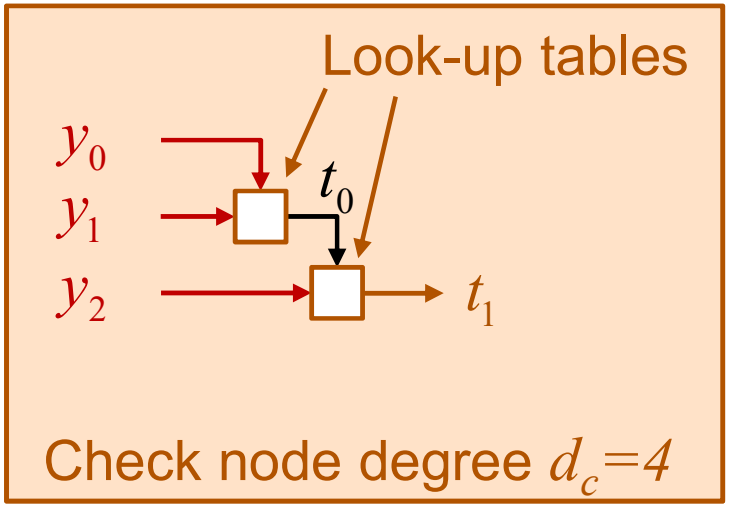
Information Bottleneck Message Passing Decoder for Irregular Codes

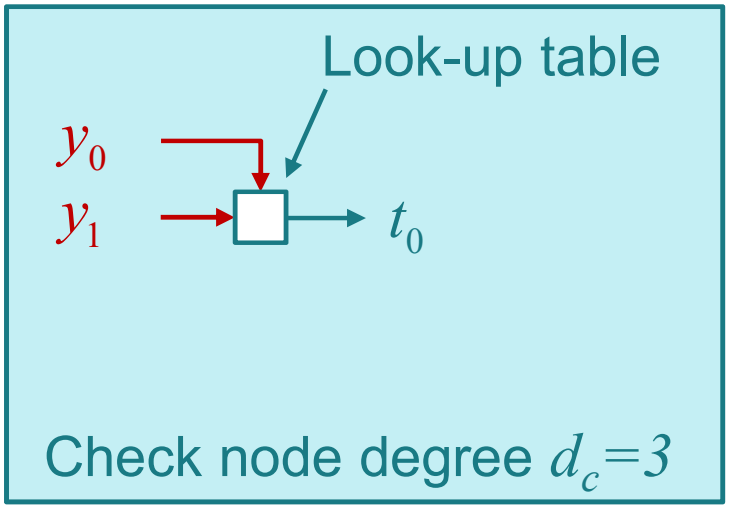


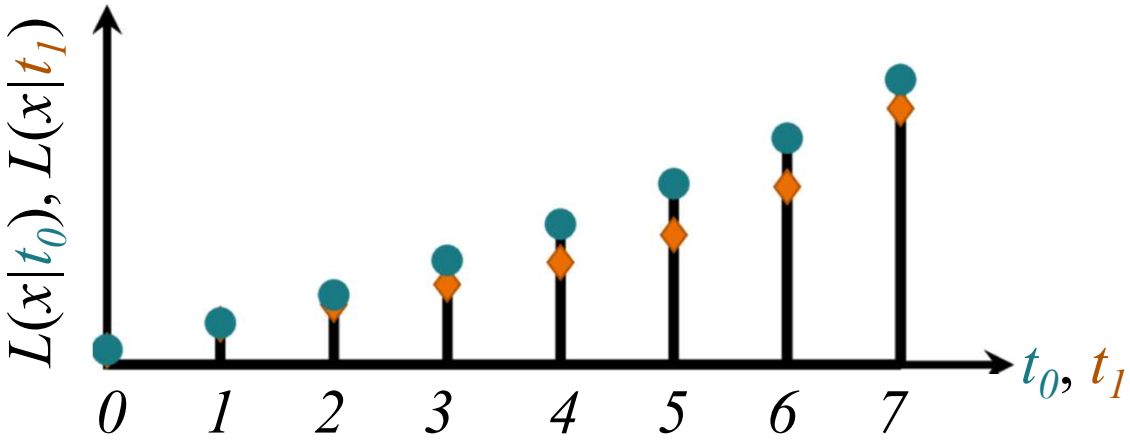




Information Bottleneck Message Passing Decoder for Irregular Codes







$t=6$ $d=4$ $t=6$ $d=3$

Different meaning

$$p(x|t, D=4) \hat{\neq} p(x|t, D=3)$$

Message Alignment

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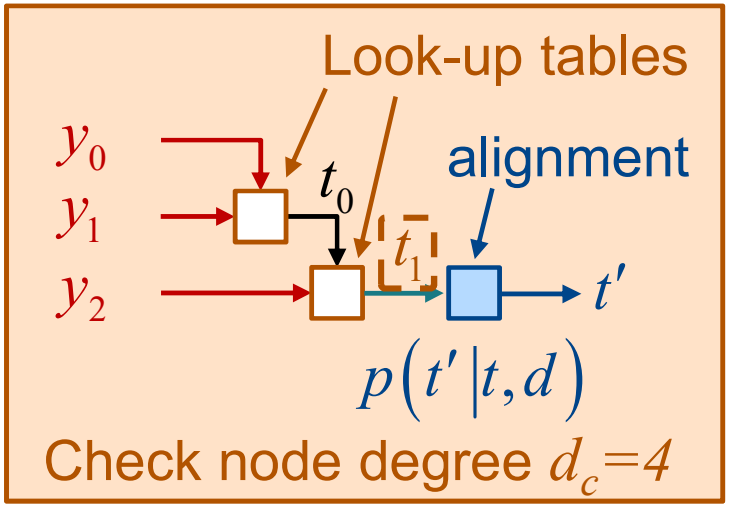
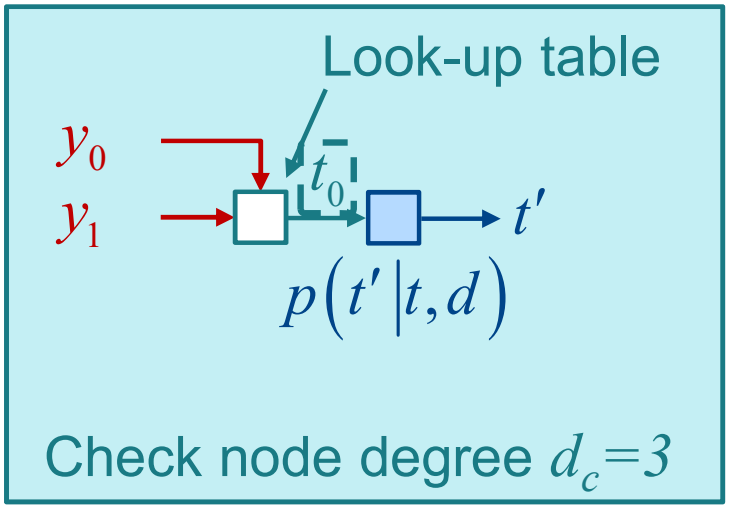
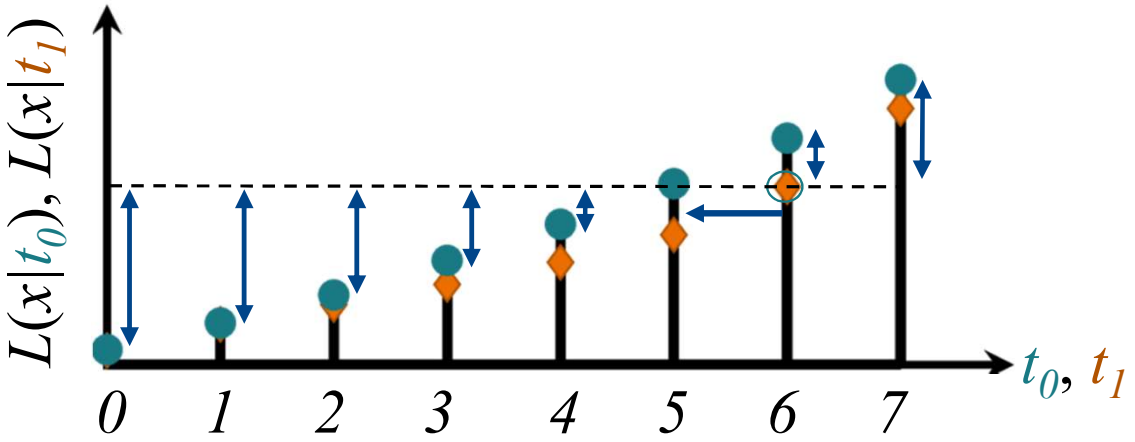
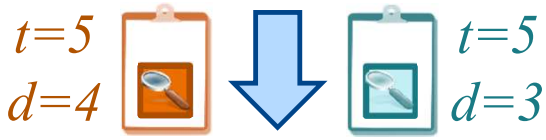
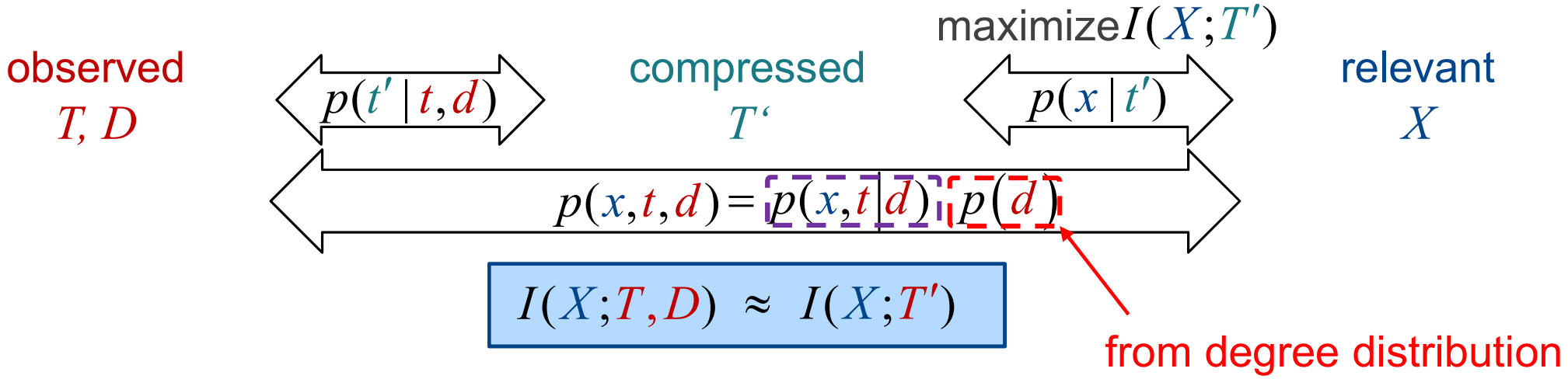


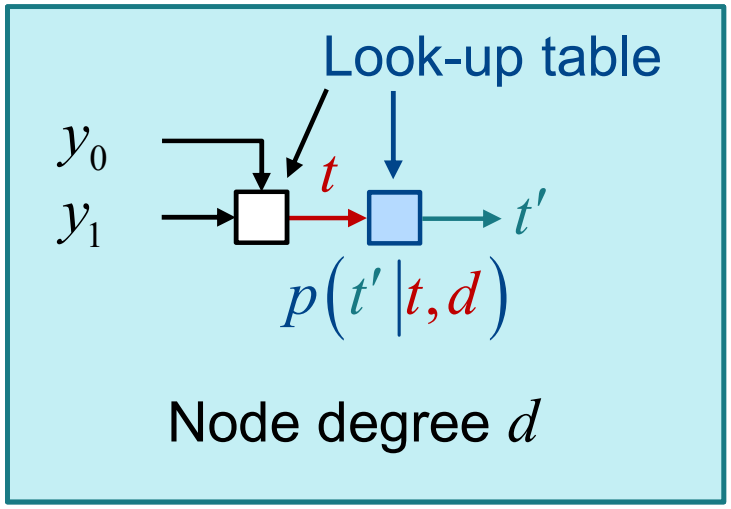


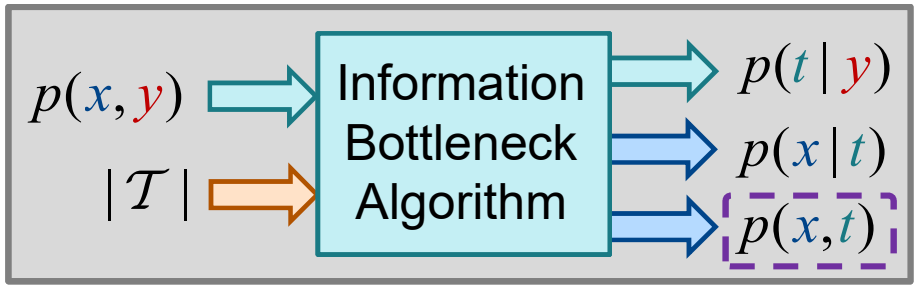




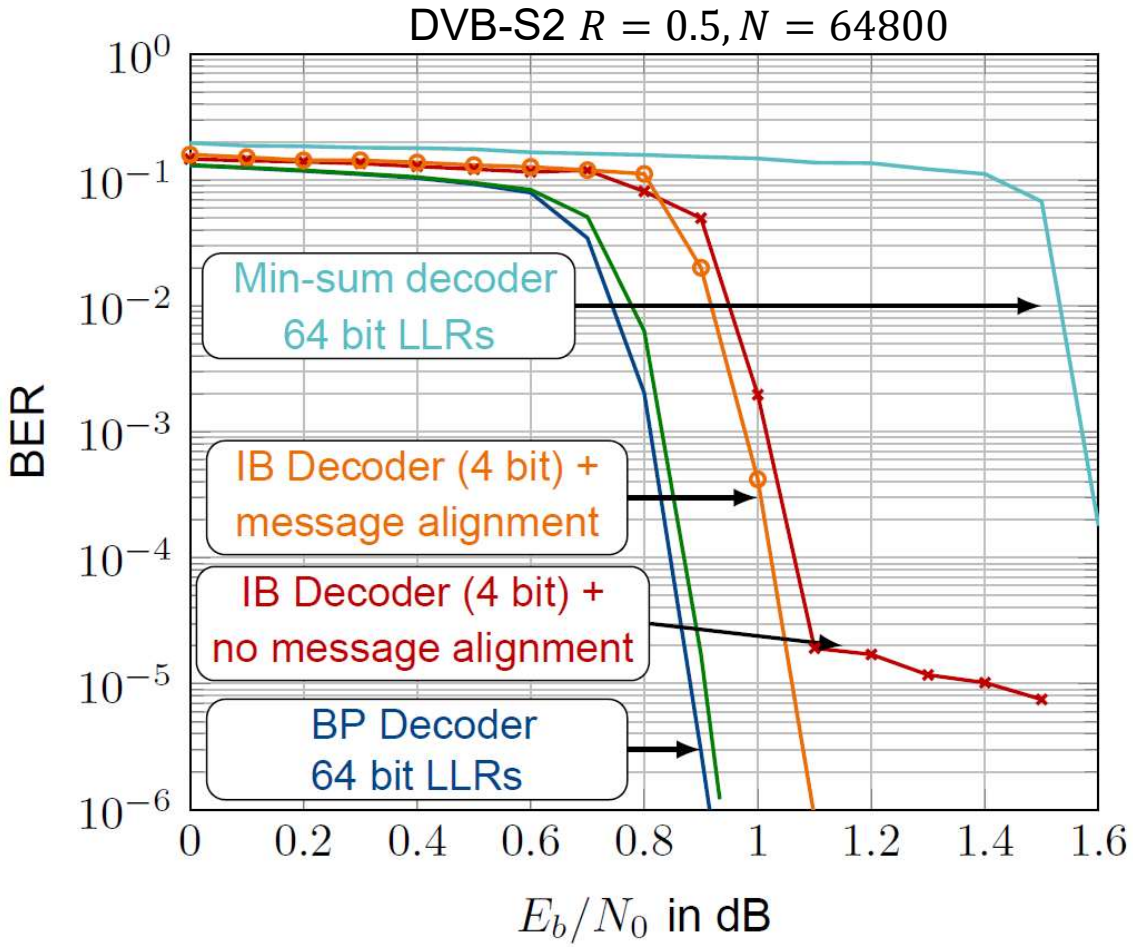
Message Alignment as Information Bottleneck Problem

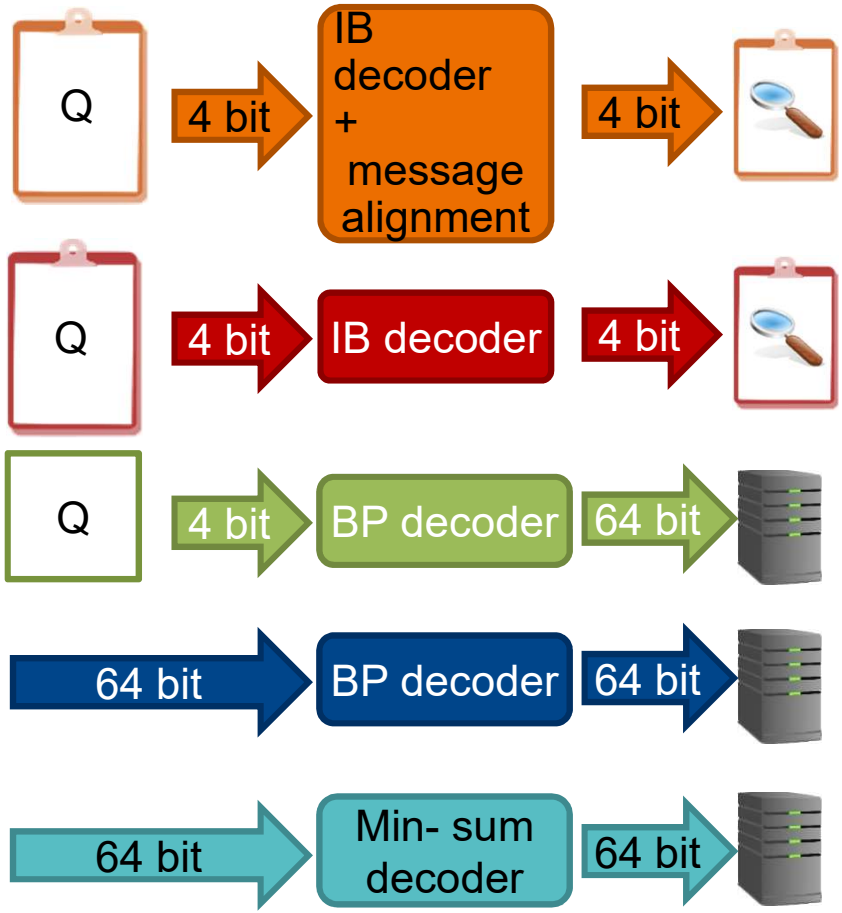




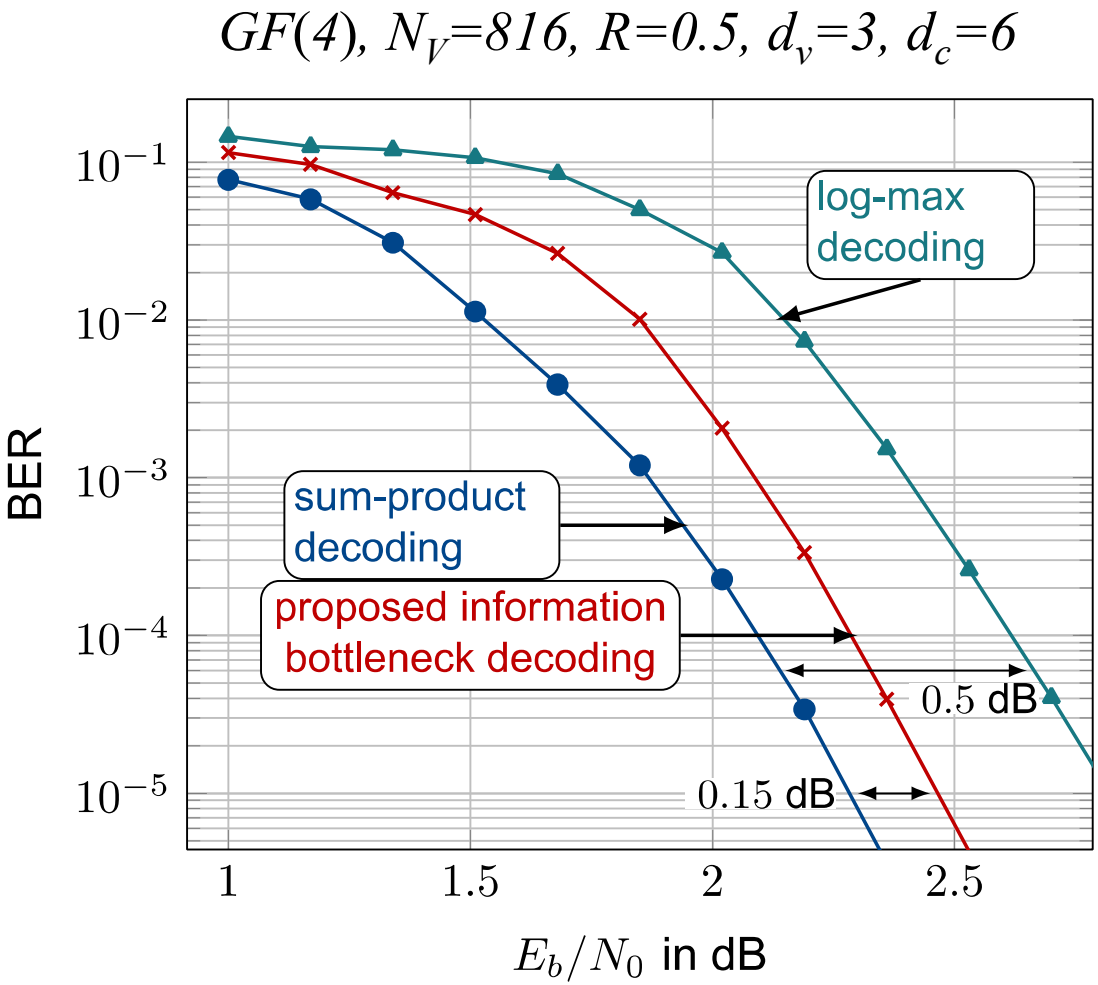


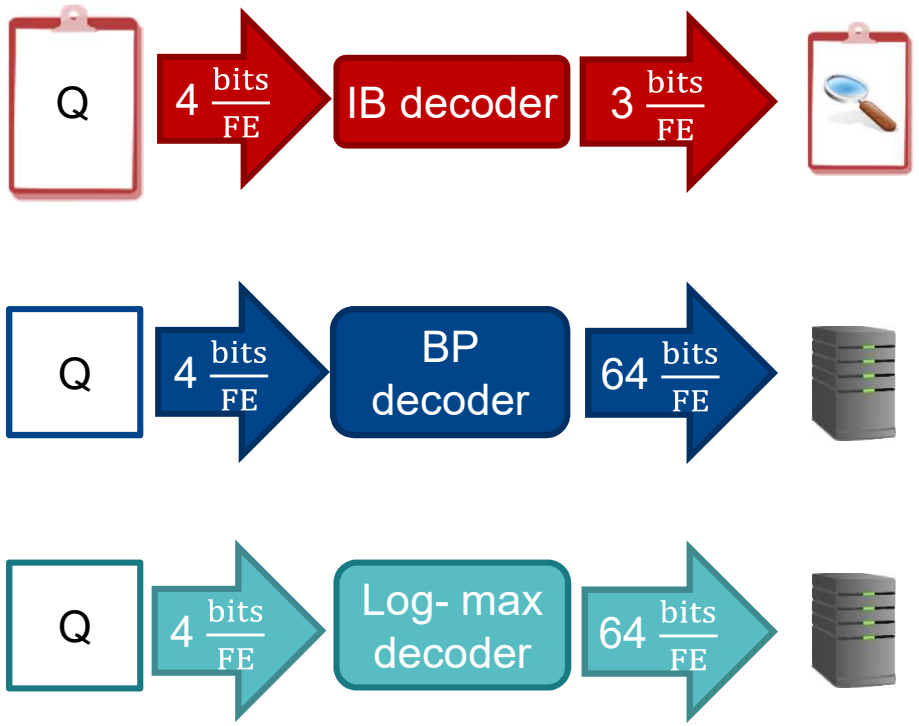
Irregular LDPC Codes – Simulation Results DVB-S2





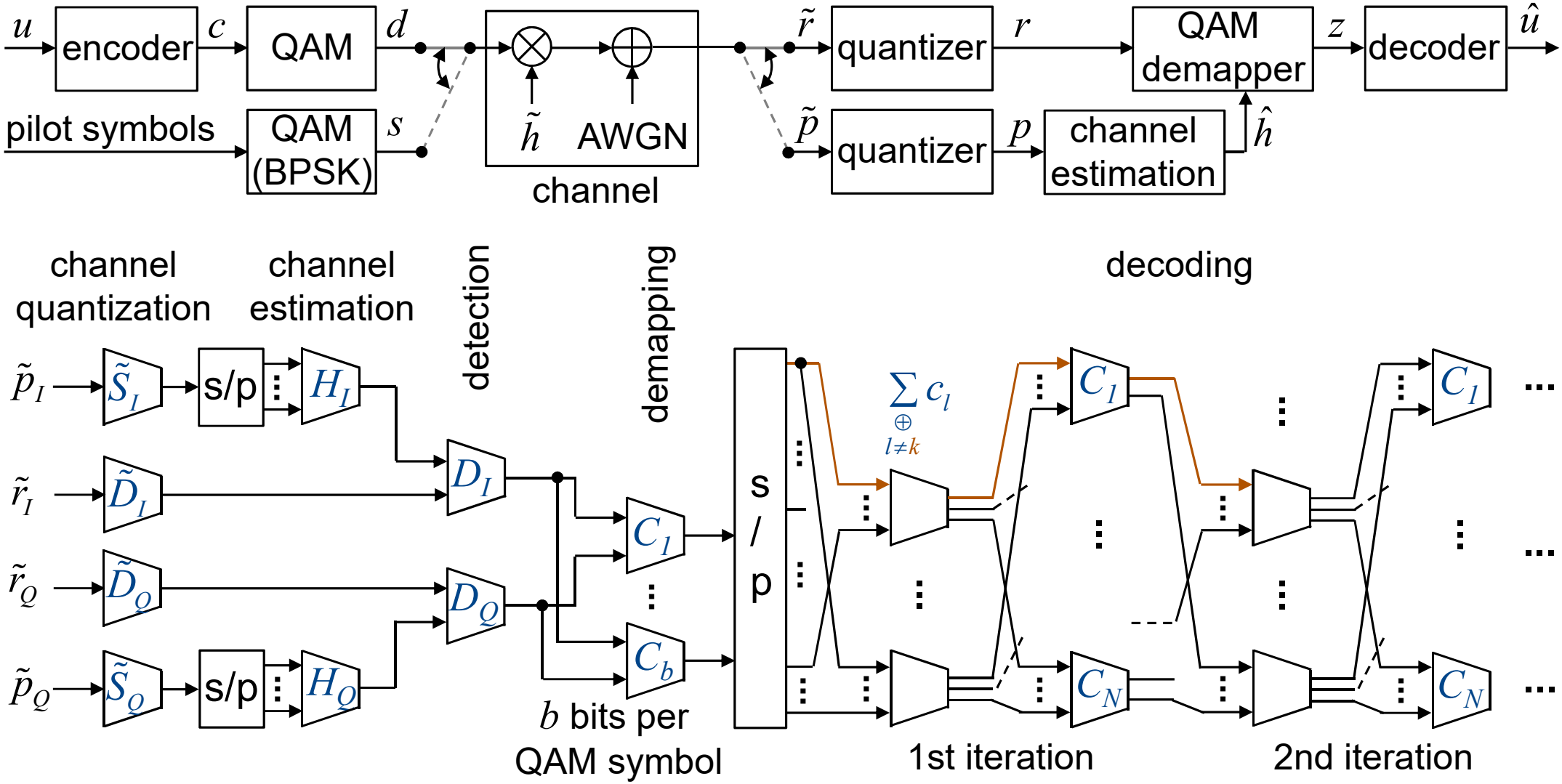
Decoding of Non-Binary LDPC Codes Using The Information Bottleneck Method – Simulation Results



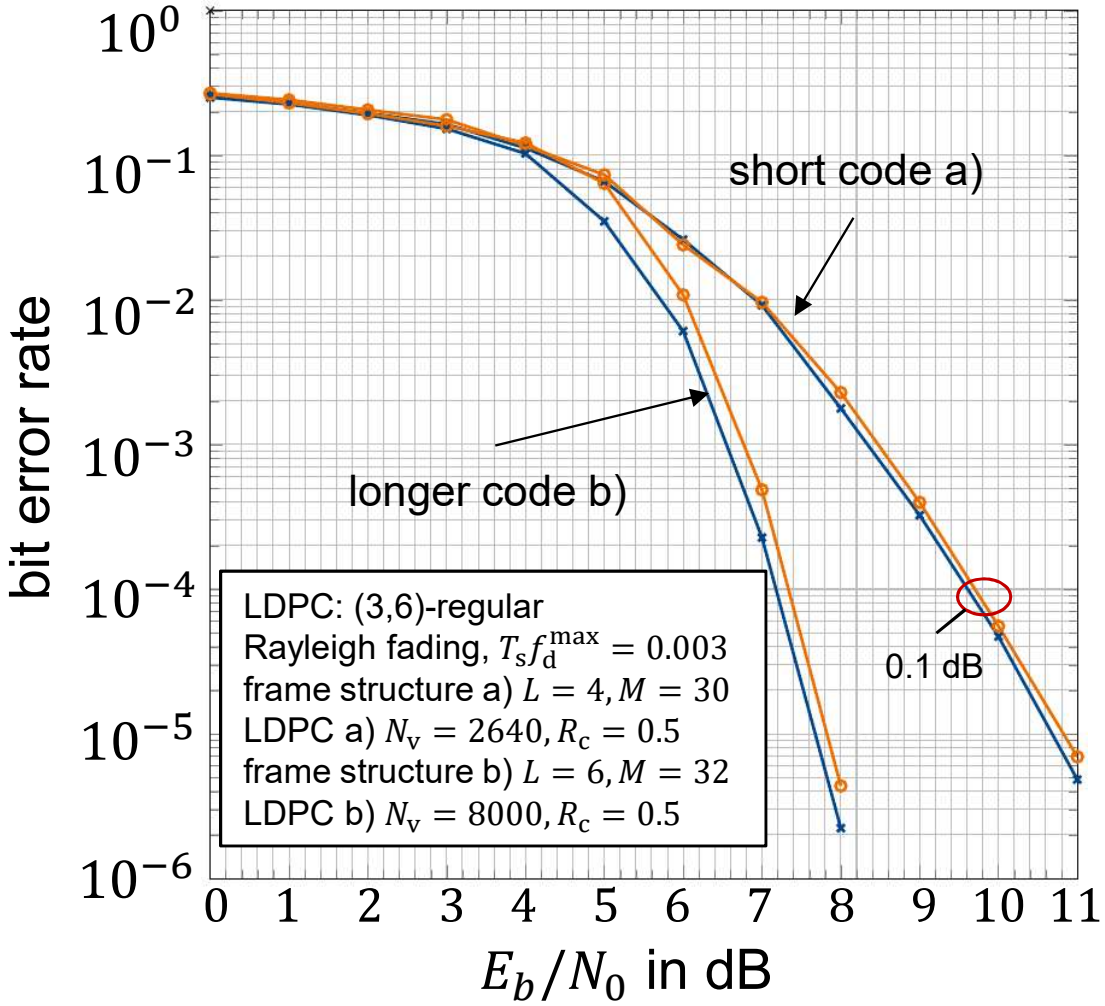


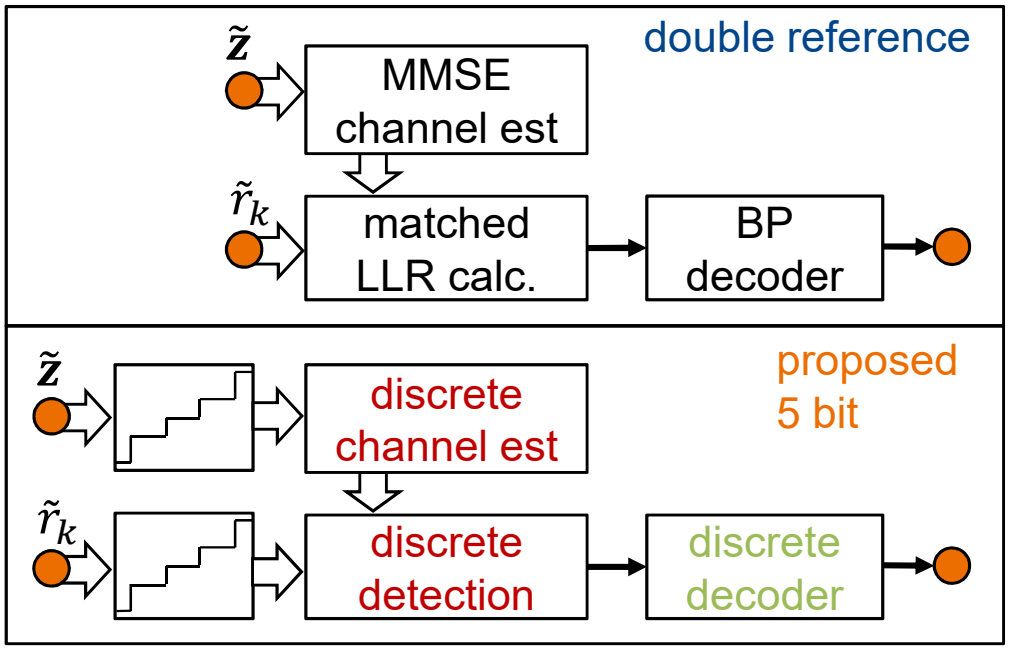
$$\frac{\text{bits}}{\text{FE}} = \frac{\text{bits}}{\text{Fieldelement}}$$

Receiver Information Bottleneck Graph



Channel Estimation and LDPC Decoding – Simulation Results





almost identical performance !

only quantization and lookups !

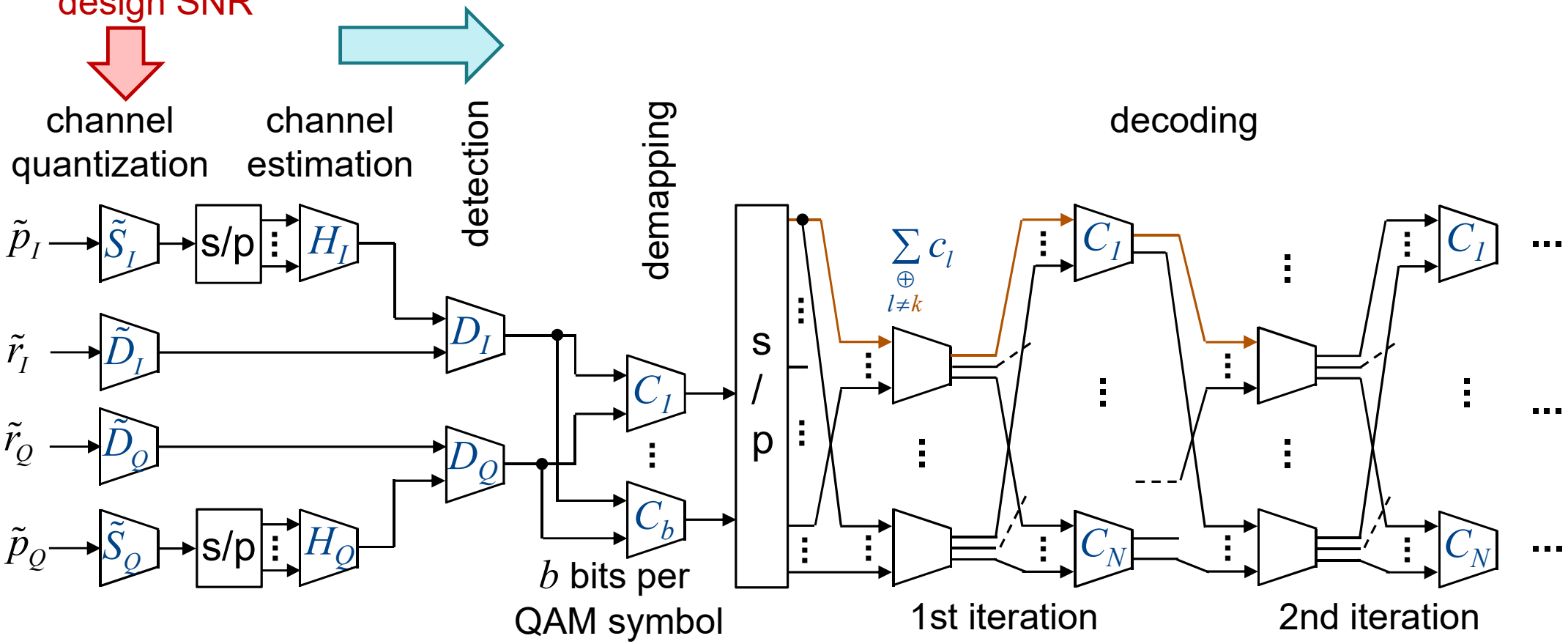
Receiver Information Bottleneck Graph

SNR dependent lookup tables

→ use fixed "design SNR"

Subsequent lookup tables follow from discrete density evolution.

→ Independent of SNR



Conclusions

The *information bottleneck method* can be used in order to design relevant information preserving signal processing stages using discrete density evolution.

→ Baseband processing consists of table look-ups only.

→ The methodology is the same for all different kinds of detection problems.

Compared to state-of-the-art implementations:

- With coarse quantization, the double precision belief propagation performance is virtually achieved.
- Significant complexity reduction.
- Chip area consumption due to look-up tables may be an issue.

TUHH OpenSource Code Repositories

Information Bottleneck Algorithm Suite

https://goo.gl/FLgFej