Institute for Communication
Systems and Data Processing
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Flexible, Iterative Source-Channel Decoding

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Flexcode Seminar Helsinki

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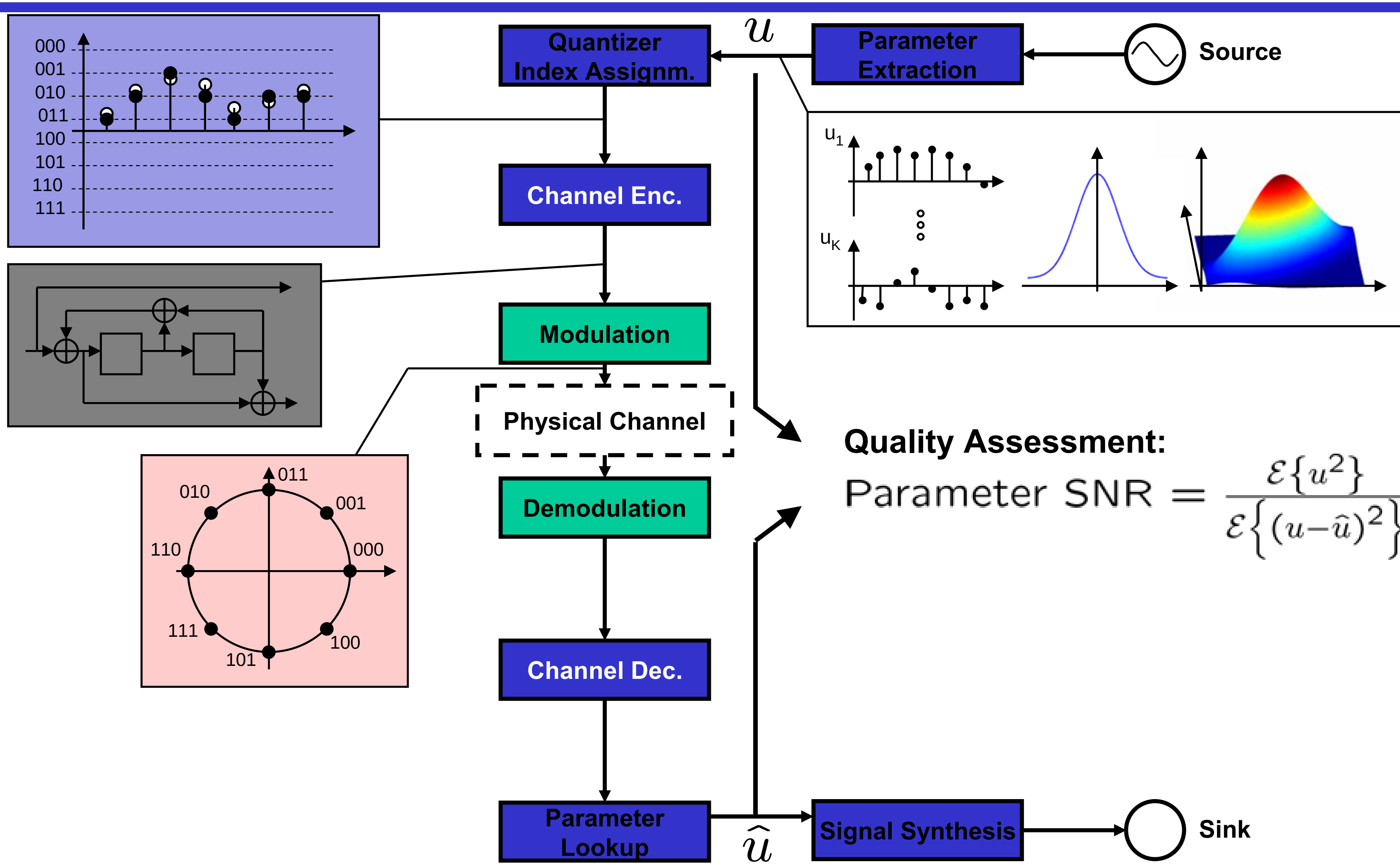
Outline

- **The Turbo Principle**
- **Iterative Source-Channel Decoding (ISCD)**
- **Multi-Mode ISCD**
- **Conclusions**

Conventional Transmission System

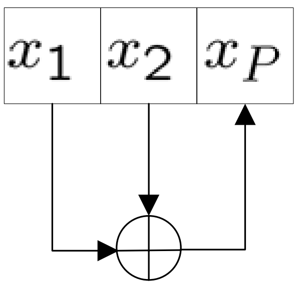


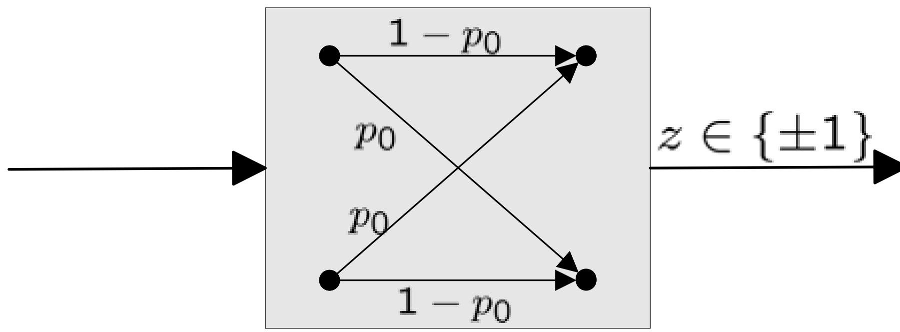
The Turbo Principle

Turbo Principle – Extrinsic Information

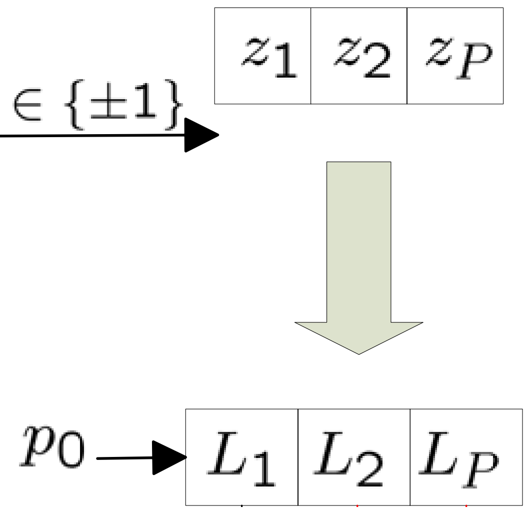
"Information on a bit originating from <u>other</u> bit positions"

- Extrinsic Information is the key element in Turbo decoders
- Example: Parity Check





Transmission Channel



$$x_P = x_1 \oplus x_2$$

$$\Rightarrow x_1 = x_2 \oplus x_P$$

Reliability information

$$L_1 = z_1 \cdot \ln \frac{1-p_0}{p_0}$$

$$L_2 = z_2 \cdot \ln \frac{1-p_0}{p_0}$$

$$L_P = z_P \cdot \ln \frac{1-p_0}{p_0}$$

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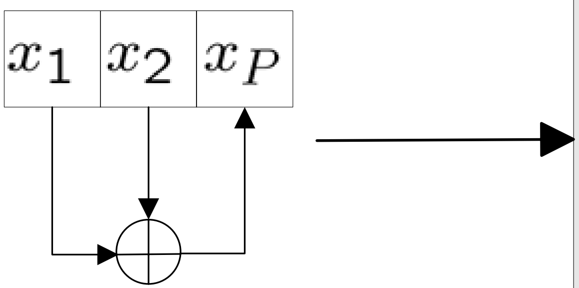

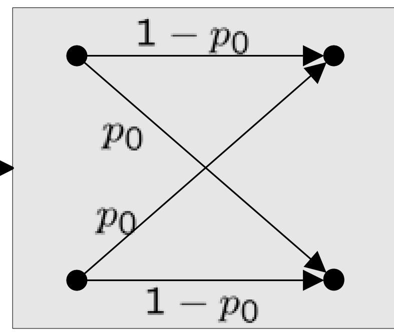

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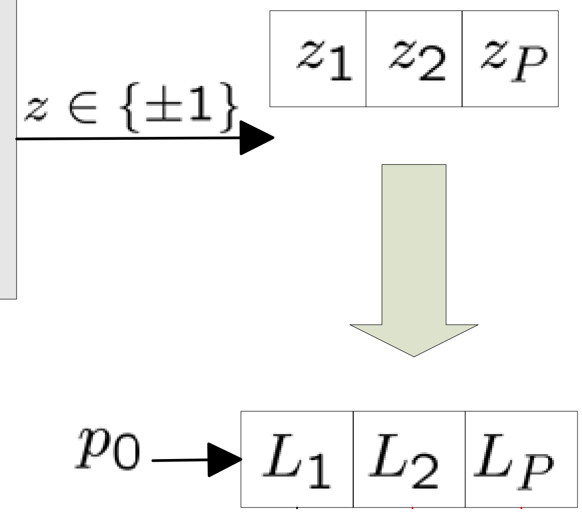

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→ intrinsic: $L_i = L(z_i | x_i)$

$$L_i = \ln\left(\frac{P(z_i | x_i = +1)}{P(z_i | x_i = -1)}\right)$$

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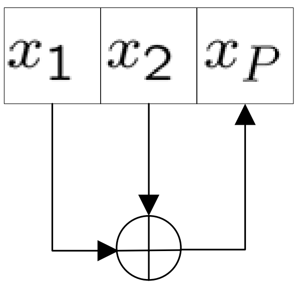

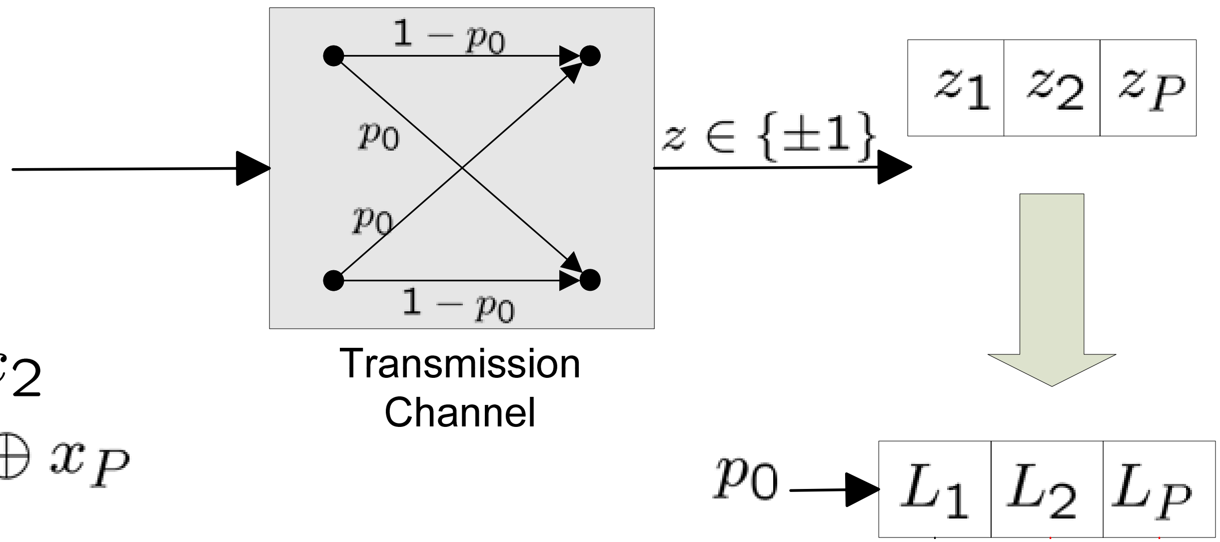

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$$L_2 = z_2 \cdot \ln \frac{1-p_0}{p_0}$$

$$L_P = z_P \cdot \ln \frac{1-p_0}{p_0}$$

→ intrinsic : $L_i = L(z_i | x_i)$

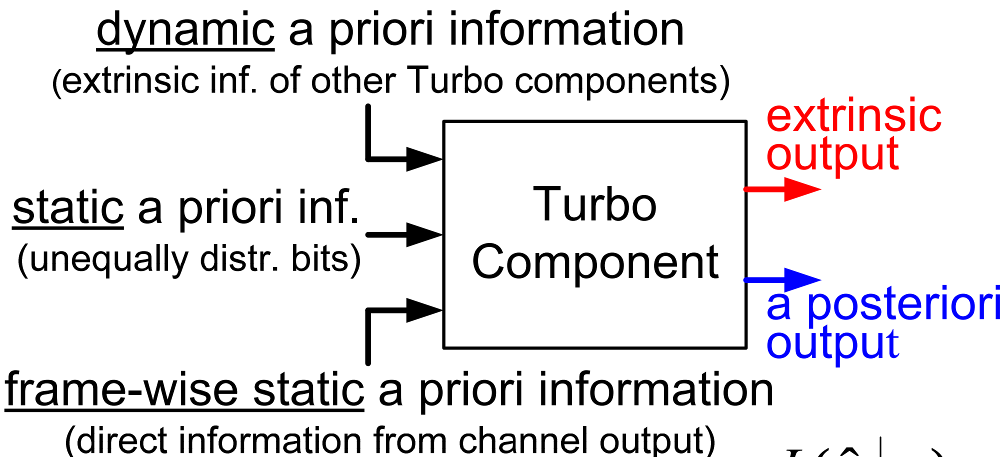
→ a posteriori $L(\hat{x}_i | z_i) = L(z_i | x_i) + L(x_i) + L_i^{[ext]}$

→ $\hat{x}_i = sign\{L(\hat{x}_i | z_i)\}$

Turbo Principle - Extrinsic Information

"Information on a bit originating from other bit positions"

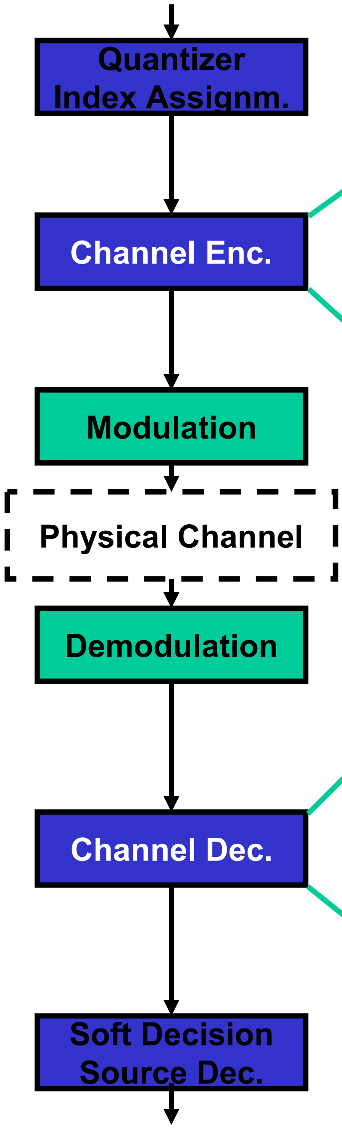
- Types of a priori information



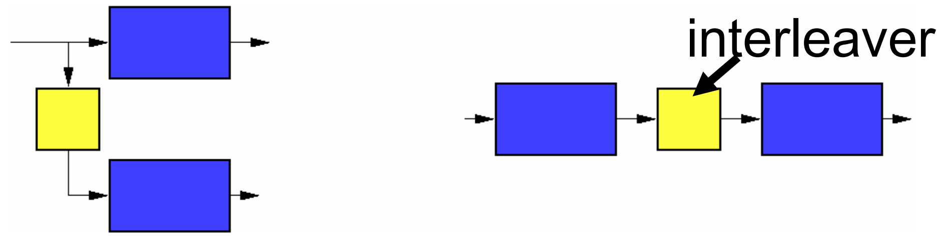
$$L(\hat{x}_i | z_i) = L(z_i | x_i) + L(x_i) + L_i^{[ext]}$$

- Gained information from other bit positions through processing in component
- Dynamic a priori information is the new key element
  - Other Turbo component's updated and improved extrinsic information
- Independent (i.e. uncorrelated) extrinsic information assumed and required

Turbo Decoding, Concept



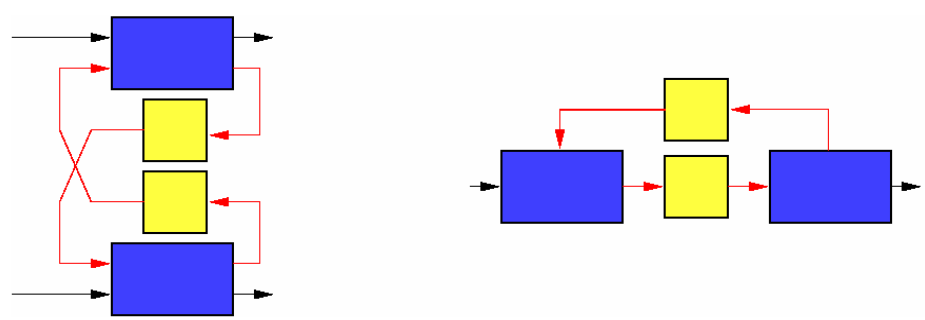
Concatenated Encoding



parallel scheme [Berrou93]

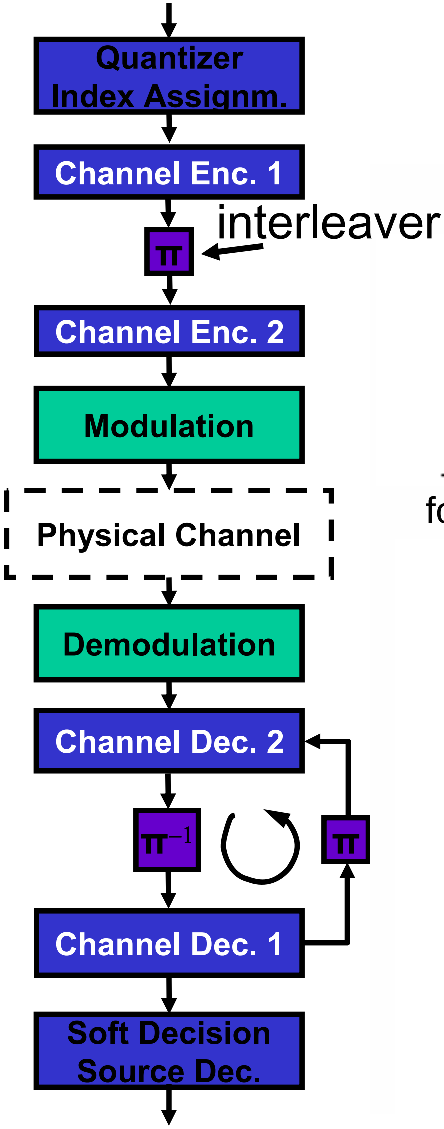
serial scheme [Benedetto98]

Iterative Turbo Decoding

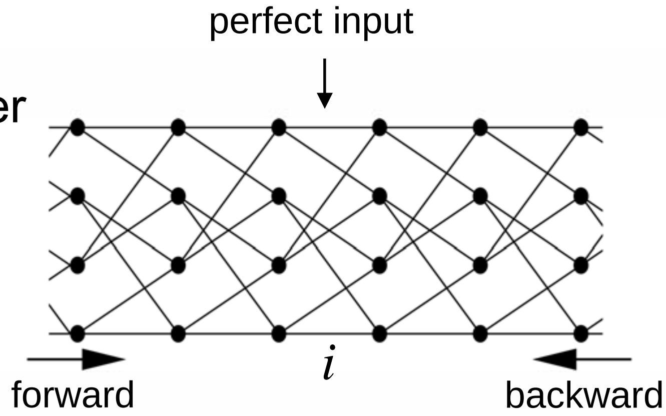


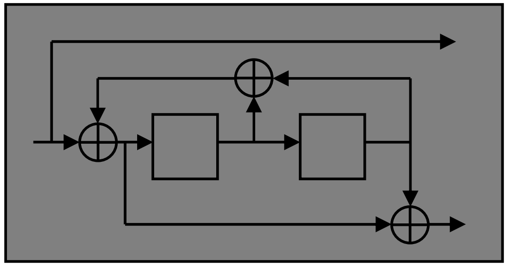
advantages by iterative feedback!

Turbo Decoding, Concept

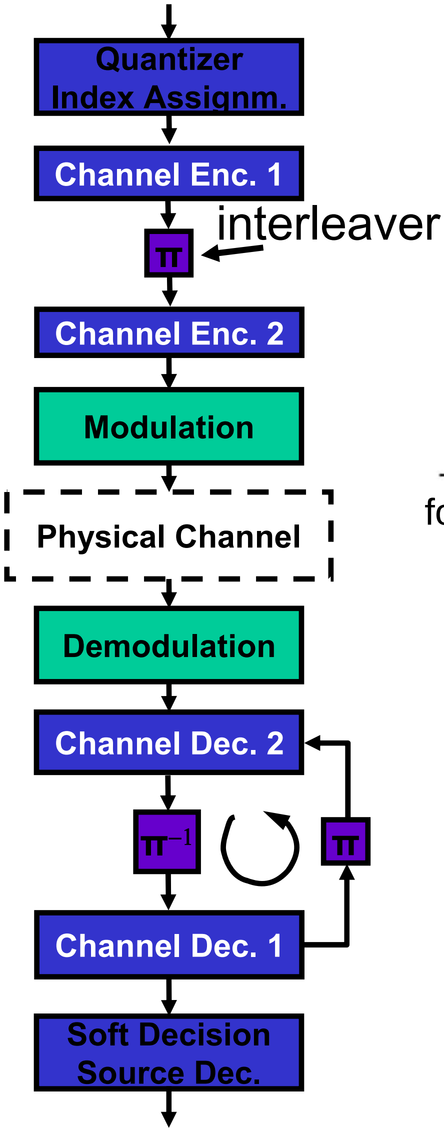


Propagation of extrinsic information

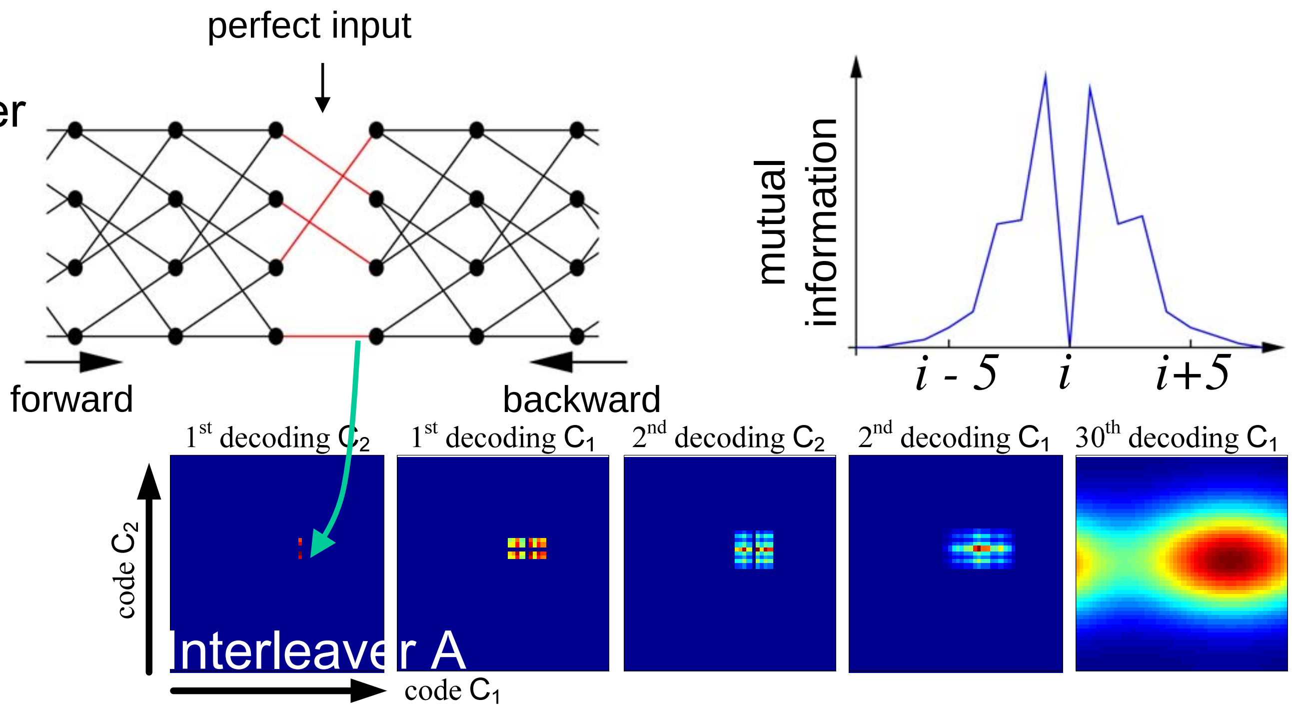




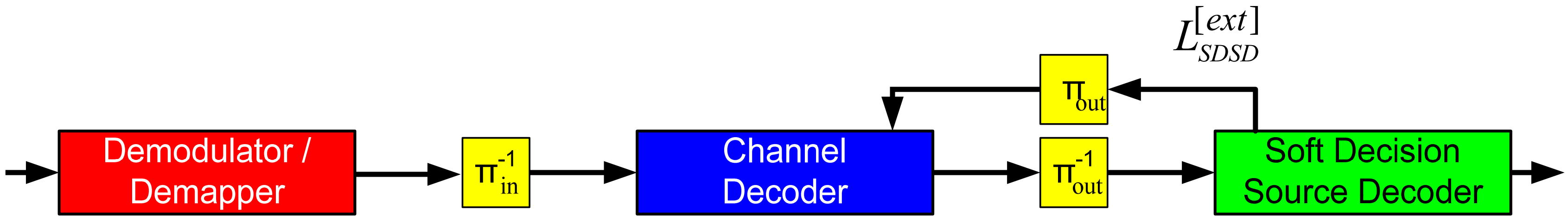
Turbo Decoding, Concept



Propagation of extrinsic information



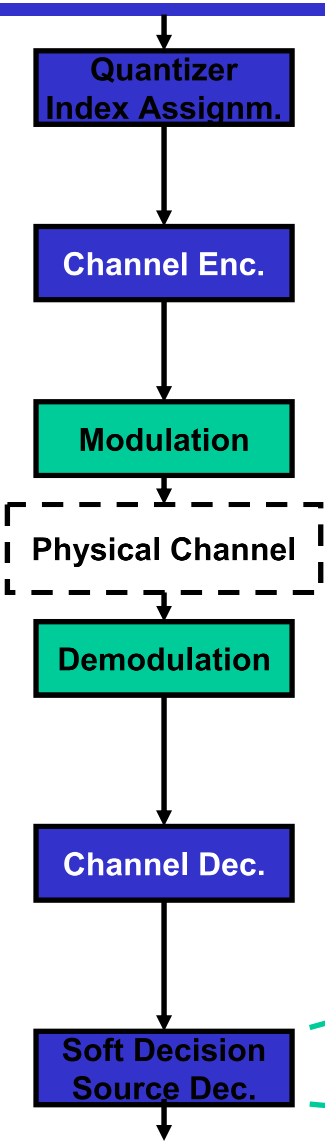
Iterative Source-Channel Decoding (ISCD)



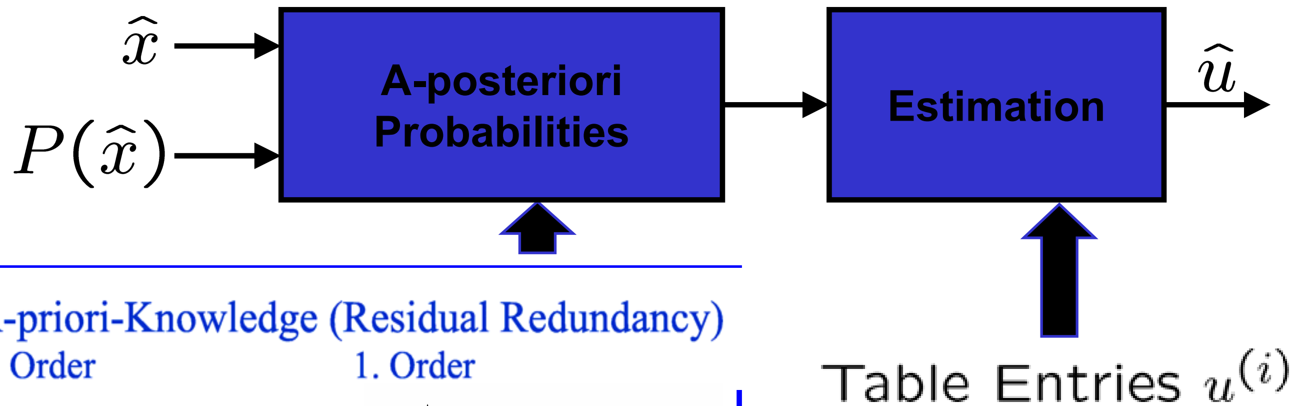
joint – channel decoding
– source decoding

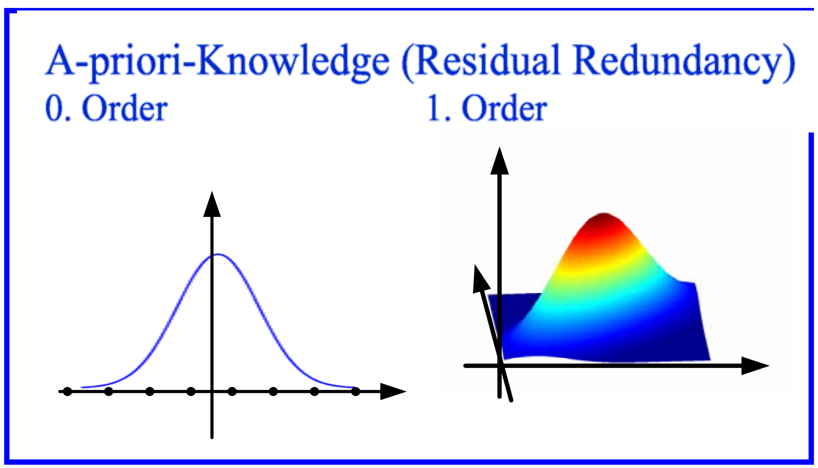
Soft Decision Source Decoding (SDSD)

[Fingscheidt98]



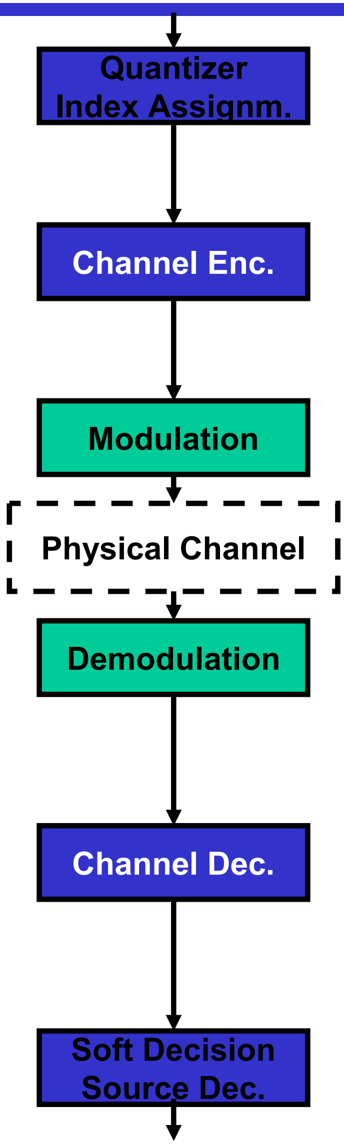
- Parameter Decoding by Estimation
  - Minimum Mean Square Error (MMSE) criterion



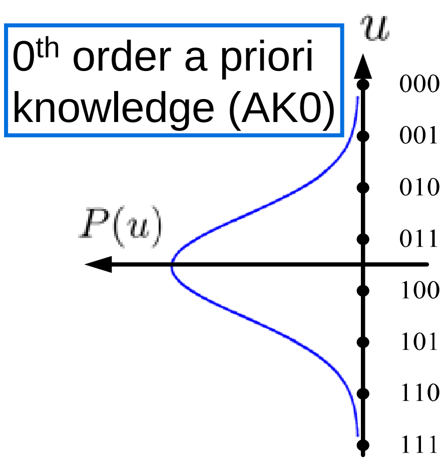


$$\hat{u} = \sum_i u^{(i)} \cdot P\left(x_t^{(i)} \middle| \hat{x}_t, \hat{X}_{t-1}\right)$$

Soft Decision Source Decoding (SDSD) [Fingscheidt98]



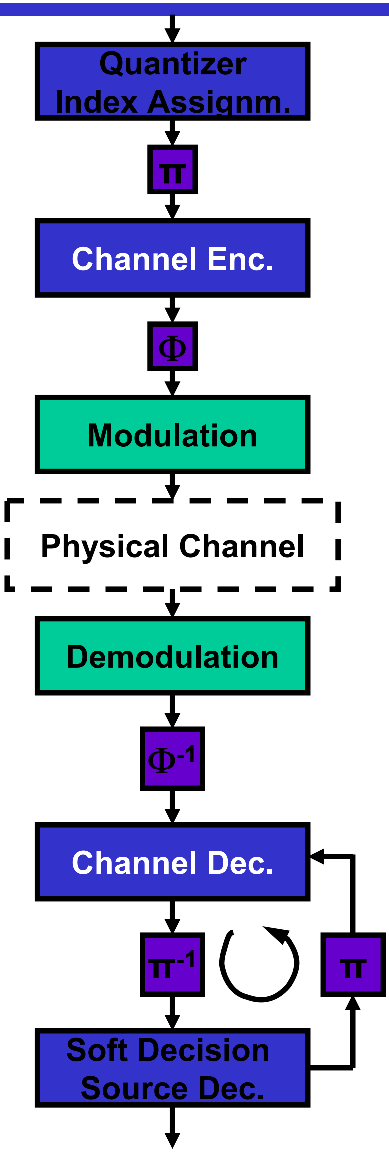
- Exploits residual redundancy in source samples
- Based on fully connected Trellis diagram



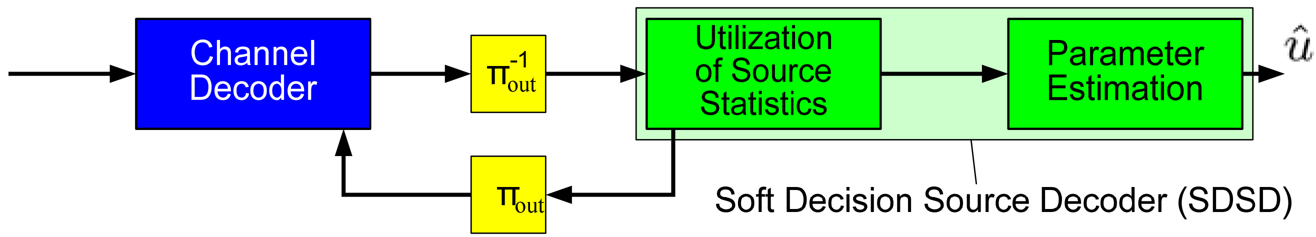
- Soft parameter estimation instead of table lookup (minimizes mean-square error)

$$\hat{u} = \sum_{\xi=0}^{Q-1} \bar{u}^{(\xi)} \cdot P(\bar{u}^{(\xi)} | \underline{z})$$

Iterative Source-Channel Decoding [Adrat03]



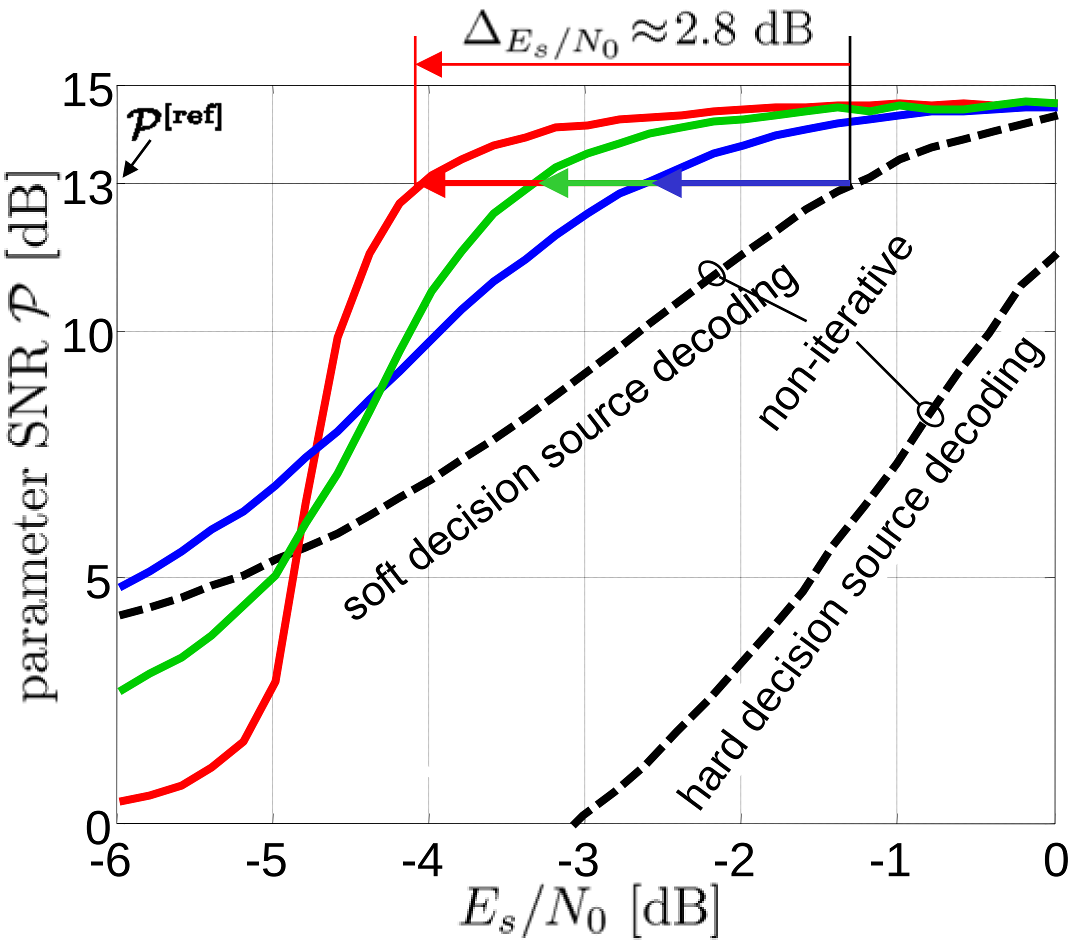
- Iterative evaluation of channel decoding and soft decision source decoding



- Key elements determining the performance of ISCD
  - Index assignment of bit patterns to quantization levels
  - Preserve (exploitable) residual redundancy in source samples after source encoding

Iterative Source-Channel Decoding - Performance

- Evaluation at reference parameter SNR $\mathcal{P}^{[\mathrm{ref}]}$

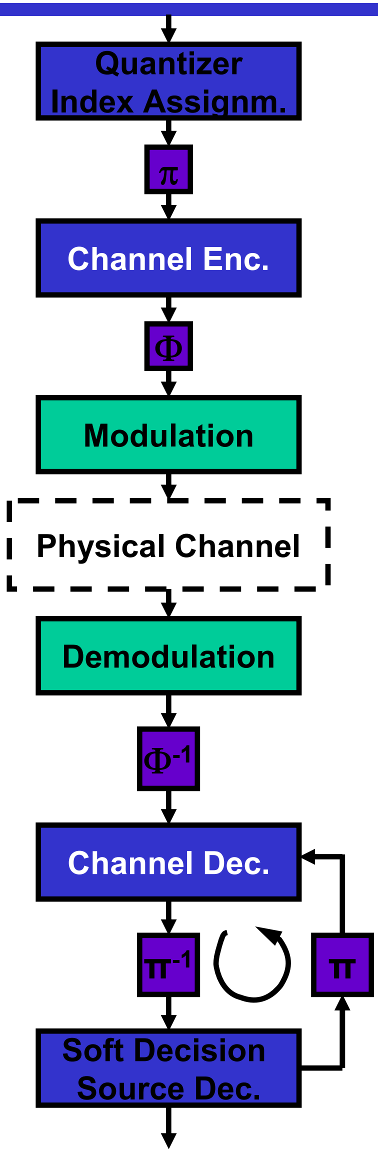


- AWGN channel
- BPSK modulation
- 250 parameters/frame
- auto-correlation ρ=0.9
- 3 bit Lloyd-Max quant. (LMQ)
- r_C=1/2 conv. code with 8 states
- 10 iterations

- **apply ISCD**
  - rec. syst. conv. (RSC) code
  - natural binary (NB) index assignm.
- **improved index assignment**
  - rec. syst. conv. (RSC) code
  - EXIT optim. (EO) index assignm.
- **improved channel code**
  - rec. non-syst. conv. (RNSC) code
  - EXIT optim. (EO) index assignm.

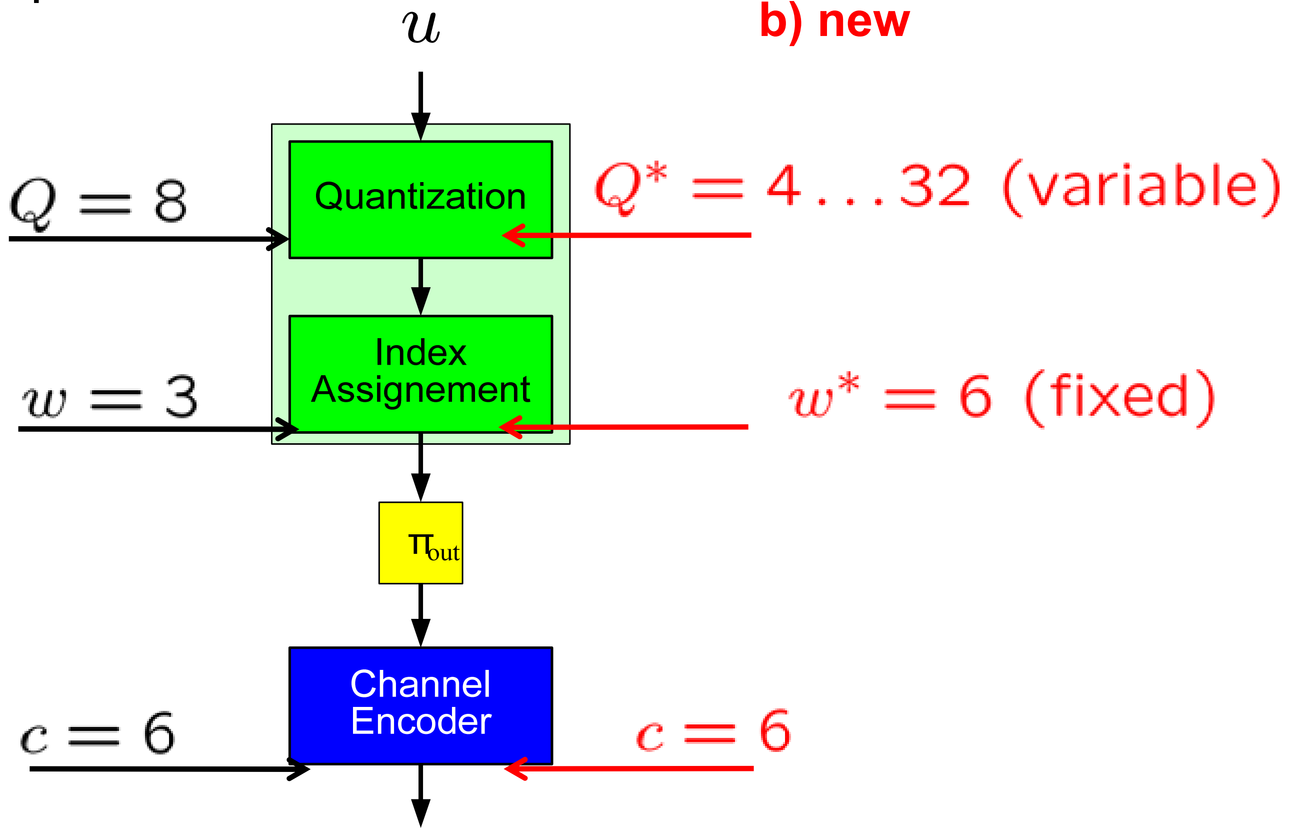
Index assignment and channel coding are key factors for ISCD performance

Redundant Index Assignments [Adrat05], [Clevorn06]



- Highly Redundant Index Assignments
- Q quantization levels

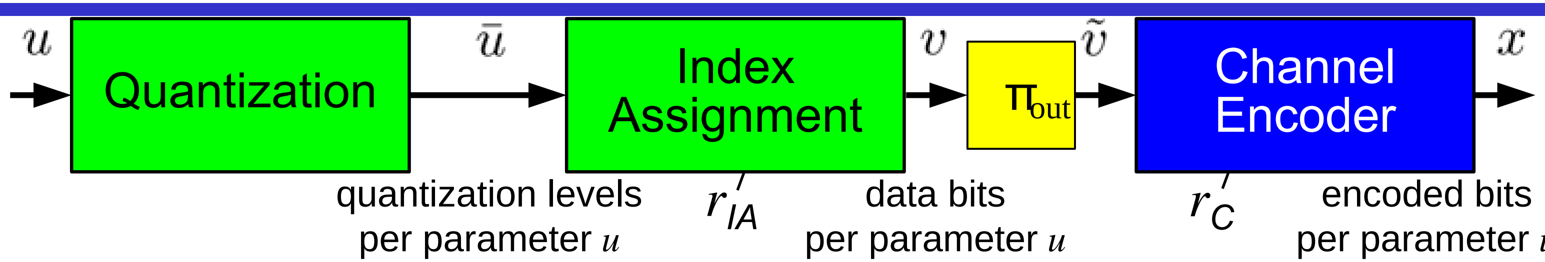
b) new



$r_C = w/c = 1/2$

$r_C = w^*/c = 1$

FlexCode ISCD - Index Assignments for Multi-Mode Extension



- classic ISCD (r_C=1/2) $\quad Q = 8 \quad w = \mathrm{ld}(Q) = 3 \quad w/r_C = 6$
- optimized ISCD (**r_C=1**) $\quad Q^* = 8 \quad w^* = w/r_{IA} = 6 \quad w^*/r_C = 6$
- multi-mode ISCD (**r_C=1**) $\quad Q^* =$ variable $\quad w^* = w/r_{IA} = 6 \quad w^*/r_C = 6$

$Q^* \leq 2^{w^*}$

Redundant index assignment optimized, e.g., block coded

ξ	$\{\xi\}_2$	v
0	000	000000
1	001	001011
:	:	:
7	111	111000

$$\mathbf{G}_{\mathrm{BC}(6,3)} = \begin{pmatrix} 1\,0\,0\,1\,0\,1 \\ 0\,1\,0\,1\,1\,0 \\ 0\,0\,1\,0\,1\,1 \end{pmatrix}$$

multi-mode, e.g., block coded with $Q^* = 16$

ξ	$\{\xi\}_2$	v
0	0000	000000
1	0001	001011
:	:	:
7	0111	111000
:	:	:
11	1011	100010
:	:	:
15	1111	111000

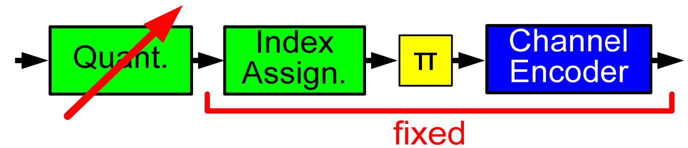
with $Q^* = 12$ (rows 0 to 11)

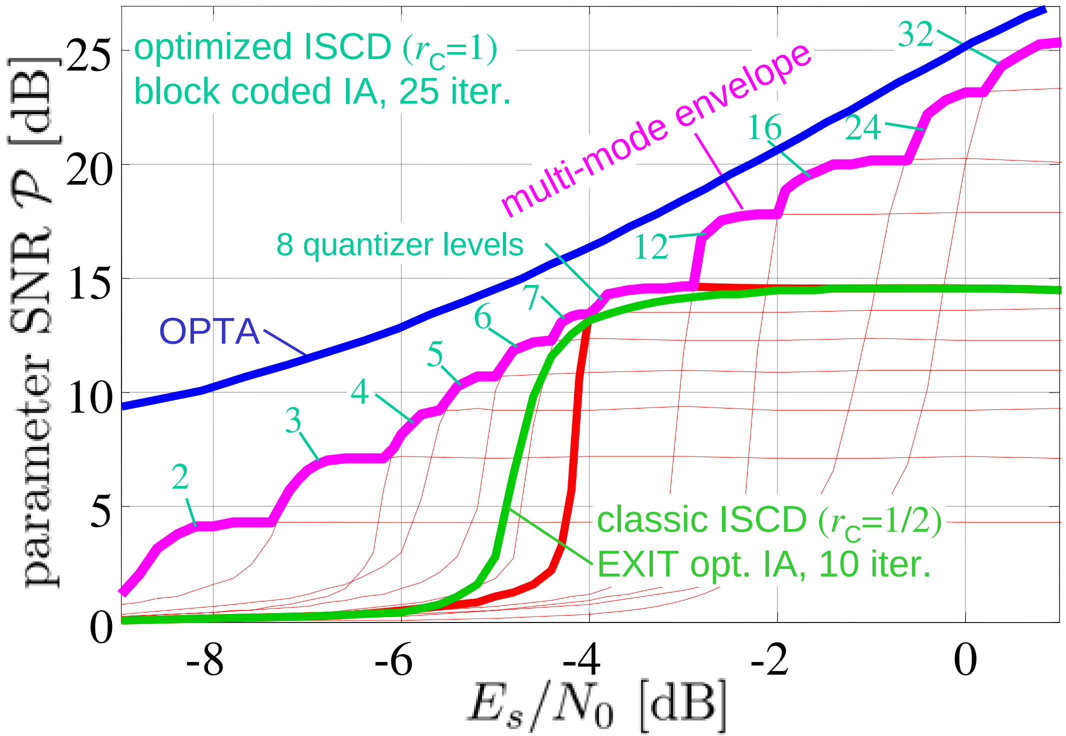
$Q^* = 8$ with $\mathbf{G}_{\mathrm{BC}(6,3)}$ included (rows 0 to 7)

$$\mathbf{G}_{\mathrm{BC}(6,4)} = \begin{pmatrix} 1\,1\,1\,1\,1\,1 \\ 1\,0\,0\,1\,0\,1 \\ 0\,1\,0\,1\,1\,0 \\ 0\,0\,1\,0\,1\,1 \end{pmatrix}$$

ISCD - Performance with Multi-Mode Extension

- With block coded index assignment only single lookup table required
- Interleaver and channel code are fixed
- Only quantizer levels must be adapted





- AWGN channel
- BPSK modulation
- 250 parameters/frame
- auto-correlation ρ=0.9
- Q level Lloyd-Max quant. (LMQ)
- 6 bits per parameter
- convolutional codes with 8 states

- Higher quality in good channel conditions due to large number of quantizer levels
- More robust transmission in bad channel conditions due to increased redundancy

Conclusions

- Iterative Source-Channel Decoding (ISCD) permits **near-capacity** decoding for BPSK modulation
- Redundant index assignments allow versatile multi-mode extension
- Additional flexibility due to multi-mode ISCD
  - good channels: small quantization error
  - bad channels: large quantization errors, but insensitive to channel noise

THANK YOU!