A Discrete Information Bottleneck Receiver with Iterative Decision Feedback Channel Estimation

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Jan Lewandowsky,
Maximilian Stark,
Prof. Dr.-Ing. Gerhard Bauch
Outline

1. Motivation and Information Bottleneck Signal Processing
2. Considered Transmitter, Channel Model and Receiver Structures
3. Results and Conclusion
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Information Bottleneck Signal Processing

Consider the shown digital receiver layout…

\[ \tilde{r} \rightarrow \tilde{r}_I \rightarrow \text{ADC} \rightarrow r_I \rightarrow \text{ADC} \rightarrow r_Q \rightarrow \text{baseband processing algorithms} \rightarrow \hat{d} \]

Examples: channel estimation

- LDPC decoding

\[ h_Q \rightarrow h_I \]

Graphical representation of the digital receiver layout with quantization thresholds and output representations.
Information Bottleneck Signal Processing

Consider the shown digital receiver layout...

\[ r \xrightarrow{\text{I/Q}} \tilde{r}_I \quad \tilde{r}_I \quad \tilde{r}_Q \quad \tilde{r}_Q \quad r_I \quad r_Q \quad \cdots 0,7,5,7,1,1,2\cdots \quad \cdots 4,3,2,0,1\]

\[ \cdots 1,3,3,2,5,5,4\cdots \quad \cdots 1,7,7,6,5,5,1 \quad \cdots 0,1,0,0,1,1,1 \]

Mutual information is independent of representation values.

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

Coarse quantization \(\rightarrow\) small bit width

Only process quantization indices?

Proposal: Information Bottleneck method!
The Information Bottleneck Method

**Workflow:** \( p(x, y) \rightarrow p(t|y), p(x|t), p(t) \)

**Example:** Box-plus replacement

lookup table

\[
Y_0, y_0 \in \{0, 1, \ldots, 2^q - 1\} \\
Y_1, y_1 \in \{0, 1, \ldots, 2^q - 1\}
\]

**pair with discretized density evolution** \( \rightarrow \) LDPC decoders working on quant. indices
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Considered Transmitter & Channel Model

\[ s = h_k \cdot re + j \cdot h_k \cdot im \]
\[ n_k = n_k \cdot re + j \cdot n_k \cdot im \]

channel coefficient 1
\[ P \text{ pilots} \quad M \text{ codeword symbols} \]

channel coefficient 2
\[ P \text{ pilots} \quad M \text{ codeword symbols} \]

channel coefficient …
\[ P \text{ pilots} \quad M \text{ codeword symbols} \]

transmission of one codeword
Considered Receiver Structures

- **Representation values** from $\mathbb{R}$ and $\mathbb{C}$
- **Well known algorithms**
- **Floating point or fixed point precision**

**conventional receiver**

- MMSE channel estimator
- $\hat{h}$
- $N_{FB}$ most rel.
- $i_{FB}$ iterations
- $i_{max}$ iterations
- LLRs
- soft demodulator

**proposed receiver**

- channel estimation lookup table
- $r_k$ integers
- $i_{FB}$ iterations
- $N_{FB}$ most rel.
- $i_{max}$ iterations
- integers
- detection lookup table
- Information Bottleneck decoder
- ints

- **Quantization indices** from $\{0,1,\ldots,Q-1\}$
- **Relevant information preserving LUTs**
- 5 to 8 bit **integers** processed
Information Bottleneck Receiver

ADC \rightarrow I \text{ quantization indices}

ADC \rightarrow Q \text{ quantization indices}

forward channel estimator lookup table

feedback channel estimator lookup table

detection lookup table

LDPC decoder
Information Bottleneck Receiver

forward channel estimator lookup table

feedback channel estimator lookup table

detection lookup table

ADC $\rightarrow$ I quantization indices

ADC $\rightarrow$ Q quantization indices

LDPC decoder

feedback path
Information Bottleneck LDPC Decoder

check node lookup tables
iteration $i$

variable node lookup tables
iteration $i + 1$

integer indices

...
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Results

frequency flat block fading channel, length 8000 (3,6)-regular LDPC (max. 25 decoder iterations), pilot overhead $\approx 8\%$, $i_{\text{FB}}$ outer iterations

proposed Information Bottleneck with $i_{\text{FB}} = 0$ and $i_{\text{FB}} = 5$ and static LUTs

<table>
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<tr>
<th>component</th>
<th>cardinality</th>
<th>bit width</th>
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<th>table size</th>
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<td>channel estim.</td>
<td>$Q^\text{ce}$ = 256</td>
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<td>detection</td>
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<tr>
<td>ADC</td>
<td>$2^{q} = 32$</td>
<td>5 bit</td>
<td>31 decision thresholds</td>
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Complexity Gains?

Information Bottleneck
4 bit messages

fixed-point belief propagation (Q4.4) with Jacobian log LUT

fixed-point min-sum (Q4.4)

Conventional LDPC decoder VS Information Bottleneck LDPC decoder

implementation on TI TMS320C6474 DSP for software defined radio application

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

AWGN with BPSK

...to be presented at ICSPCS'2018
Conclusion

One can build good receivers which only process quantization indices.

Signal processing becomes information processing.

IB design minimizes bit width with maximum preservation of relevant information.

Performance is almost optimal (double precision reference)!
References


References
