Blind Iterative Channel Estimation and Detection for LDPC-Coded Cooperation Under Multi-User Interference

Don Torrieri*, Amitav Mukherjee†, Hyuck M. Kwon‡

Army Research Laboratory*
University of California Irvine†
Wichita State University‡
dtorr@arl.army.mil; a.mukherjee@uci.edu; hyuck.kwon@wichita.edu

Nov. 19, 2008
Outline

1. Background

2. System Model
   - Coded cooperation
   - Transmitter/Receiver

3. CSI estimation methods

4. Results

5. Conclusions
Cooperative diversity is achieved when two or more users jointly relay their information by means of coordinated transmissions, resulting in a simulated spatial diversity from the perspective of the destination.

**Coded cooperation**[1]–[2]: Each user divides its codeword into 2 (or greater) segments: a part of its coded bits are transmitted by the user itself to the final destination (BS), and the remaining portion is relayed via its partner. The two users exchange roles in the next transmission interval, and so forth.

Segmentation of codeword can be done by puncturing or by using product codes.
However, coherent demodulation and iterative decoding requires channel state information!
However, coherent demodulation and iterative decoding requires channel state information!

Issues of channel estimation and multiple-user interference (MUI) in cooperative communications have largely been neglected.
However, coherent demodulation and iterative decoding requires channel state information!

Issues of channel estimation and multiple-user interference (MUI) in cooperative communications have largely been neglected.

Are conventional CSI estimation methods applicable to coded cooperation?
However, coherent demodulation and iterative decoding requires channel state information!

Issues of channel estimation and multiple-user interference (MUI) in cooperative communications have largely been neglected.

Are conventional CSI estimation methods applicable to coded cooperation?

What is the gain in performance offered by iterative processing, if any?
Proposed cooperative network example

**Figure:** Cooperative network architecture.
**Figure:** Coded cooperation time line in a TDD setting. Partners alternate their transmissions within a cooperation interval. No feedback required between partners.
Channel code chosen: *Rate-compatible low-density parity-check* (LDPC) codes with optimized puncturing for short block lengths \((N < 5000)\) [3]. Systematic 2-step search algorithm implemented to construct punctured code:

1. **Grouping**: Distribute all variable nodes into groups \(G_0, G_1, \ldots, G_k\), where \(G_k\) indicates that the punctured variable node information can be recovered in \(k\) decoder iterations.

2. **Sorting**: Determine the order of puncturing of variable nodes within each group.

Claim: Puncturing carried out to minimize the number of decoder iterations required for recovery outperforms random puncturing.
Figure: Transmitter and receiver of a user.
A receiver iteration is defined as 20 LDPC decoder iterations, followed by \( i_{\text{max}} = 10 \) EM internal iterations, and then a single demodulator metric generation.

Estimate of the fading coefficient at iteration \( i + 1 \) is

\[
\hat{h}_{(i+1)}^{(j)} = \frac{1}{N_t/2} \sum_{k=1}^{N_t/2} y(k) \bar{x}_{(i)}^{(j)}(k)
\]

(1)

where \( \bar{x}_{(i)}^{(j)}(k) = E_{z|y,\hat{\theta}_{(i)}^{(j)}}[x(k)] = E_{x|y,\hat{\theta}_{(i)}^{(j)}}[x_k] = E_{x_k|y,\hat{\theta}_{(i)}^{(j)}}[x(k)] \).

Interference-plus-noise PSD \( I_0 \) estimated as

\[
\hat{I}_{0,(i+1)}^{(j)} = \frac{1}{N_t/2} \sum_{k=1}^{N_t/2} \left| y(k) - \hat{h}_{(i+1)}^{(j)} \bar{x}_{(i)}^{(j)}(k) \right|^2.
\]

(2)
The interference with PSD $N_j$ is assumed to be active or inactive with a duty cycle $d$. The time-varying total interference-plus-noise PSD is modeled as

$$I_0 = \begin{cases} N_0 & \text{if interfering users are inactive} \\ N_0 + N_j & \text{if interfering users are active} \end{cases}$$

Simplifying approximation: MUI is modeled as additive Gaussian noise with a bandlimited white PSD $N_j$ at the same power level as the unfaded desired signal, i.e., $N_j = ME_s$, and all interfering users are active or inactive at the same time.
CSI estimation methods

Initial estimation

Three methods compared for the initial CSI estimates:

1. Multiplexed Pilot-assisted Channel Estimation (M-PACE): multiplex or embed pilot symbols at known locations throughout the transmitted codeword.

2. Superimposed or Overlaid PACE (O-PACE): periodic, non-random pilot sequence superimposed on to all data code symbols within the codeword.

3. Blind (no-pilot): CSI estimated directly from received symbols using heuristic formula.

- No-pilot and O-PACE codewords have the same number of information symbols.
- M-PACE and O-PACE allocate the same total power for pilot symbols per frame.
CSI estimation methods

Figure: Transmitted codeword with data and pilot power allocations for (a) M-PACE (b) O-PACE (c) proposed method without pilot symbols. Shaded regions in (a) and (b) represent the pilot symbol locations.
CSI estimation methods

**M-PACE:** initial channel coefficients are obtained using a simple average of the received pilot symbols per fading block, then obtain $\hat{I}_{0,(i_{\max})}$ from (2) with $\bar{x}_{(i_{\max})}(k)$ set to the known pilot symbols.

**O-PACE:** initial fading-coefficient estimate per fading block obtained using an approximate least-squares method as

$$
\hat{h}^{(0)}_{o,i_{\max}} = \frac{1}{\sqrt{E_p/E_s N_t/2}} \sum_{k=1}^{N_t/2} y(k) p^*(k).
$$

(4)

**Blind:** simple heuristic method to obtain initial CSI from the received data:

$$
|\hat{h}^{(0)}_{(i_{\max})}| = \frac{1}{N_t/2} \sum_{k=1}^{N_t/2} |y(k)|
$$

(5)

$$
\hat{l}^{(0)}_{0,(i_{\max})} = \max \left( D - |\hat{h}^{(0)}_{(i_{\max})}|^2, f \cdot |\hat{h}^{(0)}_{(i_{\max})}|^2 \right)
$$

(6)
Two possible configurations exist for the iterative coded-cooperation system.

**Case-I**: Additional \( (j_{\text{max}} \geq 1) \) receiver iterations at either partner or destination only.

**Case-II**: Additional \( (j_{\text{max}} \geq 1) \) receiver iterations at both partner and destination.

Case II is expected to provide the best decoding performance, albeit at the cost of increased latency (processing delay).
Table: Rate-Compatible LDPC Parameters

<table>
<thead>
<tr>
<th>Rate</th>
<th>0.5</th>
<th>0.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Column, Row) Weights</td>
<td>(3,6)</td>
<td>(3,6)</td>
</tr>
<tr>
<td>Length</td>
<td>4096</td>
<td>2926</td>
</tr>
<tr>
<td>Punctures</td>
<td>0</td>
<td>1170</td>
</tr>
</tbody>
</table>

**Channel model**: correlated, fading-block size of $F = 4$ symbols, information-bit rate of 100 kb/s.

**No. of interfering pairs**: One
Interference environment BER

Blind methods 0.4 dB from PACE at $BER = 10^{-3}$

**Figure:** BER versus $E_b/N_0$ for the blind and PACE methods.
Blind case II: highest throughput (within 10% of perfect CSI) M-PACE and O-PACE: 17% lower throughput than perfect CSI.
Conclusion

Blind channel-coefficient and interference-plus-noise PSD estimation method based on expectation-maximization was proposed for LDPC-coded cooperative communications.
Conclusions

**Conclusion**

- Blind channel-coefficient and interference-plus-noise PSD estimation method based on expectation-maximization was proposed for LDPC-coded cooperative communications.
- The importance of estimating the interference-plus-noise PSD was shown by the noticeable improvement in LDPC decoding performance under multi-user interference.
**Conclusion**

- Blind channel-coefficient and interference-plus-noise PSD estimation method based on expectation-maximization was proposed for LDPC-coded cooperative communications.
- The importance of estimating the interference-plus-noise PSD was shown by the noticeable improvement in LDPC decoding performance under multi-user interference.
- The proposed blind estimation method has a decoding performance superior to superimposed PACE and within 0.6 dB of M-PACE.
Conclusion

- Blind channel-coefficient and interference-plus-noise PSD estimation method based on expectation-maximization was proposed for LDPC-coded cooperative communications.
- The importance of estimating the interference-plus-noise PSD was shown by the noticeable improvement in LDPC decoding performance under multi-user interference.
- The proposed blind estimation method has a decoding performance superior to superimposed PACE and within 0.6 dB of M-PACE.
- The proposed method provides the highest information throughput out of the three CSI estimation methods considered in this paper.


