Iterative Decoding of LDPC in the Presence of Strong Phase Noise

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Contribution

We propose a new efficient message passing algorithm for decoding LDPC transmitted over a channel with strong phase noise.

- Based on a factor graph representation of the channel and code joint posterior.
- Improved canonical model for the messages of the Sum & Product Algorithm.
- Method for clustering the messages using the directional statistics framework.
- Treatment for phase slips.

The proposed algorithm demonstrates a superior accuracy versus complexity tradeoff, over the current state of the art algorithms.

System Model

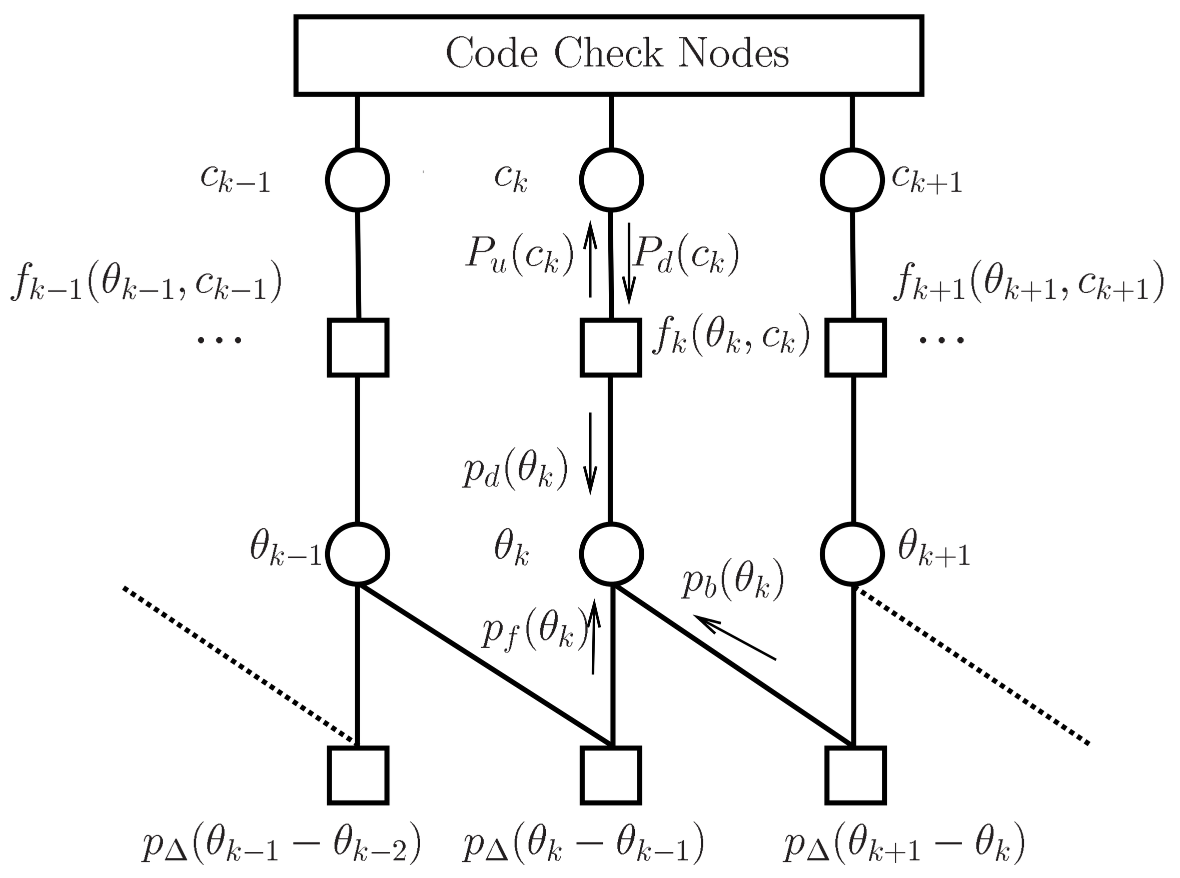
The discrete-time baseband complex equivalent channel model at the receiver is given by:

$$r_k = c_k e^{j\theta_k} + n_k \quad k = 0, 1, ..., K-1.$$

The phase noise stochastic model is a wiener process

$$\theta_k = \theta_{k-1} + \Delta_k$$

Factor Graph representation of the joint posterior and the SPA messages is:



Phase noise SPA messages are continuous and must be approximated using a canonical model.

Circular Mean & Variance Matching

(CMVM): Let $f(\theta) = \sum_{i=1}^{N} \alpha_i \frac{e^{Re[k_i e^{-j(\theta-\mu_i)}]}}{2\pi I_0(|k_i|)}$ be a Tikhonov mixture. Then the Tikhonov distribution $g(\theta)$ which minimizes $D(f||g)$ (KL Divergence) is

$$g(\theta) = \frac{e^{Re[\hat{k}e^{-j(\theta-\hat{\mu})}]}}{2\pi I_0(\hat{k})}$$

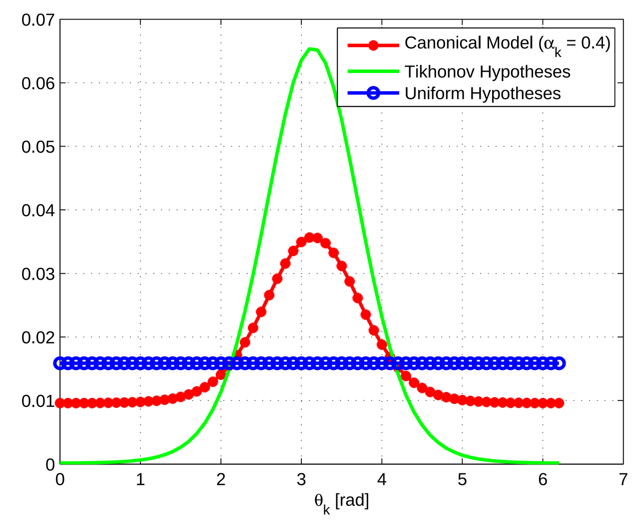
$$\hat{\mu} \approx \arg[\sum_{i=1}^{N} \alpha_i (1 - \frac{1}{2k_i}) e^{j\mu_i}]$$

$$\frac{1}{2\hat{k}} \approx 1 - \sum_{i=1}^{N} \alpha_i (1 - \frac{1}{2k_i}) \cos(\hat{\mu} - \mu_i)$$

Canonical Model

$$Message(\theta_k) = \alpha_k T(\theta_k) + (1 - \alpha_k) U(\theta_k)$$

- $T(\theta_k)$ - Tikhonov (Tracked phase trajectory).
- $U(\theta_k)$ - Uniform (All the other trajectories).
- α_k - The probability that there hasn't been a phase slip.



When pilots are available, the uniform distribution helps regain tracking after phase slip.

Algorithm

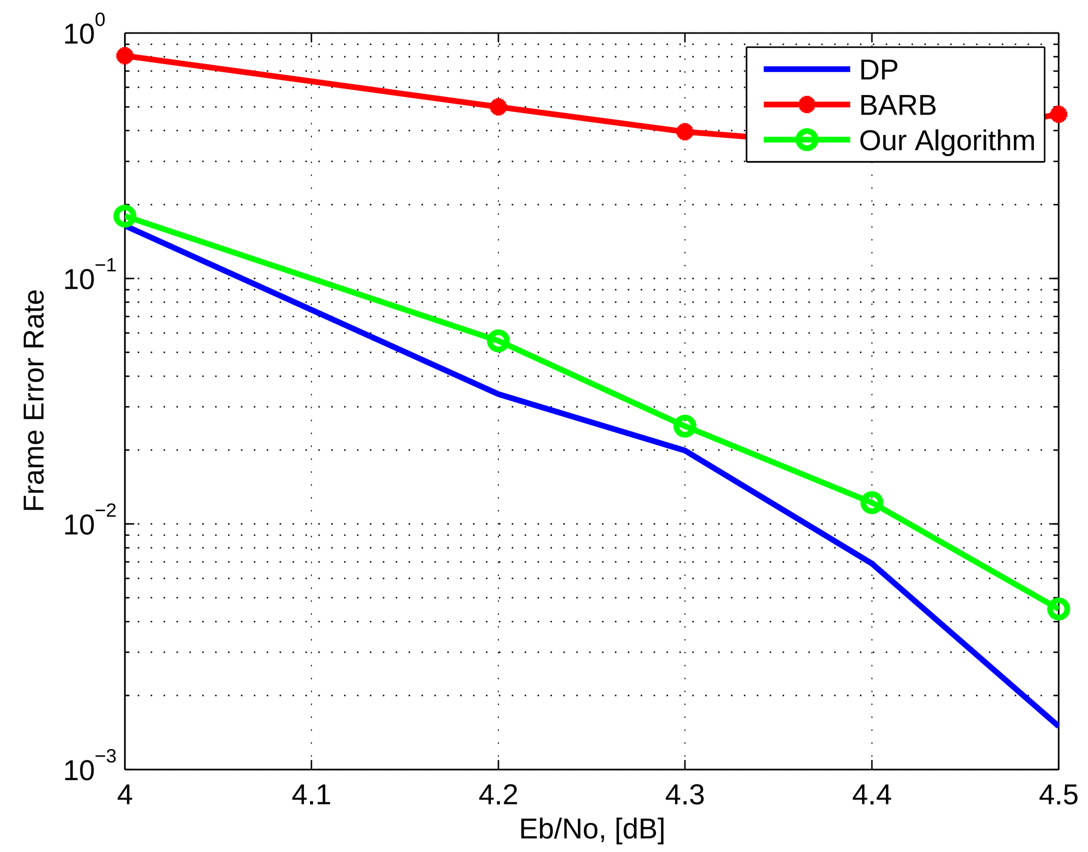
SPA messages become mixtures $\sum_{i=1}^{N} a_i \frac{e^{Re[z_i e^{-j\theta_k}]}}{2\pi I_0(|z_i|)}$ and a component selection algorithm is applied:

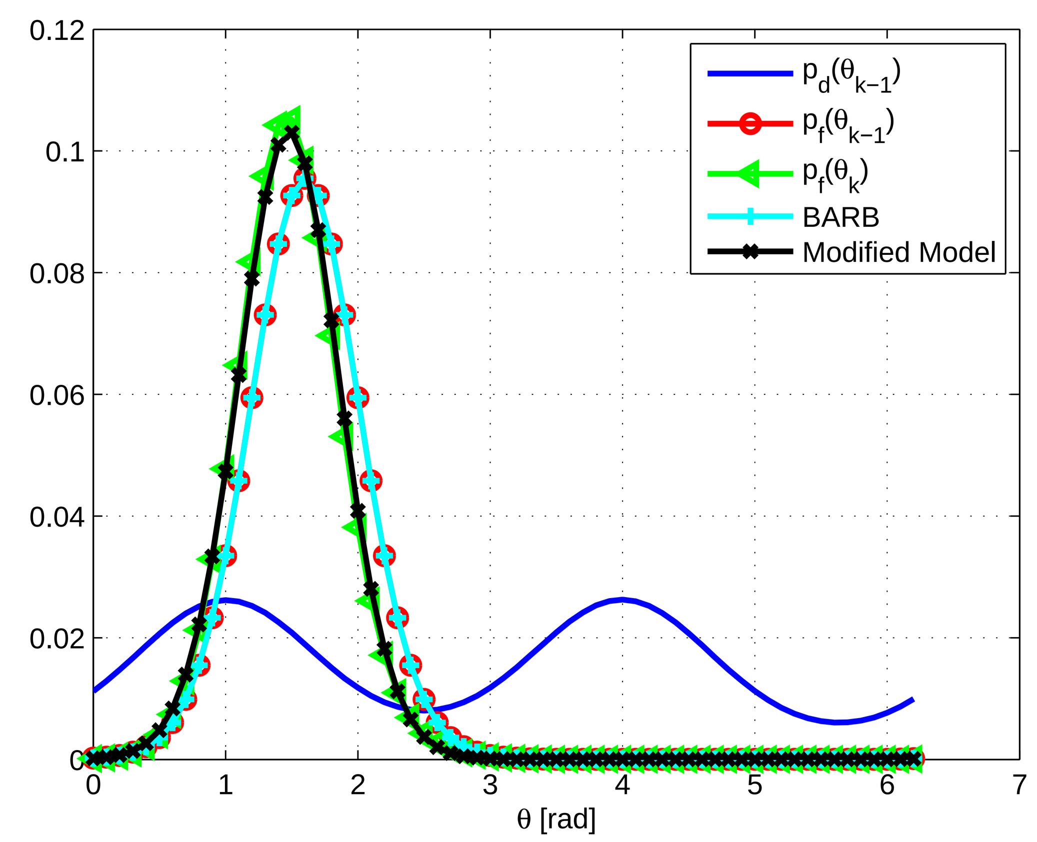
$lead \leftarrow argmax_i\{\frac{a_i}{|z_i|^{-1}}\}$
$idx \leftarrow lead$
for $i = 1 \rightarrow N$ **do**
  if $D(f_{lead}(\theta)||\frac{e^{Re[z_i e^{-j\theta_k}]}}{2\pi I_0(|z_i|)}) \leq T_D$ **then**
    $idx \leftarrow [idx, i]$
  end if
end for
$T(\theta_k) \leftarrow CMVM(a(idx), \frac{e^{Re[z_{idx} e^{-j\theta_k}]}}{2\pi I_0(|z_{idx}|)})$
$\alpha_k \leftarrow \alpha_{k-1} \sum a(idx)$

Simulation Results

Monte Carlo simulation results for the proposed algorithm, algorithm proposed in [1] (BARB) and algorithm based on phase quantization (DP).

- Length 4608 LDPC code with rate 0.889.
- BPSK constellation.
- Phase noise model with $\sigma_\Delta = 0.1$ [rads/symbol].
- A single pilot was inserted every 80 symbols.
- The DP algorithm was simulated using 8 quantization levels.





The new algorithm has a negligible loss with respect to DP algorithm while BARB demonstrates a high error floor.

Complexity

The computational load per code symbol per iteration for M-PSK constellation for the different algorithms is summarized in the following table:

	DP	BARB	Our Algorithm
Operations	13ML+10QL-9L-3M	17M+11	40M
LUT	3ML+2QL-3L-M	3M+3	5M

M is the constellation order, L is the number of quantization levels and Q is a parameter for the DP algorithm explained in [1].

References

[1] G. Colavolpe, A. Barbieri and G. Caire. Algorithms for Iterative Decoding in the Presence of Strong Phase Noise In *IEEE Journal on Selected Areas in Communications 2005*
[2] S. Shayovitz, D. Raphaeli. Efficient Iterative Decoding of LDPC in the Presence of Strong Phase Noise In *ArXiv e-prints 2012*