Iterative Decoding and Phase Noise Tracking for High-order QAM Constellations

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Introduction

The Wiener phase noise channel is studied and a low-complexity phase noise (PN) tracking algorithm is designed. The method is validated on an EDFA fiber optic communication channel with non-ideal lasers with linewidth of 10kHz, 100kHz and 1MHz for 16QAM, 64QAM and 256QAM. The method is integrated with a coded modulation system with iterative demapping and decoding. It is shown that iterations improve the BER performance by more than 1dB in some cases.

Channel model

Consider a standard Wiener phase noise channel:

- $y_k = x_k \exp(j\theta_k) + z_k$, where $x_k \in \mathcal{X}$, and
  $\theta_k = \theta_{k-1} + v_k, \;\; z_k \sim \mathcal{N}(0, \sigma^2; z_k), \;\; v_k \sim \mathcal{N}(0, \Delta^2; v_k)$,
- The process variance is found as $\Delta^2 = 2\pi \cdot f_W \cdot T_s$, where f_W is the oscillator's linewidth, and T_s is the symbol rate

Receiver's task: Estimate the posteriors $p(x_k|y_1^K)$, which are used for achievable information rate (AIR) calculation and later for demodulation.

Algorithm (in a nutshell)

Model the forward and backward recursions by mixture of Tikhonov distributions, and use the sum-product update rules for finding them

- $\xi_1 = p(\theta_{k-1}|y_1^{k-1}) = \sum_{m=1}^{M} \alpha_{m,k-1} \cdot t(w_{m,k-1}; \theta_{k-1})$
- $\xi_2 = p(\theta_k|y_1^{k-1}) = \int_{-\pi}^{\pi} \xi_1 \cdot p(\theta_k|\theta_{k-1}) d\theta_{k-1}$
- $\xi_3 = p(y_{k+1}^K|\theta_k) = \int_{-\pi}^{\pi} \xi_4 \cdot p(\theta_{k+1}|\theta_k) d\theta_{k+1}$
- $\xi_4 = p(y_{k+1}^K|\theta_{k+1}) = \sum_{n=1}^{N} \beta_{n,k+1} \cdot t(u_{n,k+1}; \theta_{k+1})$
- $\xi_5 = \xi_2 \cdot \xi_3$
- $\xi_6 = \int_{-\pi}^{\pi} \xi_5 \cdot p(y_k|\theta_k, x_k) d\theta_k$
- $\xi_7 = p(x_k)$

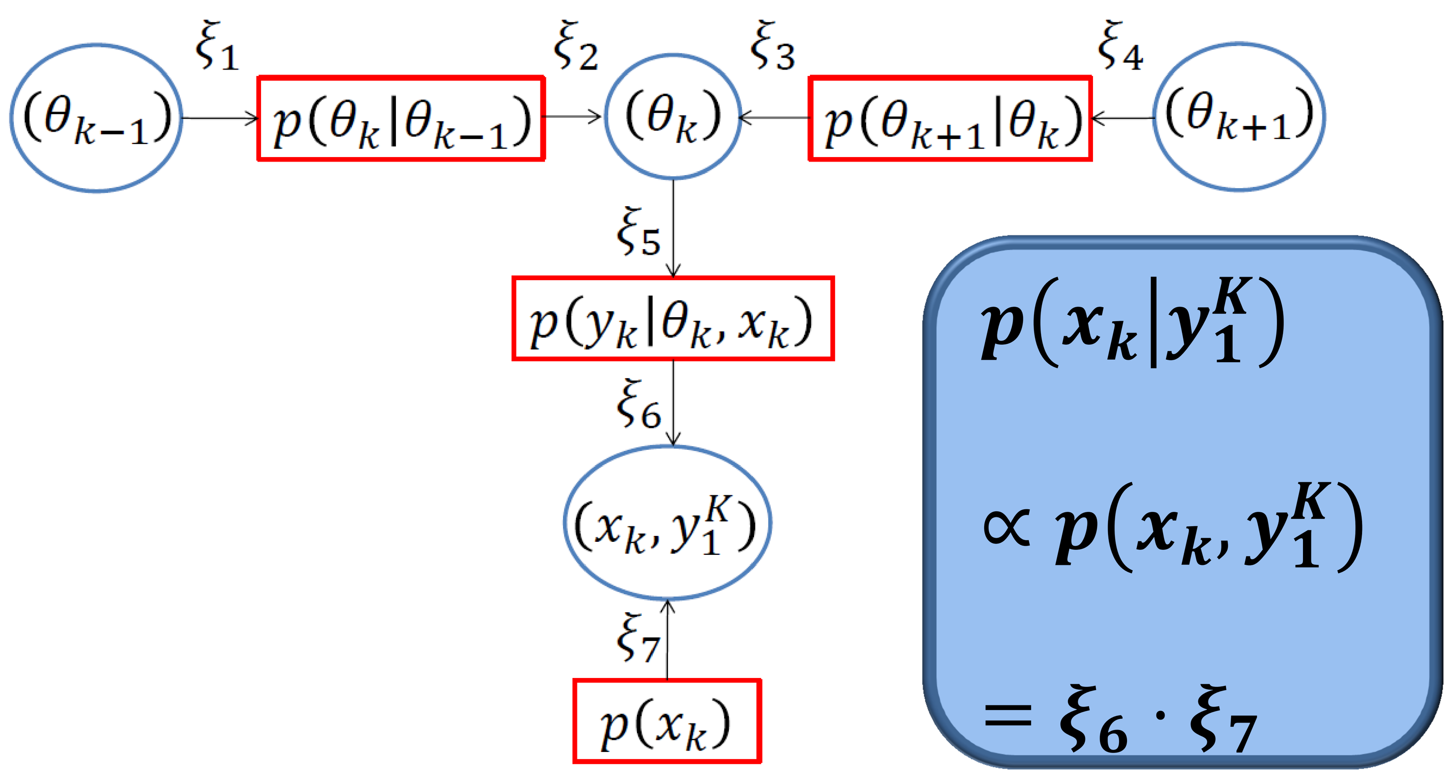


Figure 1. Factor graph of the receiver processing

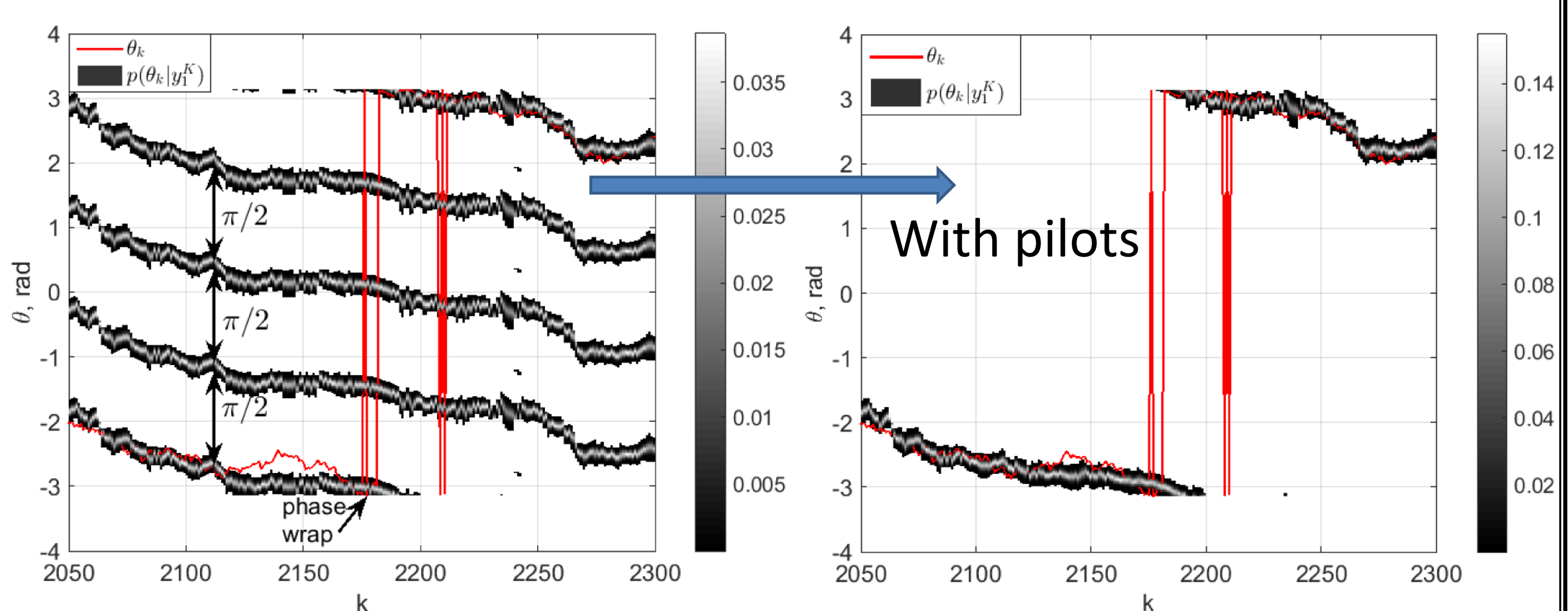


Figure 2. Example phase noise distribution. With the insertion of pilots the $\pi/2$ ambiguity is resolved

References:
[1] L. Barletta *et. al.*, "Pilot-aided trellis-based demodulation," Photon. Techn. Lett., vol. 25, no. 13, pp. 1234-1237, July 1, 2013.
[2] T. Pfau, *et. al.*, "Hardware-efficient coherent digital receiver concept with feedforward carrier recovery for M-QAM constellations," J. of Lightw. Techn., vol. 27, no. 8, pp. 989-999, Apr. 15, 2009.

Results – EDFA WDM optical channel

- We study the achievable information rates (AIR)s on an Erbium doped fiber amplified (EDFA) wavelength division multiplexed (WDM) optical channel. We compare the performance of the Tikhonov mixture model (TMM) proposed here, the trellis method from [1] and the decision-directed (DD) algorithm from [2].
- The pseudo-ideal phase-noise removal (PIPNR) is obtained via genie approach by subtracting the sliding window average phase-noise sample $\hat{\theta}_k = \angle \sum_{l=k-L-1}^{k-1} y_l x_l^*$, and is also an AIR.

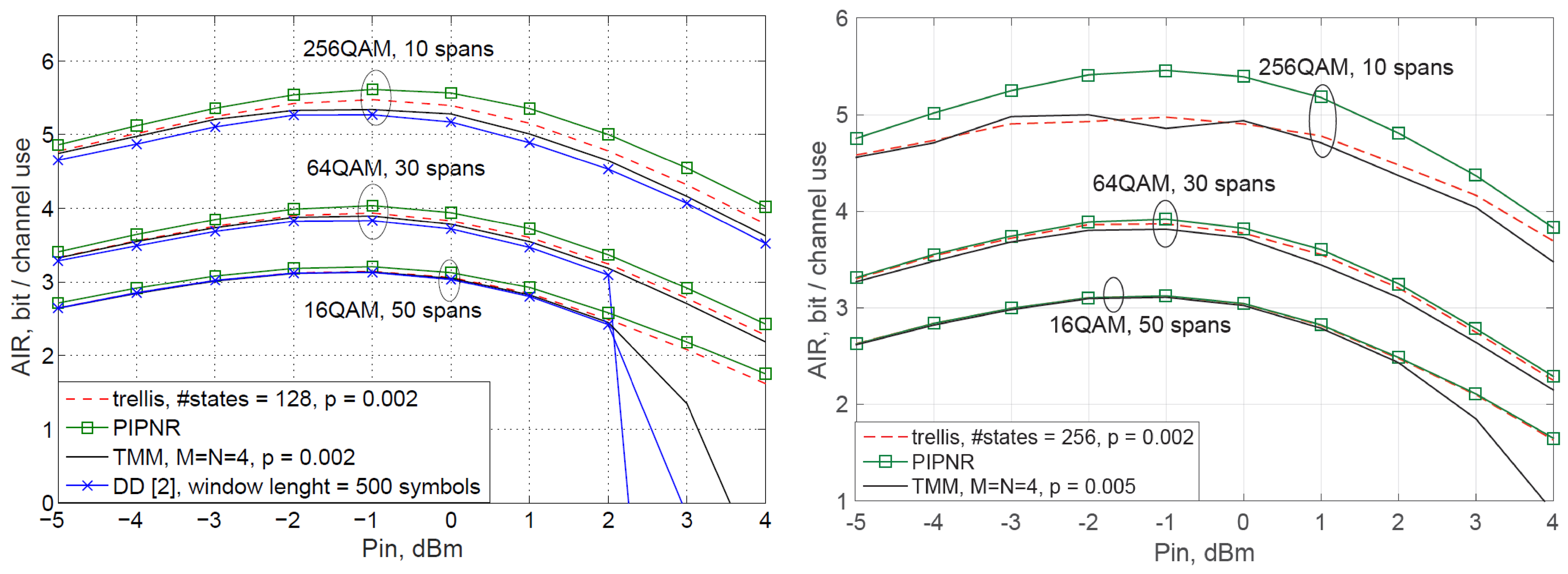
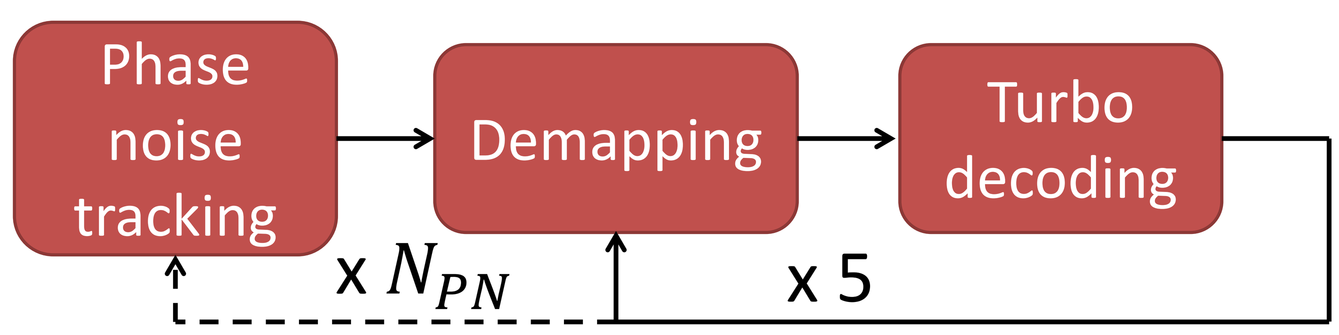


Figure 3. AIRs on a standard single mode fiber EDFA link with 17x28GBaud channels, 100km span between EDFAs. **Left - $f_W = 10$kHz, right - $f_W = 100kHz$**

Iterative processing performance

- We study bit-interleaved coded modulation BER performance in severe phase noise scenarios and large QAM constellations. The data are encoded by a convolutional turbo code.
- The phase-noise tracking is inserted in the iterative demapping and decoding loop, which results in inclination of the EXIT function of the demapper => **iterative demapping in phase noise scenarios is beneficial.**



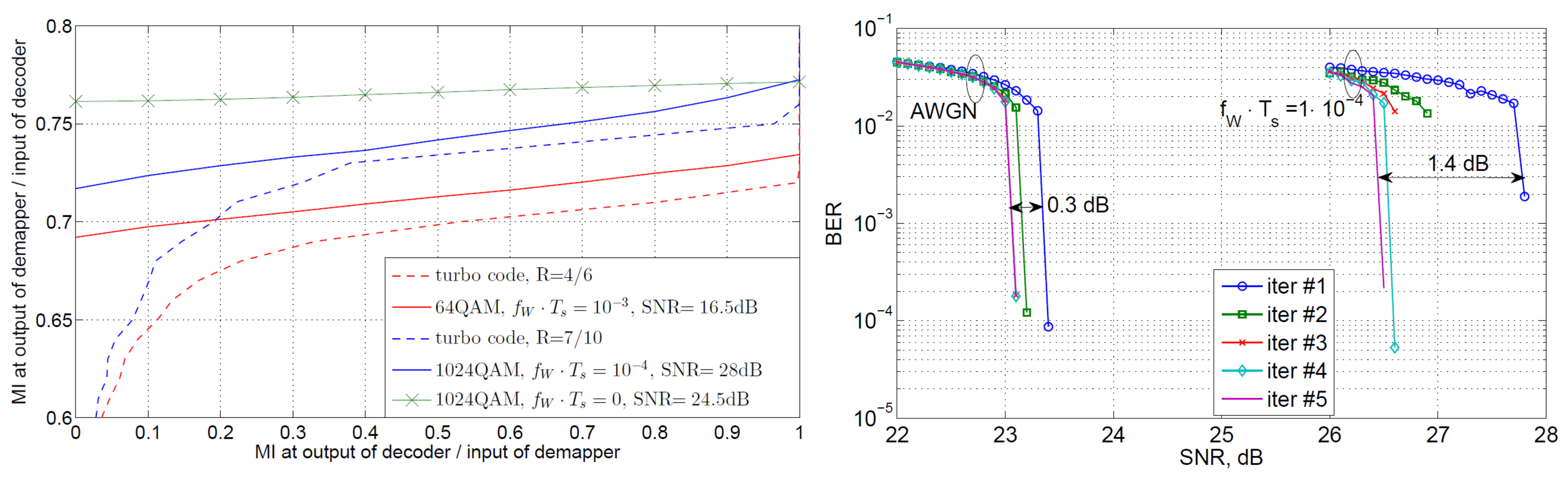


Figure 3. Iterative processing performance. Pilot rate – 5%. **Left – EXIT chart** for an AWGN and phase noise scenarios, **right – BER for 1024QAM.** $f_W \cdot T_s = 10^{-4}$, turbo code of rate $R = 7/10$, 10 turbo iterations, 5 demapping, 2 PN iterations.

Conclusion

- **New method for phase noise tracking was designed, based on Tikhonov parametrization**
- **Near-optimal performance in the analyzed EDFA WDM channels**
- **Iterative processing is beneficial in severe phase noise scenarios. Pilots are needed in such cases**