IMPULSIVE NOISE MITIGATION IN OFDM SYSTEMS USING SPARSE BAYESIAN LEARNING

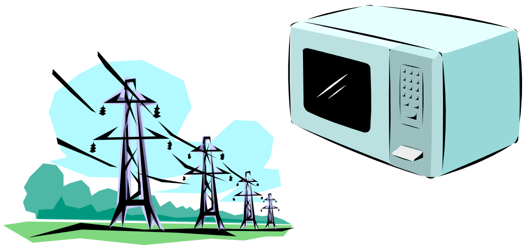
Jing Lin, Marcel Nassar and Brian L. Evans

Department of Electrical and Computer Engineering
The University of Texas at Austin

THE UNIVERSITY OF TEXAS AT AUSTIN
UT ECE
ELECTRICAL & COMPUTER ENGINEERING

WNCG Wireless Networking & Communications Group

Impulsive Noise at Wireless Receivers



Non-Communication Sources

Electromagnetic radiations

Wireless Communication Sources

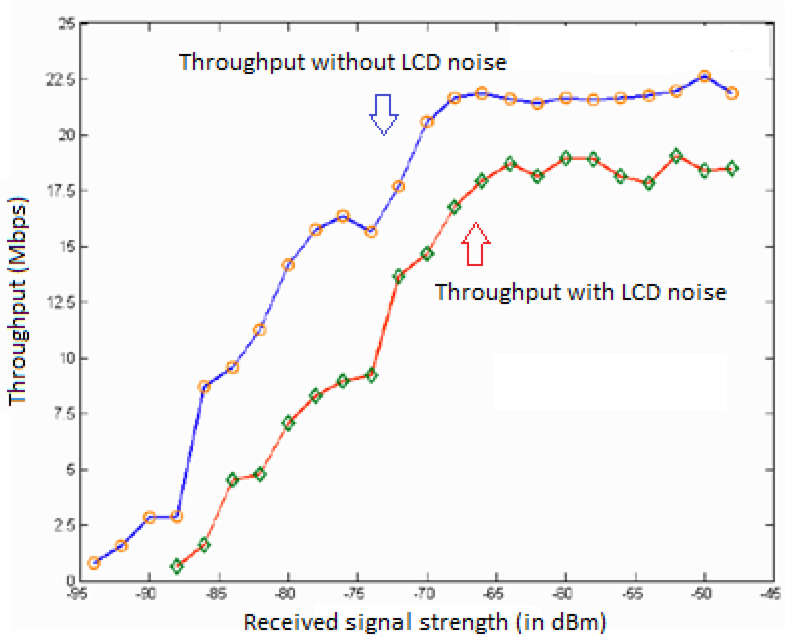
Uncoordinated transmissions

Computational Platform

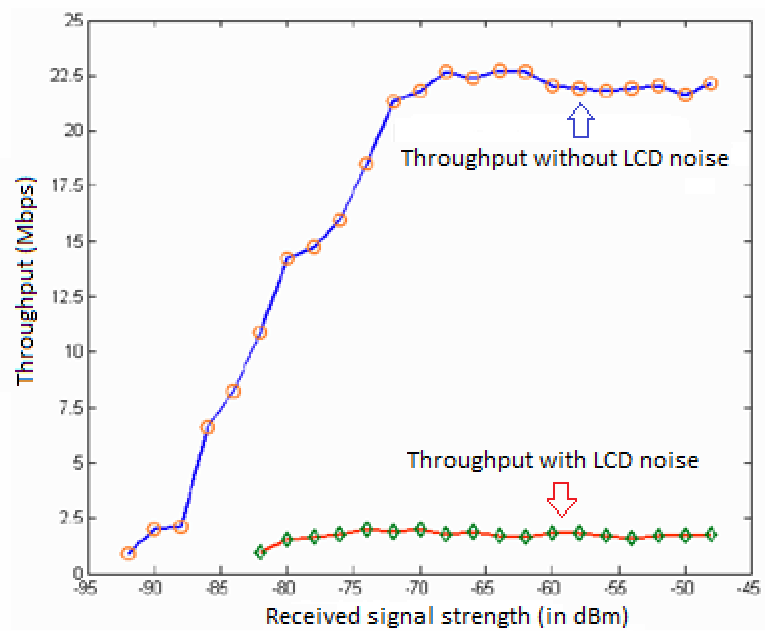
- Clocks, busses, processors
- Other embedded transceivers

In-Platform Interference

- May severely degrade communication performance
- Impact of LCD noise on throughput for IEEE 802.11g embedded wireless receiver ([Shi2006])

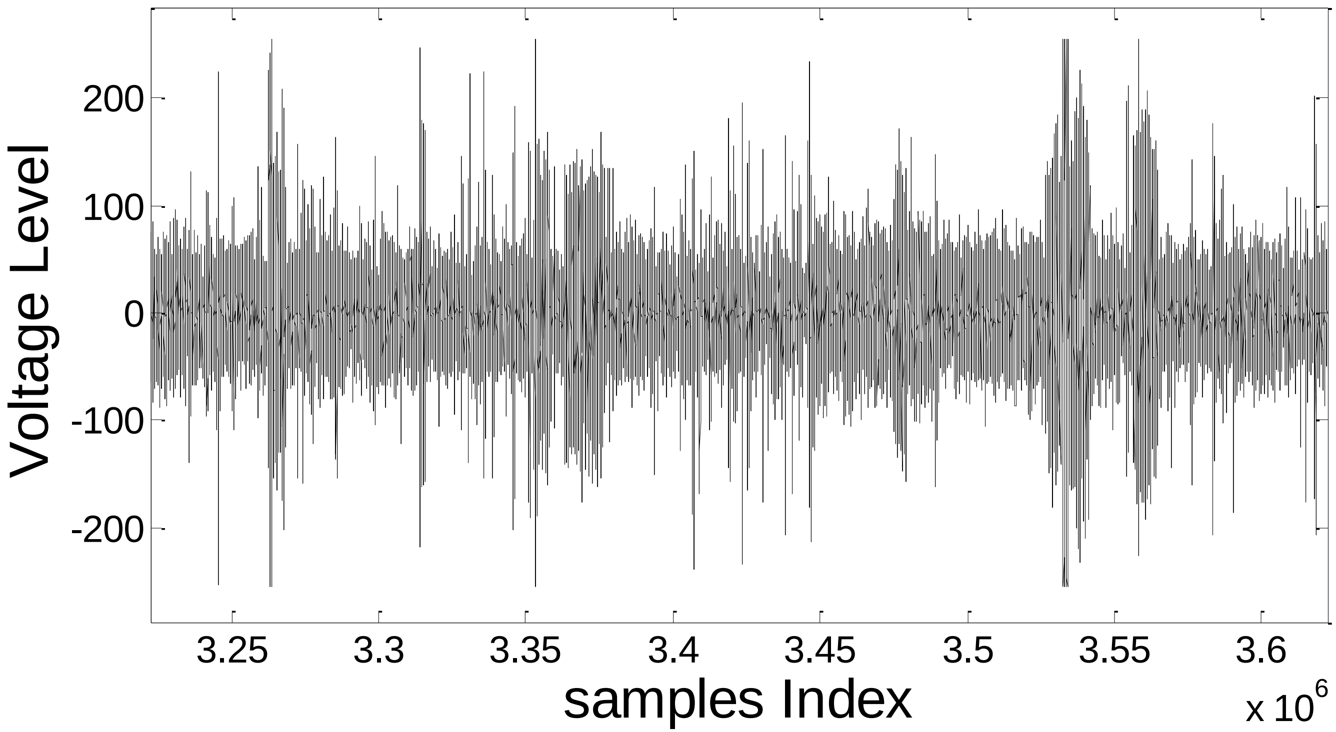


(a) 802.11g, Channel 1

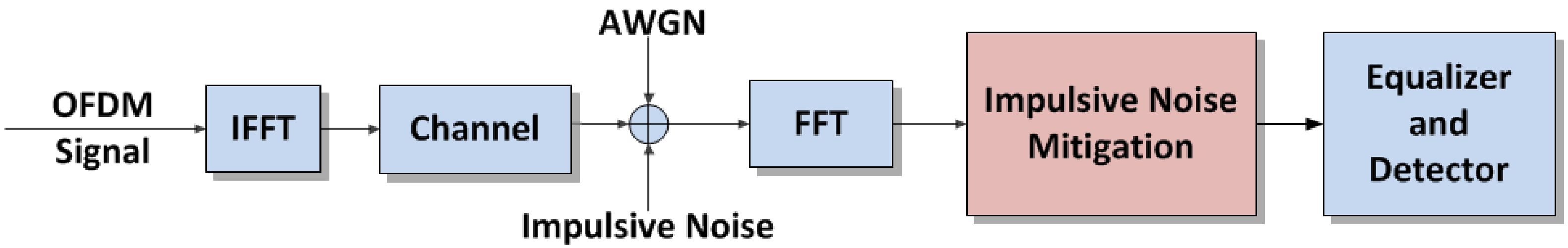


(b) 802.11g, Channel 7

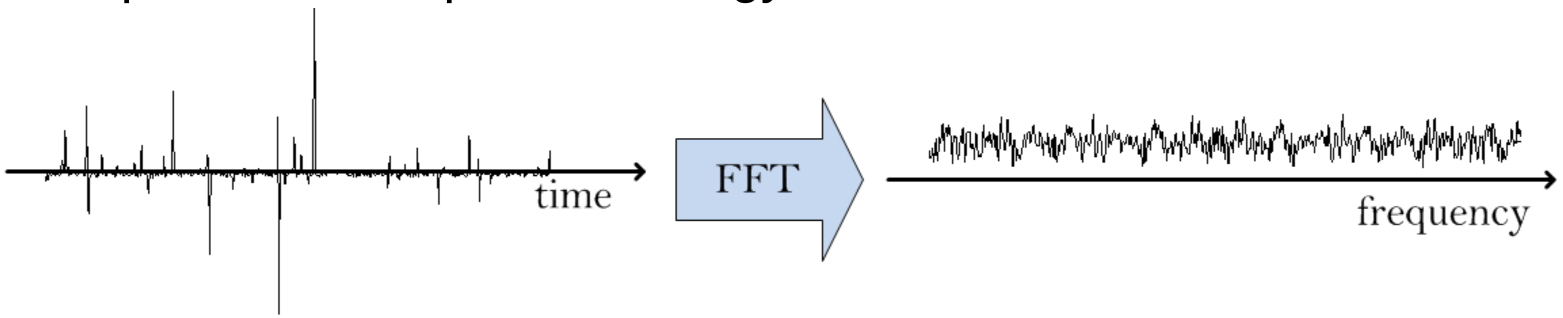
Noise Trace for Platform Noise



OFDM System in Impulsive Noise



- FFT spreads out impulsive energy across all tones



  - SNR of each tone is decreased
  - Receiver performance degrades
  - Noise in each tone is asymptotically Gaussian (as $N_{DFT} \to \infty$)

Prior Work

- Parametric vs. non-parametric methods (Noise Statistics)

	Param.	Non-Param.
Assume parameterized noise statistics	Yes	No
Performance degradation due to model mismatch	Yes	No
Training needed	Yes	No

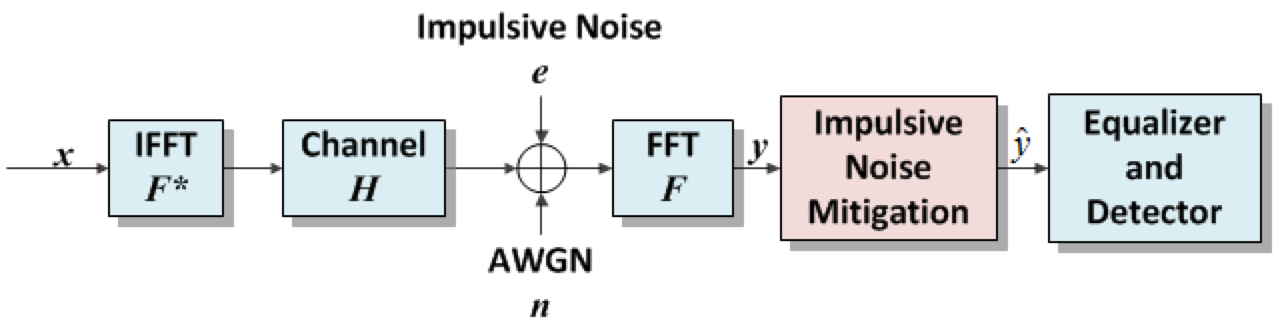
- Impulsive noise mitigation in OFDM

		Parametric?	Technique	Optimality	Complexity
	[Nassar09]	Yes	Pre-filtering	★☆☆☆	★☆☆☆
✓	[Haring02]	Yes	MMSE** estimate	★★★☆	★★☆☆
	[Haring03]	Yes	Iterative decoder	★★★★	★★★★
✓	[Caire08]	No*	Compressed sensing & LS**	★★☆☆	★★★☆

* Semi-non-parametric since threshold tuning is needed

** MMSE: Minimum mean squared error; LS: least squares

System Model



- A linear system with Gaussian disturbance

$$y = Fe + \overbrace{\underbrace{FHF^*}_{\Lambda} x + \underbrace{Fn}_{g}}^{v} = Fe + v, \quad v \sim CN(\Lambda x, \sigma^2 I)$$

✓ Estimate the impulsive noise and remove it from the received signal

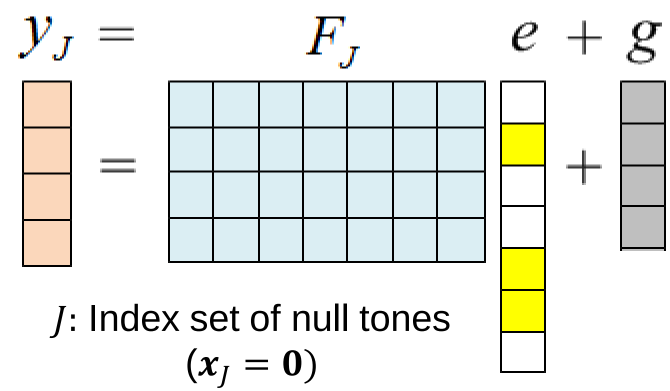
$$\hat{y} = y - F\hat{e} = \Lambda x + g + F(\hat{e} - e) \xrightarrow{\hat{e} \approx e} \Lambda x + g$$

✓ Apply standard OFDM decoder as if only Gaussian noise were present

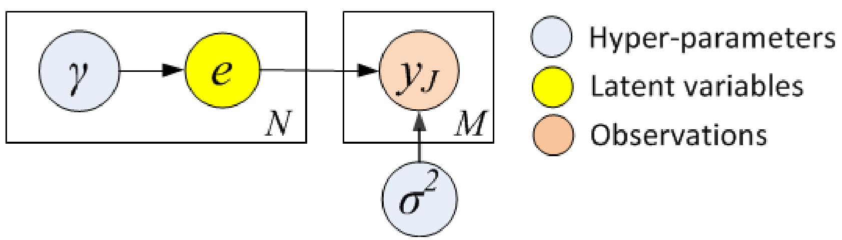
✓ Goal: Non-parametric impulsive noise estimator

Estimation Using Null Tones

- Underdetermined linear regression
  - F_J: over-complete dictionary
  - e: sparse weight vector
  - $g \sim CN(0, \sigma^2 I)$ with σ^2 unknown



- Sparse Bayesian learning (SBL)
  - Prior: $e|\gamma \sim CN(0, \Gamma), \Gamma \triangleq diag(\gamma)$
  - Likelihood: $y_J|\gamma, \sigma^2 \sim CN(0, F\Gamma F^* + \sigma^2 I)$
  - Posterior: $e|y_J; \gamma, \sigma^2 \sim CN(\mu, \Sigma_e)$



Step 1: Maximum likelihood estimate of hyper-parameters: $(\hat{\gamma}, \hat{\sigma}^2) = \underset{\gamma, \sigma^2}{\operatorname{argmax}}\ p(y_J; \gamma, \sigma^2)$

Treat e as latent variables and solve by expectation maximization (EM)

$\hat{\gamma}$ and $\hat{\sigma}^2$ are inter-dependent and updated iteratively

Step 2: Estimate e from posterior mean: $\hat{e} = E[e|y_J; \hat{\gamma}, \hat{\sigma}^2] = \hat{\mu}$

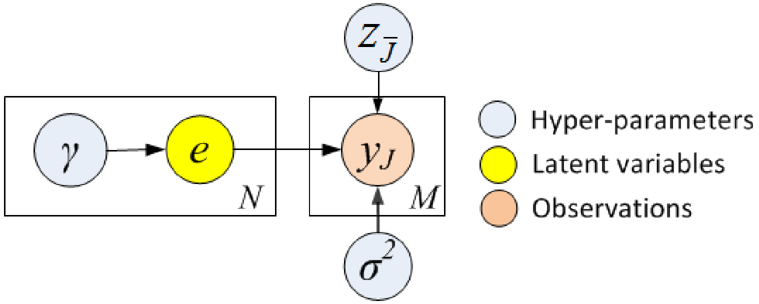
Guaranteed to converge to a sparse solution.

Estimation Using All Tones

- Joint estimation of data and noise

$$y = Fe + v \qquad v \sim CN(\Lambda x, \sigma^2 I)$$

  - Similar SBL approach with additional hyper-parameters of the data



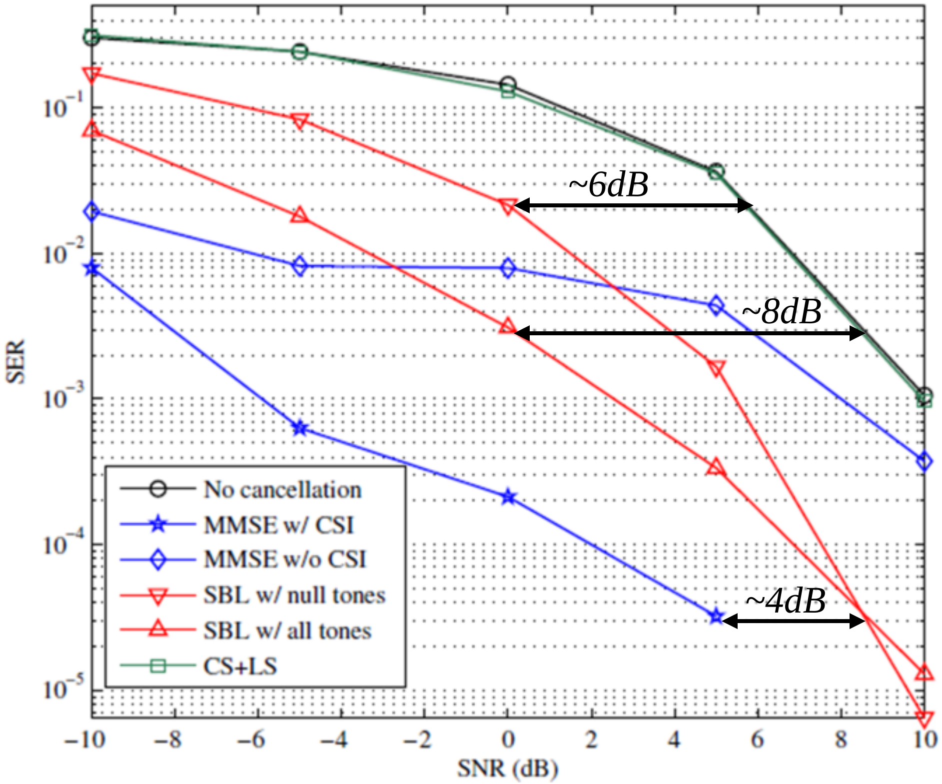
$z \triangleq \Lambda x$

$\bar{J}$: Index set of data tones

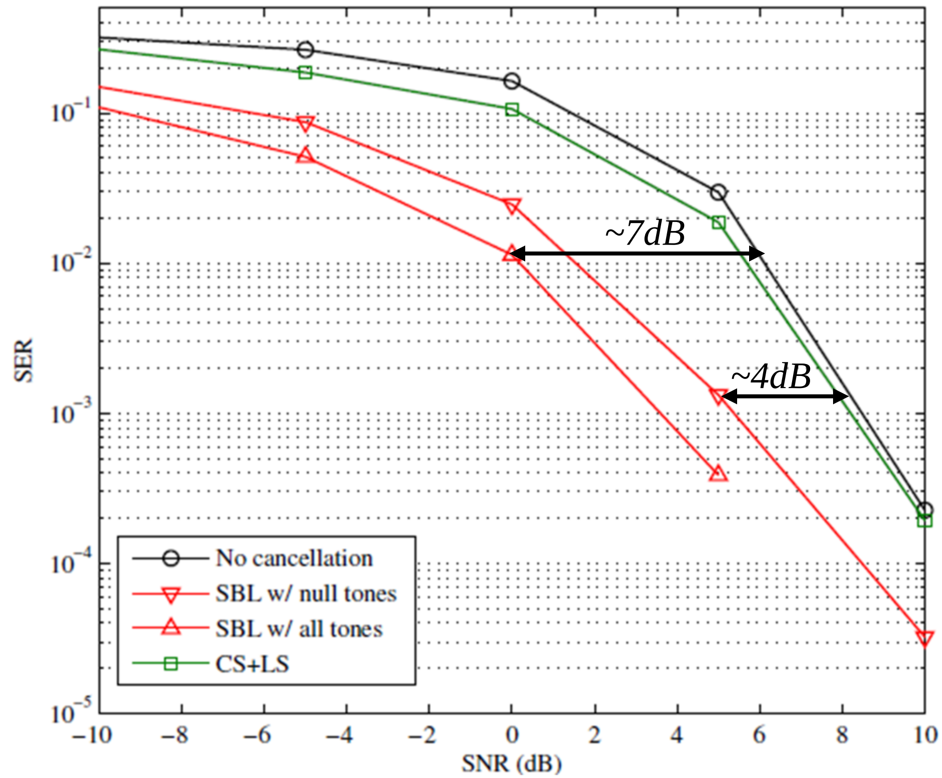
  - Step 1 involves ML optimization over 3 sets of hyper-parameters: $\left(\gamma, \sigma^2, (\Lambda x)_{\bar{J}}\right)$
  - $x_{\bar{J}}$ is relaxed to be continuous variables to insure a tractable M-step
  - Estimate of $(\Lambda x)_{\bar{J}}$ is sent to standard OFDM channel equalizer and MAP detector
  - Increase complexity from $O(N^2M)$ to $O(N^3)$ per EM iteration

Simulation Results

- Symbol error rate (SER) performance in different noise scenarios



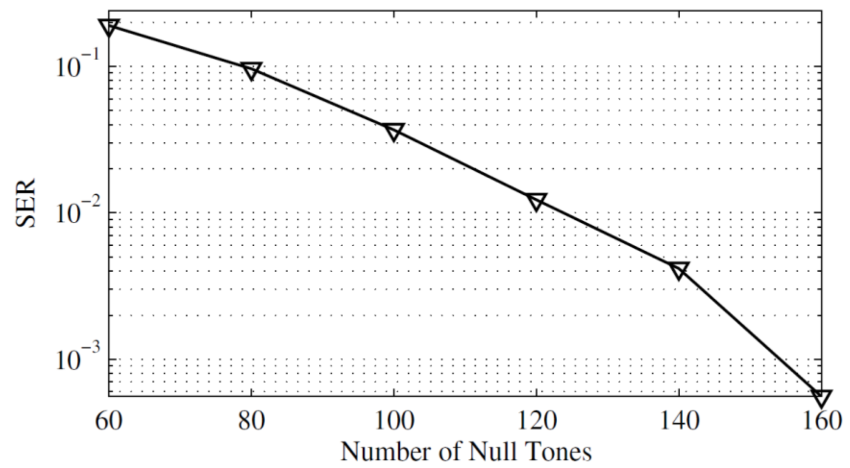
Middleton’s Class A model



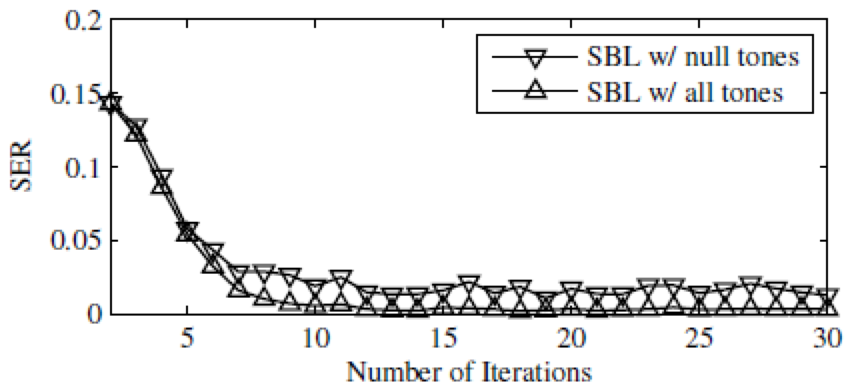
Symmetric alpha stable model

Simulation Results

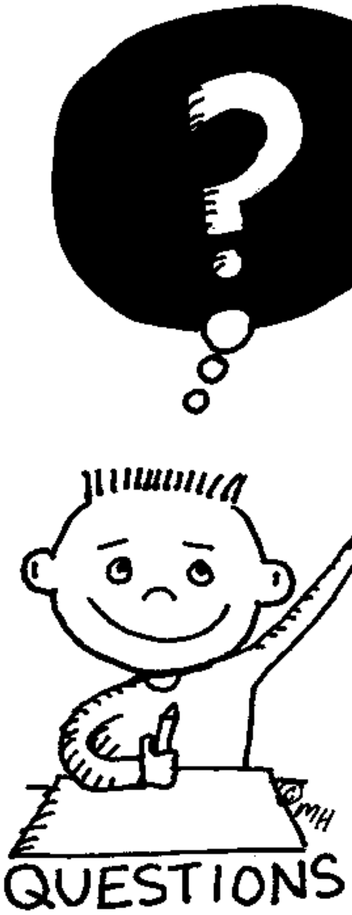
- Performance of the first algorithm vs. the number of null tones
  - SNR = 0dB
  - 256 tones
  - Middleton Class A noise



- In both algorithms, EM converges after a few iterations



Thank you for your attention!



References

- D. Middleton, "Non-Gaussian noise models in signal processing for telecommunications: new methods and results for Class a and Class b noise models," *IEEE Trans. on Info. Theory*, vol. 45, no. 4, pp. 1129–1149, 1999.
- M. Nassar, K. Gulati, M. DeYoung, B. Evans, and K. Tinsley, "Mitigating near-field interference in laptop embedded wireless transceivers," *Journal of Signal Proc*. Sys., pp. 1–12, 2009.
- J. Haring, *Error Tolerant Communication over the Compound Channel*, Shaker-Verlag, Aachen, 2002
- J. Haring and A. Vinck, "Iterative decoding of codes over complex numbers for impulsive noise channels," *IEEE Trans. Info. Theory*, vol. 49, no. 5, pp. 1251–1260, 2003.
- G. Caire, T. Al-Naffouri, and A. Narayanan, "Impulse noise cancellation in OFDM: an application of compressed sensing," *Proc. IEEE Int. Sym. on Info. Theory*, 2008, pp. 1293–1297.
- D. Wipf and B. Rao, "Sparse Bayesian learning for basis selection," *IEEE Trans. Signal Proc*., vol. 52, no. 8, pp. 2153–2164, 2004.