STATISTICAL MODELING OF ASYNCHRONOUS IMPULSIVE NOISE IN POWERLINE COMMUNICATION NETWORKS

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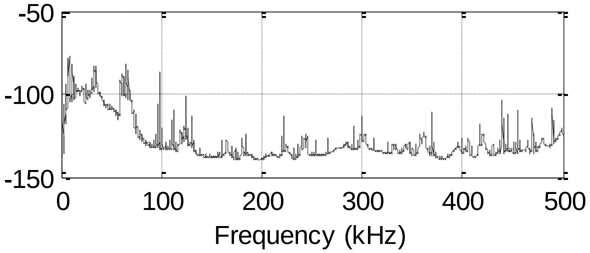
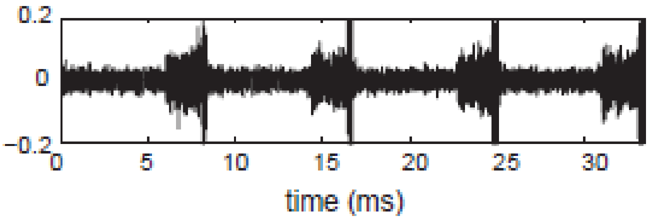
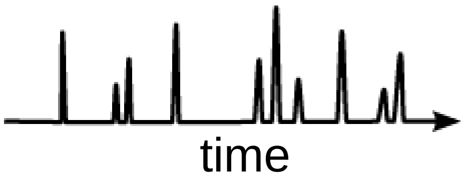
Outline

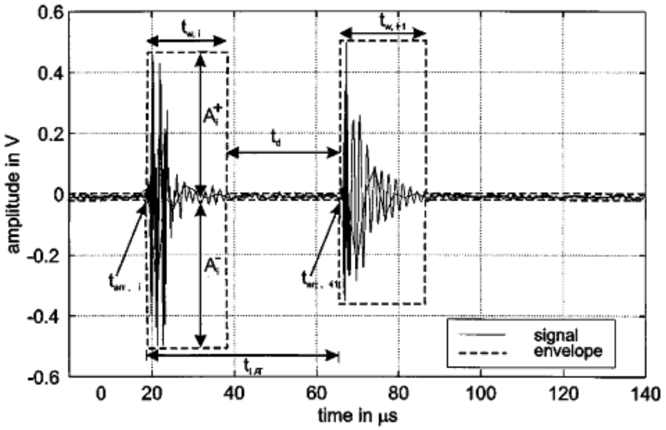
- Intro on Noise in Powerline Communications (PLC)
- Prior Work on Asynchronous Noise Modeling
- System Model and Assumptions
- Summary of the Approach
- Simulation Results and Verification

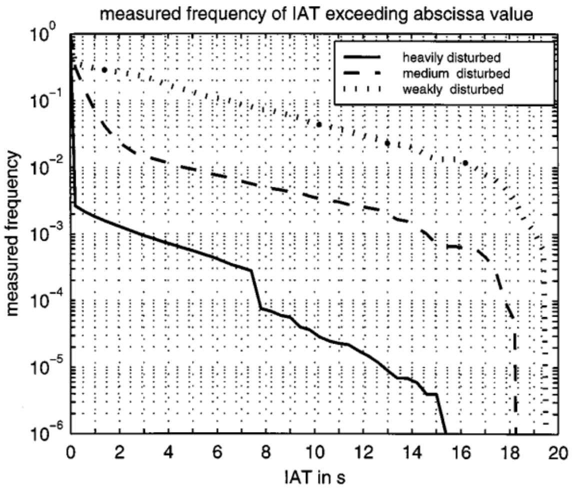
Noise in Powerline Communications

Background Noise	**Periodic and Cyclostationary Noise**	**Asynchronous Impulsive Noise**
		
• colored noise • superposition of lower-intensity sources • decreases with frequency • includes narrowband interference	• modulated periodic signal • cylostationary in time and frequency • synchronous and asynchronous wrt AC mains • Sources: rectified and switched power supplies • dominant in 3-500kHz	• Caused by switching transients • Duration: micro to millisecond • arbitrary inter-arrival time • 50db above background noise • present 0.2-20MHz
[Zimmermann02]	[Zimmermann02],[Corripio06], [Reiken11],[Nassar12]	[Zimmermann02],[DiBert11]

Prior Work on Asynchronous Noise

- Empirical Measurements *[Zimmermann, Dostert 2002]*





- Empirical Fitting and Modeling
  - Hidden Markov Models *[Zimmermann,Dostert2002]*
  - Middleton’s class-A *[Umehara,Yamaguchi,Morihiro 2004]*
  - Gaussian Mixture *[Di Bert,Caldera, Schwingshackl,Tonello 2011]*
  - Rayleigh *[Chan,Donaldson 1989]*
  - Nakagami-m *[Meng,Guan,Chen 2005]*

Statistical Models

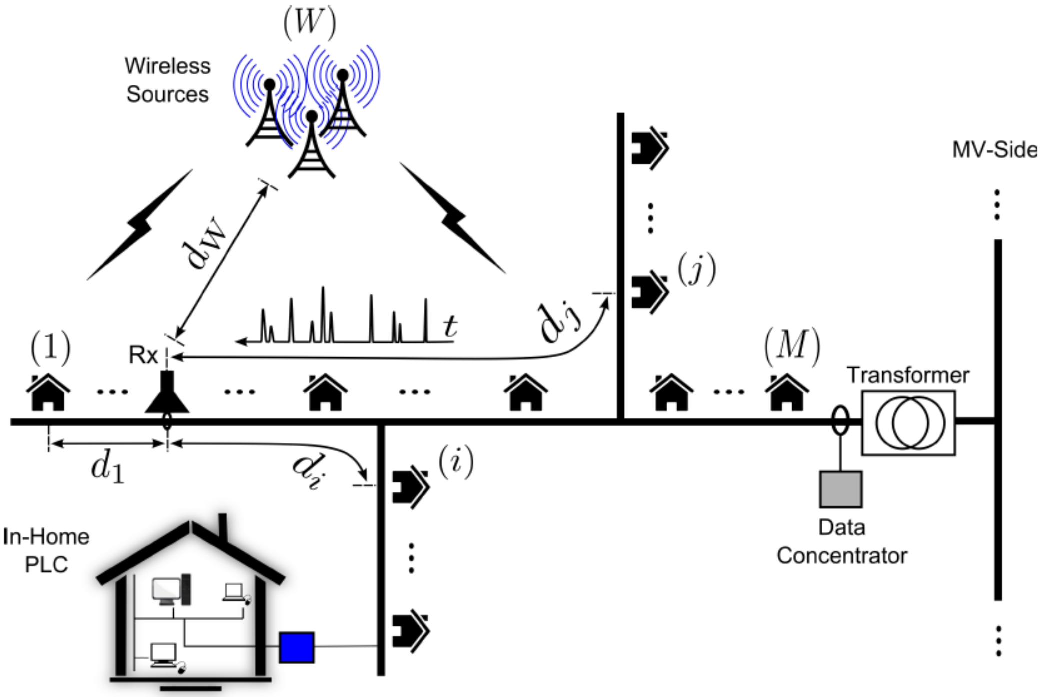
- Gaussian Mixture
  - Probability Density Function: $p(z) = \sum_{i=1}^{K} \pi_i N(0, \sigma_i^2)$

Parameter	Description
K	Number of Gaussian components
π_i	Mixing probabilities
σ_i^2	Component variances (power)

- Middleton’s Class A *[Middleton 1977]*
  - Statistical Physical Model for Spatio-Temporal Interference
  - Probability Density Function: $p(z) = \sum_{i=0}^{\infty} \frac{e^{-A} A^i}{i!} N(\frac{0, 2i\Omega}{A})$

Parameter	Description
A	Overlap index (indicates impulsiveness)
Ω	Mean intensity

Powerline Communication Networks



Sources of Asynchronous Noise:

Bursty Wireless Transmissions

Uncoordinated users (coexistence issues)

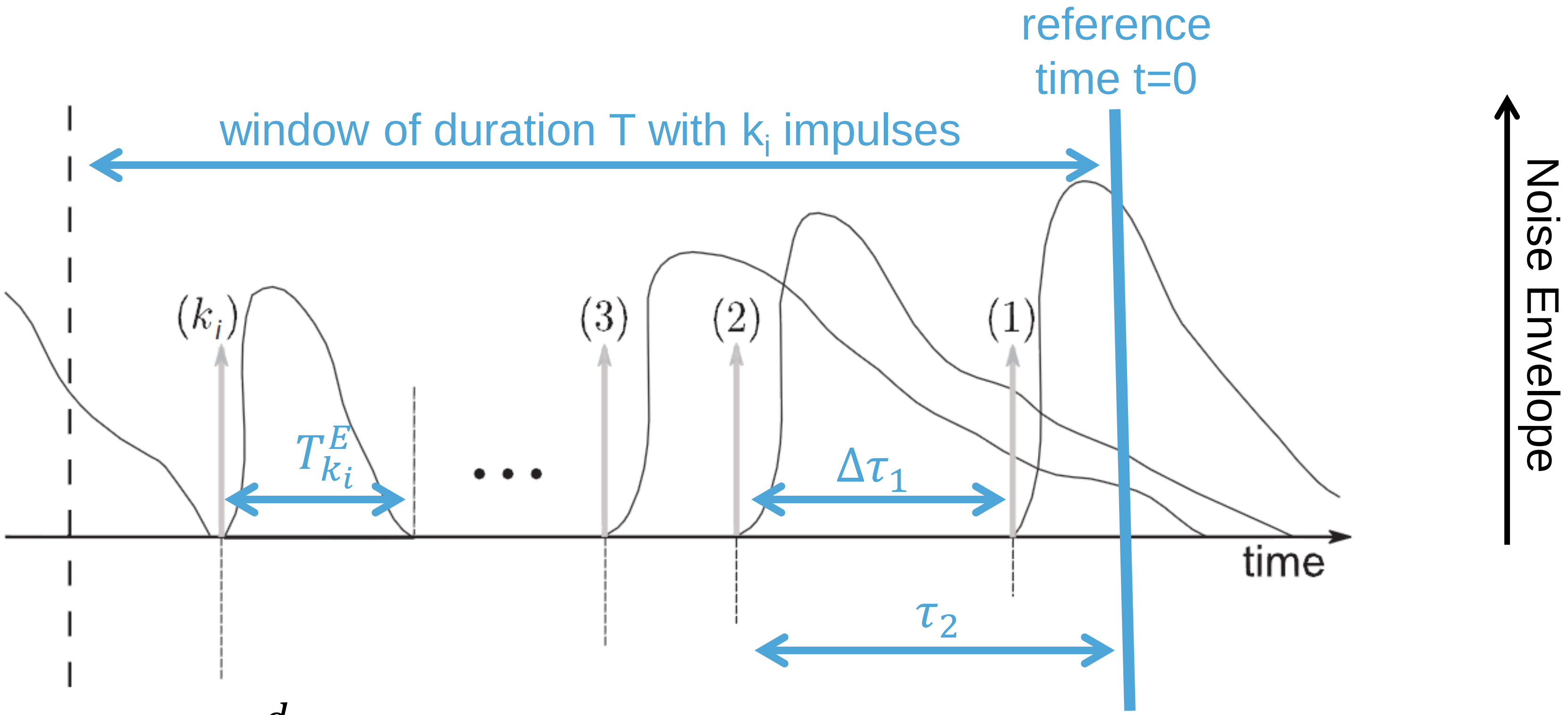
Switching Transients

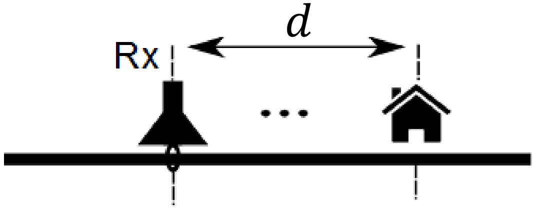
Objective: Statistical-Physical model for interference at the receiver from M sources

$$\Psi = \sum_{i=1}^{M} \Psi_i$$

Interference from source i

Interference from a Single Source i (Ψ_i)





$$\Psi_i = \lim_{T\to\infty} I_i(T)$$

$\Delta\tau_l \sim \mathrm{Exp}(\lambda_i)$: inter-arrival time

λ_i : impulse rate

$\tau_l \sim PPP(\lambda_i)$: impulse arrivals

T_l^E : impulse duration

Assumptions and System Model

Emission Duration

- Impulse duration is bounded i.e. $T_l^E < T_{max}, \forall l$
- Result depends only on $E[T_l^E]$

Flat Fading Channel

- Impulse duration larger than channel delay spread $T_l^E \gg \tau_h$
- Memoryless channel $\boldsymbol{h}$
- Result depends only on $E[\boldsymbol{h}]$

Resulting Interference $\Psi_i = \lim_{T\to\infty} I_i(T)$

$$\mathbf{I}_i(T) = \gamma(d_i) \sum_{l=1}^{\mathbf{k}_i} \mathbf{h}_{i,l}\mathbf{B}_{i,l}\mathbf{1}\left(\boldsymbol{\tau}_{i,l} \le \mathbf{T}_{i,l}^E\right)$$

pathloss

Channel experienced by impulse l

Amplitude of impulse l at t=0

Is impulse l active at t=0?

Summary of Statistical Modeling

- Total Interference :

$$\mathbf{I}_i\left(T\right) = \gamma\left(d_i\right)\sum_{l=1}^{\mathbf{k}_i}\mathbf{h}_{i,l}\mathbf{B}_{i,l}\mathbf{1}\left(\boldsymbol{\tau}_{i,l} \le \mathbf{T}_{i,l}^{E}\right)$$

- After messy calculations, the characteristic function is:

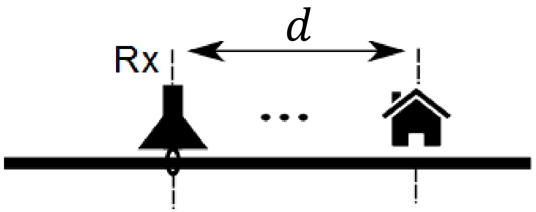
$$\Phi_{\mathbf{I}_m}\left(\omega\right) = e^{\lambda_m\mu_m\left(-1+e^{\frac{-|w|^2\mathbb{E}\left\{\mathbf{h}_m^2\mathbf{B}_m^2\right\}}{4}}\right)}$$

Middleton's Class-A

- Aggregate for multiple Interfering sources

Modeling Results

Dominant Interference Source

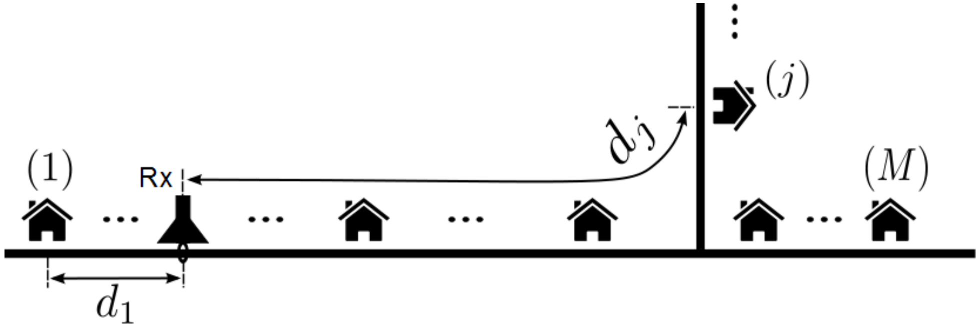


Impulse rate: λ
mean duration: μ

Middleton's Class A

$$A = \lambda\mu,$$
$$\Omega = \frac{A\gamma(d)E[h^2B^2]}{2}$$

Homogeneous PLC Network

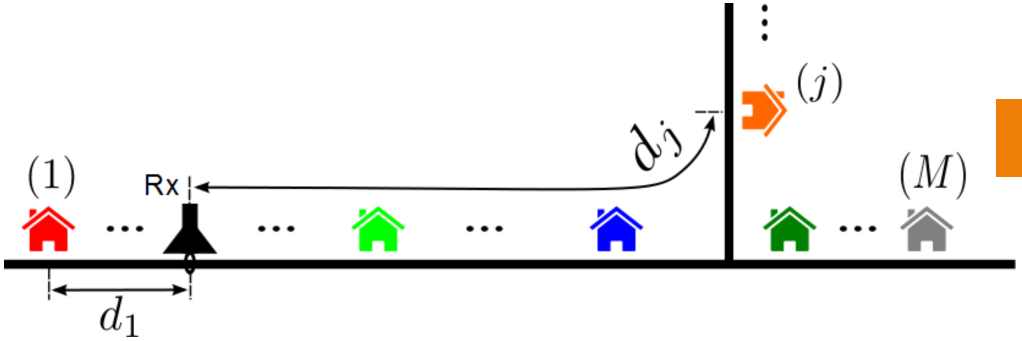


$$\boldsymbol{\lambda_i = \lambda}$$
$$\boldsymbol{\mu_i = \mu}$$
$$\boldsymbol{\gamma(d_i) = \gamma}$$

Middleton's Class A

$$A = M\lambda\mu,$$
$$\Omega = \frac{\lambda\mu\gamma E[h^2B^2]}{2}$$

General PLC Network

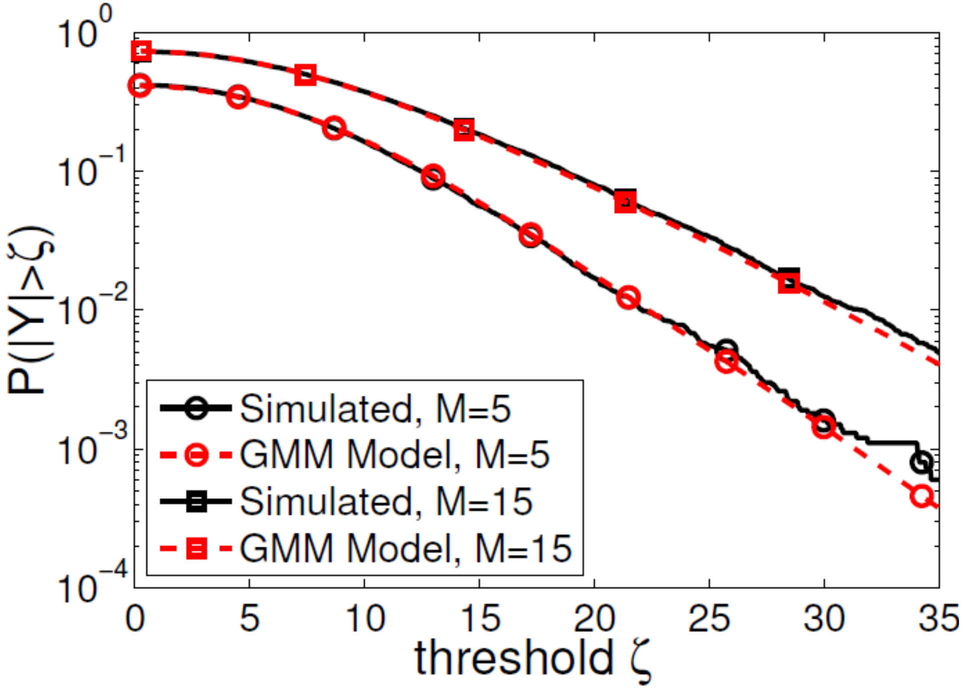


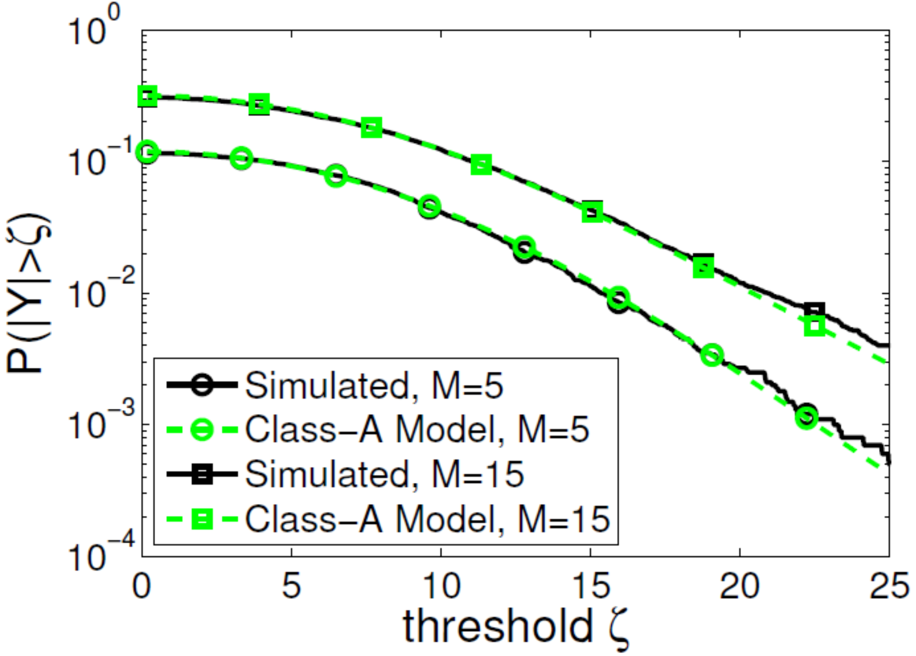
$$\boldsymbol{\lambda_i, \mu_i, d_i}$$

Gaussian Mixture

π and σ^2 (refer to paper)

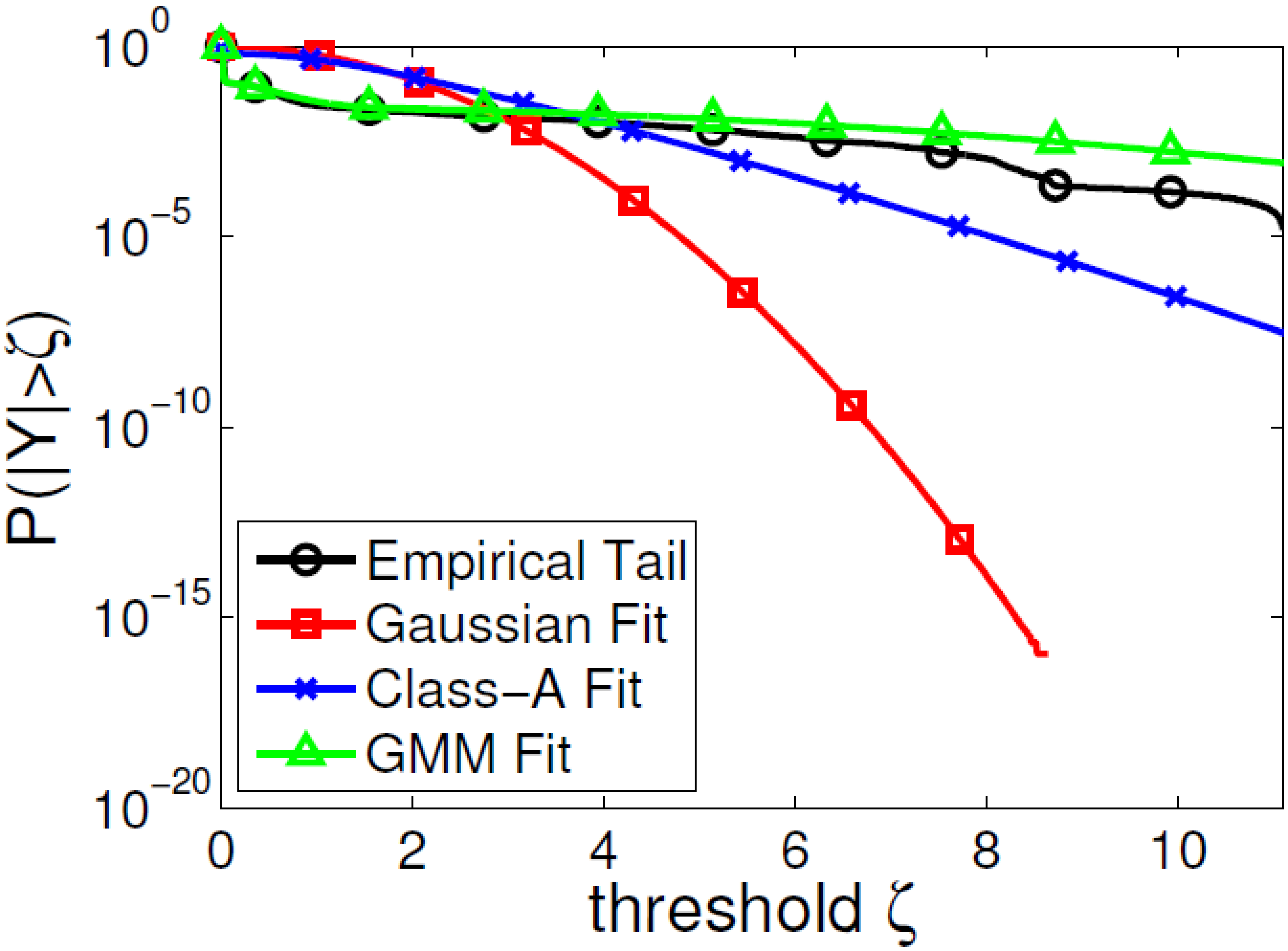
Simulation Results (Tail Probabilities)


General PLC Network


Homogenous PLC Network

As expected, larger networks have higher interference power.

Some Measurements of PLC Noise



Collected in the 3-500kHz range indoors

Gaussian Mixture provide a good fit as well

Thank you

Questions?

References

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[2] D. Umehara, H. Yamaguchi, and Y. Morihiro, “Turbo decoding in impulsive noise environment,” in Proc. IEEE Global Telecommun. Conf., vol. 1, 2004, pp. 194–198.

[3] L. Di Bert, P. Caldera, D. Schwingshackl, and A. Tonello, “On noise modeling for power line communications,” in Proc. Int. Symp. Power-Line Comm. and its Appl., 2011, pp. 283–288.

[4] H. Meng, Y. Guan, and S. Chen, “Modeling and analysis of noise effects on broadband power-line communications,” IEEE Trans. Power Del.,vol. 20, no. 2, pp. 630–637, 2005.

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[2] D. Middleton, “Statistical-physical models of electromagnetic interference,” IEEE Trans. Electromagn. Compat., vol. 19, no. 3, pp. 106–127, 1977.

[3] K. Gulati, B. L. Evans, J. G. Andrews and K. R. Tinsley, "Statistics of Co-Channel Interference in a Field of Poisson and Poisson-Poisson Clustered Interferers", IEEE Transactions on Signal Processing, vol. 58, no. 12, Dec. 2010, pp. 6207-6222.