UNIVERSITY OF TEXAS AT AUSTIN, ECE DEPARTMENT

Response to Questions from Prof. Evans talk on RFI Mitigation at Intel on Feb 25th, 2008

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Presentation Slides can be accessed at:

http://users.ece.utexas.edu/~bevans/projects/rfi/talks/Feb2008RFIMitigationSlides.ppt

1) **[Eddie Lin]**
Derived a good fit for measured data on slide 12 (data is PCI Express noise)

- **How far does the data deviate from Gaussian?**
- **What was the best NMSE for Class A fit?**
- **Second moment of residual distribution when fitting with SaS, Gaussian, Class A**

Deviation from the Gaussian depends on the impulsiveness of the measured noise. The measurement data from PCI Express noise was not very impulsive and does not deviate much from the Gaussian model.
Figure 1 shows the PCI Express noise data fitting with symmetric alpha stable, Middleton class A and an equi-power Gaussian model. Since the noise is not very impulsive, all three models provide a close fit. Following are the parameters and the KL divergence of the estimated models.

Parameter	Estimated Value	KL Divergence
Middleton Class A model		
Impulsive Index (A)	0.6481	0.0230
Gaussian Factor (Γ)	0.5039	
Symmetric Alpha Stable		
Characteristic Exponent (α)	1.7644	0.0187
Localization Parameter (δ)	-0.0039	
Dispersion Parameter (γ)	0.4484	
Gaussian Model		
Mean (μ)	0	0.0172
Variance (σ)	1	

The Kullback-Leibler (KL) divergence is used to quantify the closeness of two probability distribution functions, where a KL divergence of zero indicates an exact match of the densities. As seen from the plots and the KL divergence computed, all three models provide a close fit in this case. We have omitted quoting the normalized mean squared error (NMSE) of the fits since the KL divergence provides a better metric to quantify the distance of two probability density functions.

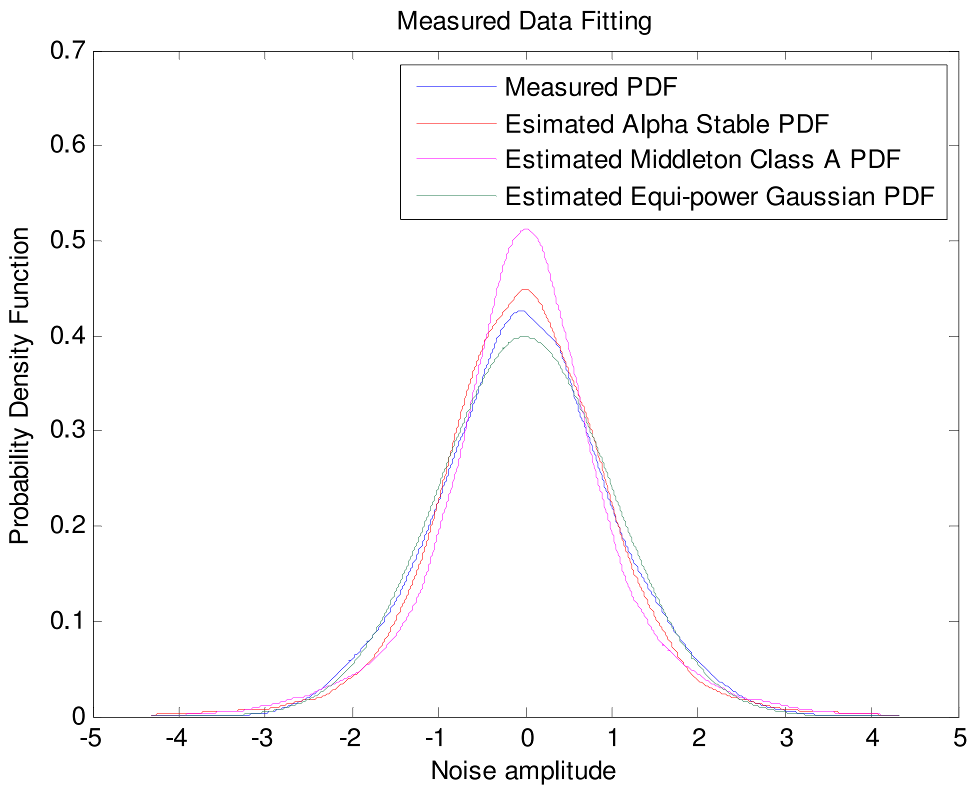

Figure 1: Measured data fitting for PCI Express noise (Less Impulsive Noise)

However, if the noise is more impulsive, the Gaussian model deviates considerably for the measured PDF. The 2-antenna datasets given by Keith were analyzed to represent a more impulsive noise. Hence, we performed the univariate model fitting using only the noise samples at one of the two antennas. The following table shows the results of the estimated parameters in this case. As seen from the estimated parameters (characteristic exponent of the alpha-stable model), the noise is more impulsive than the PCI Express noise. Further, in this case, the symmetric alpha stable model (and also the Middleton Class A model) represent the noise considerable better that the Gaussian model. Figure 2 plots the estimated and measured PDF and provides a visual justification of the same.

Parameter	Estimated Value	KL Divergence
Middleton Class A model		
Impulsive Index (A)	0.1036	0.0825
Gaussian Factor (Γ)	0.7763	
Symmetric Alpha Stable		
Characteristic Exponent (α)	1.2105	0.0514
Localization Parameter (δ)	0.0043	
Dispersion Parameter (γ)	0.2413	
Gaussian Model		

Mean (μ)	0	0.2217
Variance (σ)	1	

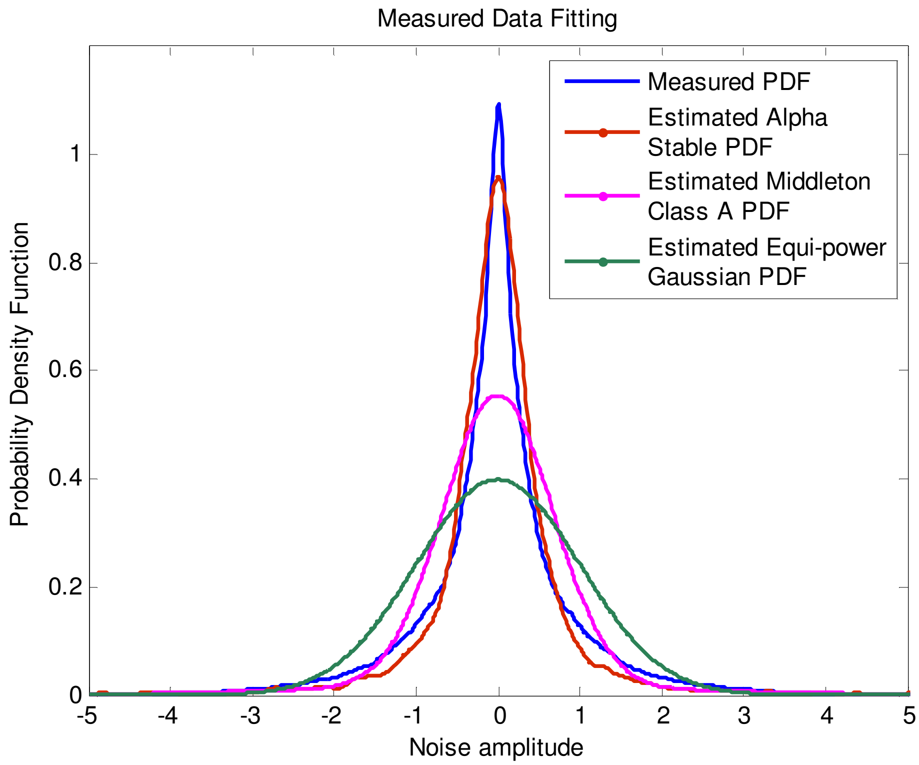

Figure 2: Measured Data Fiting (for a significantly impulsive noise)

2) [Eddie Lin]
Fit for two-antenna datasets sent by Keith?

Yes, the two-antenna datasets sent by Keith were analyzed. We used bivariate Middleton Class A model and Gaussian model to fit the data. Following are the results we obtained 2-antenna dataset labeled, "`Santa_Rosa_Platform_ClassBRFIWifiCh11_2.462GHz/ch11_blk01.txt`".
The KL divergence of the empirical density was computed as **1.004** from the estimated bivariate Middleton Class A density and **1.682** from an equi-power Gaussian density. Hence, the measured RFI data was modeled better by the bivariate Middleton Class A model as compared to the Gaussian model.

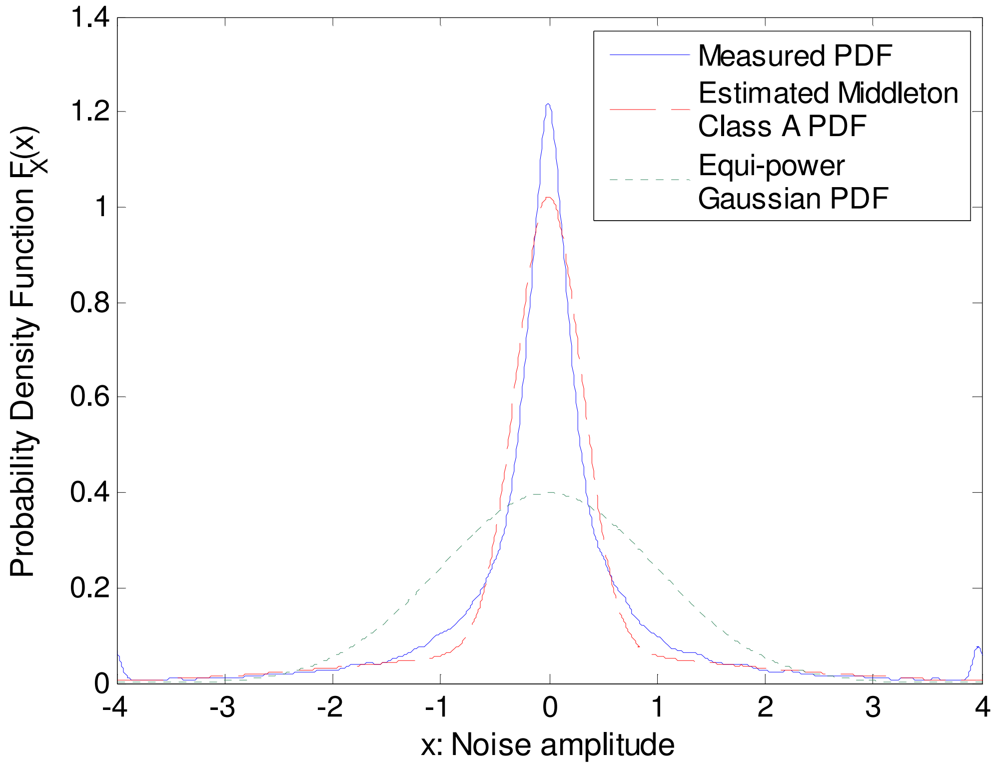

Figure 3: Measured Fitting for 2-antenna dataset.
This figure shows the marginal PDF of the measured data as compared to marginals of the estimated bivariate Middleton Class A PDF (estimated parameters A = 0.313, Γ_1 = 0.105, Γ_1 = 0.101, κ = -0.085) and an equi-power Gaussian PDF at one of the antenna.

3) **[Eddie Lin]**
Model Bluetooth packet transmission (1600 hops/s with gaps between them) as Class A interference w/r to 802.11b
Suggestion: Which model to use?

We believe that Middleton Class A model can be used to model such interference. In particular, the Middleton models can be used to describe any interference where the number of interference sources at any instant has a Poisson distribution and the source emissions are for short time instants.
We are working with Keith to obtain such data sets and experiment with the same.

4) **[Eddie Lin]**
What happens to communication performance with 64-QAM for hole punching?

As we increase the size of our constellation the performance of the hole puncher decreases. In particular using 64-PAM with a hole puncher that randomly selects a constellation point when the signal surpasses a given threshold provided a relatively poor performance; less than 1 dB when compared to the correlation receiver.

5) **[Eddie Lin]**
How to estimate noise in the presence of transmission of digital data, e.g. in digital TV?

Estimation of noise model parameters can be done in the presence of transmission by using the training symbols already present in the standard. However, the estimates hence obtained would not have high accuracy since we would have a restricted size of the data set. Furthermore, the estimated parameters would suffer from the errors in channel estimation that would be done using the same training symbols.

6) **[Keith Tinsley]**
Small signal approximation for nonlinear filtering step for Class A noise

- **Lower-bound on number of terms for small signal approximation**
- **Complexity of series expansion**
- **Lookup-table approximation**

Number of Terms in the Series Expansion vs. Performance

As the accuracy of the approximation of the PDF decreases the performance is expected to decrease. The accuracy of the PDF is directly related to the number of terms used in the expansion. Figure 4 illustrates the communication performance as we vary the number of terms in the series expansion.

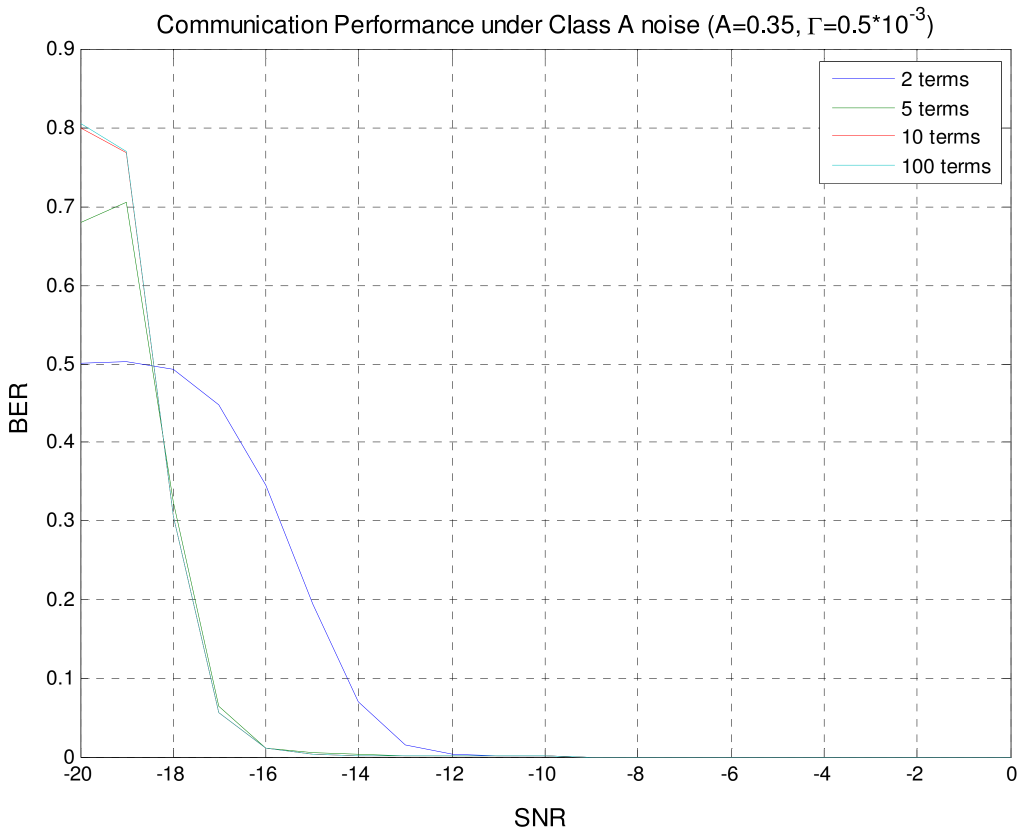

Figure 4: Communication Performance with varying number of terms in the series expansion

Lookup-Table Approximation of the PDF

Still being investigated and various quantization algorithms that will take the structure of the PDF into consideration are being implemented.

7) **[Keith Tinsley]**
What about using particle filtering on slide 13?

Currently not implemented in our simulator, its benefits in signal detection can be evaluated only in implementing a channel and a channel tracking algorithm (still under development). However, particle filtering may be used in parameter estimation where updates to the parameters can be modified as new samples are received.

8) **[Nageen Himayat]**
How long would an OFDM symbol need to be to be resistant to impulsive events?

As discussed in the presentation slides the resilience of OFDM systems to impulsive noise increases with the increase of the OFDM symbol length. This was due to the fact that orthogonal transformations like the DFT and IDFT linear transformation spread the impulse energy across the symbol length resulting in a reduced effect of the impulse on each individual signal. This is the result of Guassianizing the impulsive noise due to the orthogonal coding. The table below summarizes the variation of the gap in performance from the Gaussian case (when the noise is Gaussian) for 4-QAM with memoryless channel with additive class A impulsive noise with A=0.1 and $\Gamma=10^{-3}$.

Number of Subcarriers (K)	Gap from Gaussian Performance @ BER=10^{-4} (in dB) (around 11.66dB)
5	4.43
10	3.4
20	2.41
30	1.64
50	1.4
70	0.95
100	0.74
500	0.2
1000	0.09

As is noticed from the graph below (Figure 5) and the table above, the gap is reduced as the number of carriers increases (This is seen clearly in Figure 6).

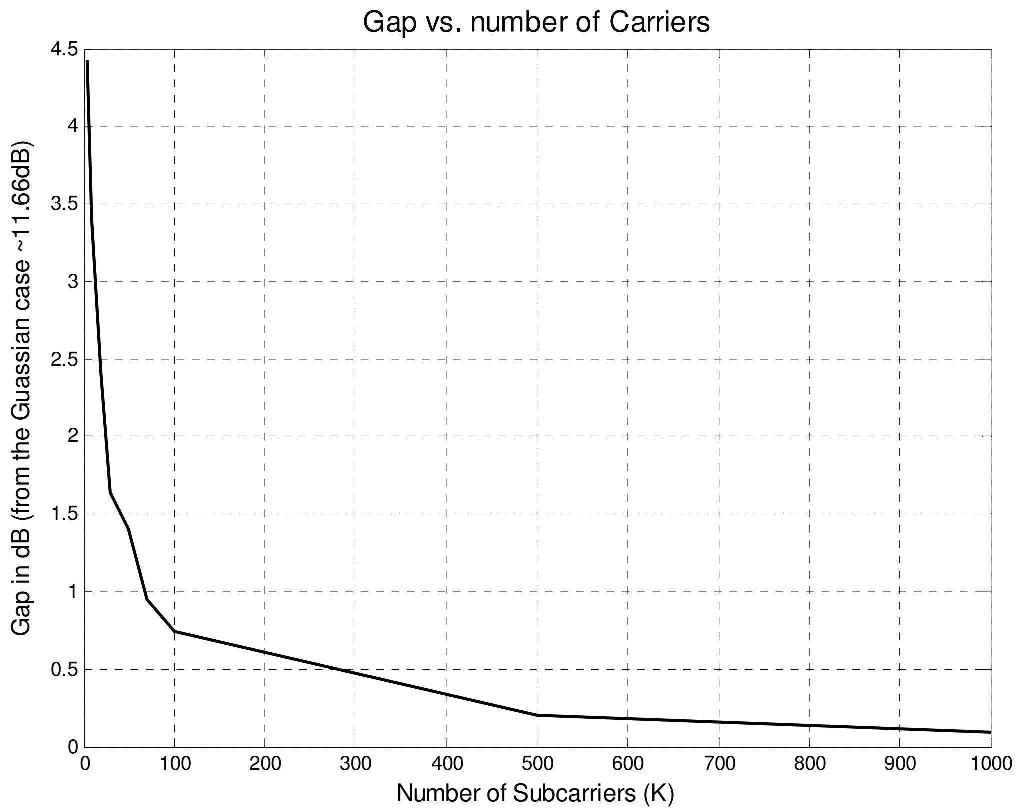

Figure 5: Gap vs. No. of Carriers (A = 0.1, Γ=10-3)

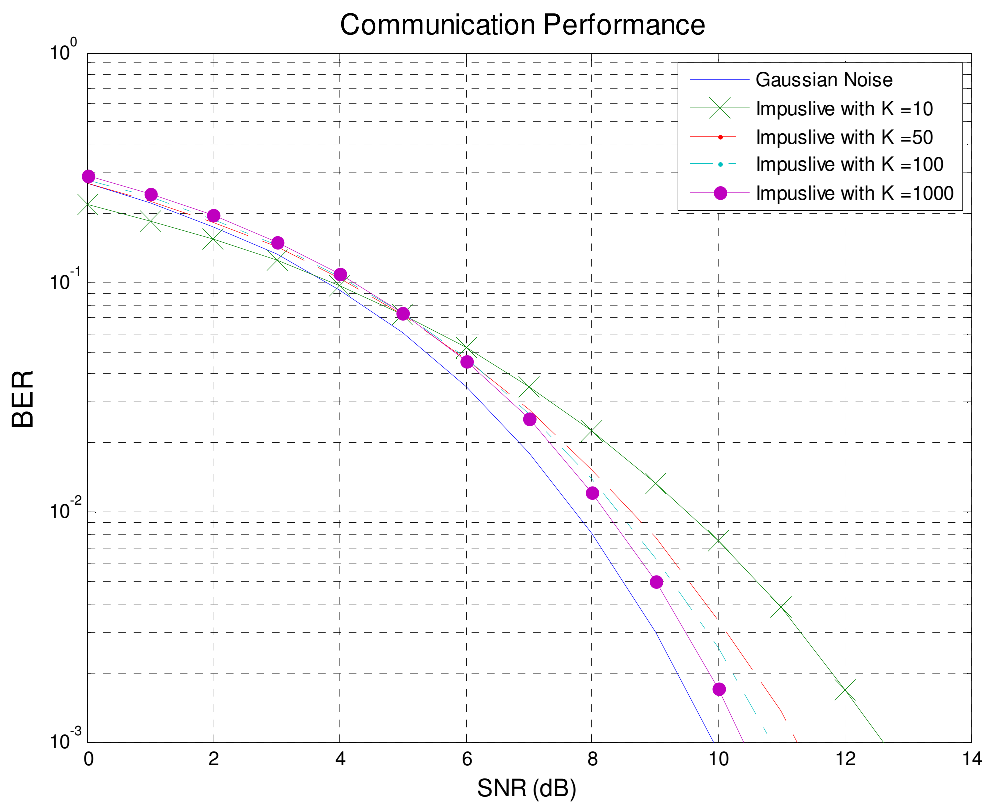

Figure 6: Communication Performance with different number of subcarriers

9) **[Kevin Slattery]**
What percentage of samples can be corrupted and still get good detection?

TBD

10) **[Kevin Slattery]**
What is long enough for the symbol length to be resistance to impulsive noise?

See Answer to Question 8

11) **[Kevin Slattery]**
How much impulsive energy can be tolerated in a symbol?

As seen from Figure 5 and Figure 6, this will depend on the required probability of error and possibly coding techniques.

12) [Kevin Slattery]

Do we have to recompute the distribution parameters for each block of samples?

This will depend on how fast the platform conditions are changing, and the optimal length of the block with respect to impulsive noise resistance and rate.

13) [Harry Skinner]

When to use Class A models vs. Symmetric Alpha Stable models?

Middleton Class A models should be used when the interference is narrowband, while Symmetric Alpha stable models should be used when the interference is broadband.

14) [Kathyayani]

What if WiFi leaks into WiMax? Can they receive simultaneously without time coordination. Can you use impulsive noise models to mitigate RFI?

Yes. We believe that we should be able the WiFi (for example) signal as an interference for the WiMax signal and describe it using the Middleton models. The assumption here is that the undesired signal transmission can be described as a poison interference source which were used to derive the Middleton Class A model.

Further, the following reference shows how we can model the Co-Channel interference as Middleton Class A interference under the Poisson field of interferers assumption.

Xueshi Yang and Athina P. Petropulu, "Co-Channel Interference Modeling and Analysis in a Poisson Field of Interferers in Wireless Communications", IEEE Transactions on Signal Processing, Vol. 51, No. 1, January 2003.

This is a topic of current and future research. We are working with Keith to obtain such measurements and quantify if they can be modeled using the RFI models we use.