Measuring Pulsed Interference in 802.11 Links

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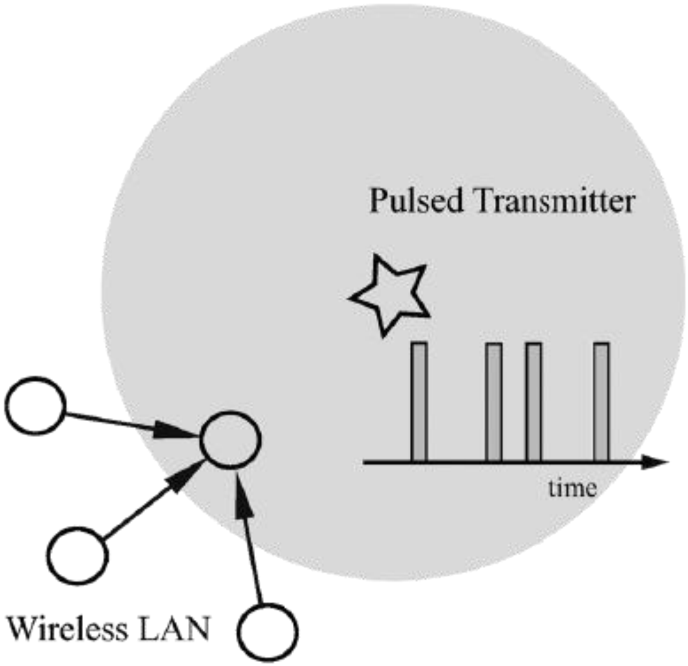
Presentation Outline

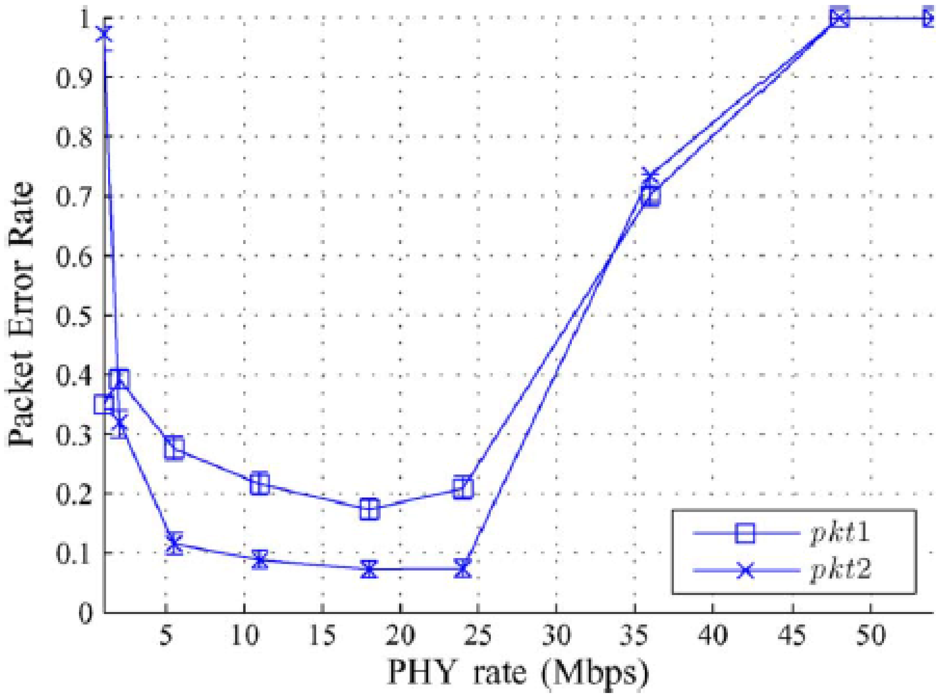
- Basic Premise
- Nonparametric Estimation
  - Analysis
  - Examples
- Parametric Estimation
  - Analysis
  - Examples
- Results and Conclusions

Based on, and all figures drawn from:

Brad W. Zarikoff, Douglas J. Leith; "Measuring Pulsed Interference in 802.11 Links", IEEE/ACM TRANSACTIONS ON NETWORKING 2012

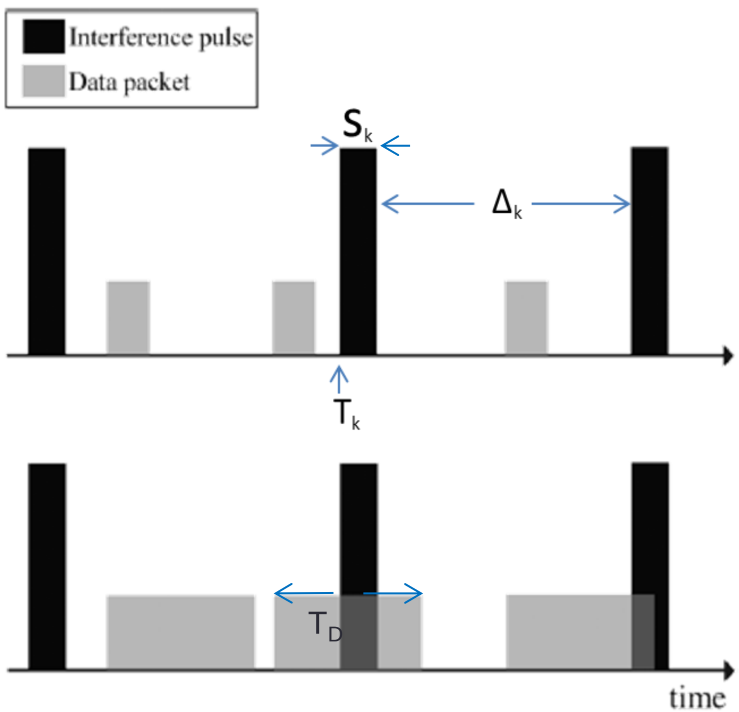
Basic Idea





- Interference vs. Noise Losses
- Depends on transmission duration

Nonparametric Model



$$X_t := (t, T_{k(t)}, S_{k(t)}, \Delta_{k(t)})$$

$$\text{Prob}[\Delta \leq x] = F(x)$$

$$U_{T_\text{D}}(X_t) = \begin{cases} 1, & t \in [T_k + S_k + T_\text{D}, T_{k+1}) \text{ for some } k \\ 0, & \text{otherwise.} \end{cases}$$

$$\hat{P}_t(T_\text{D}) = 1 - \frac{1}{N(t)} \sum_{j=1}^{N(t)} U_{T_\text{D}}(X_{t_j})$$

$$\lim_{t\to\infty} \hat{P}_t(T_\text{D}) = \lim_{t\to\infty} P_t(T_\text{D}) =: p(T_D)$$

$$P_t(T_\text{D}) = 1 - \frac{1}{t} \int_0^t U_{T_\text{D}}(X_s)ds.$$

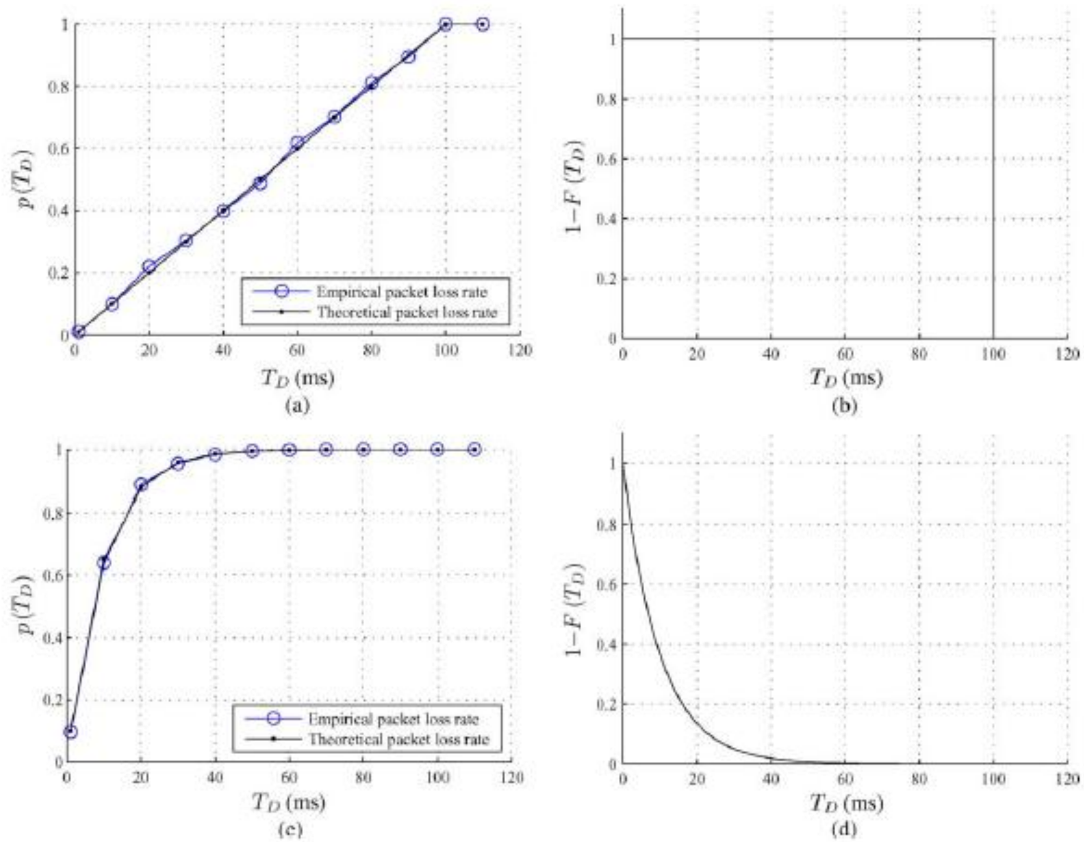
$$p(T_\text{D}) = 1 - \frac{1}{\mathbb{E}[S+\Delta]} \int_{T_\text{D}}^{\infty} (x - T_\text{D})dF(x)$$

$$\frac{dp}{dT_\text{D}}(T_\text{D}) = \frac{1}{\mathbb{E}[S+\Delta]}\text{Prob}[\Delta > T_\text{D}]$$

$$\text{Prob}[\Delta > T_\text{D}] = \frac{1}{\frac{dp(0)}{dT_\text{D}}} \frac{dp}{dT_\text{D}}(T_\text{D})$$

Simplified Simulation Results

$$p(T_{\mathrm{D}}) = 1 - \frac{1}{\mathbb{E}[S+\Delta]} \int_{T_{\mathrm{D}}}^{\infty} (x - T_{\mathrm{D}}) dF(x)$$
$$= \begin{cases} \frac{T_{\mathrm{D}}}{T_{\Delta}}, & T_{\mathrm{D}} \leq T_{\Delta} \\ 1, & T_{\mathrm{D}} > T_{\Delta}. \end{cases}$$



$$p(T_{\mathrm{D}}) = 1 - \frac{1}{\mathbb{E}[S+\Delta]} \int_{T_{\mathrm{D}}}^{\infty} (x - T_{\mathrm{D}}) dF(x)$$
$$= 1 - \lambda_{\Delta} \int_{T_{\mathrm{D}}}^{\infty} (x - T_{\mathrm{D}}) \lambda_{\Delta} e^{-\lambda_{\Delta} x} dx$$
$$= 1 - e^{-\lambda_{\Delta} T_{\mathrm{D}}}.$$

Collisions, Noise, and Interference

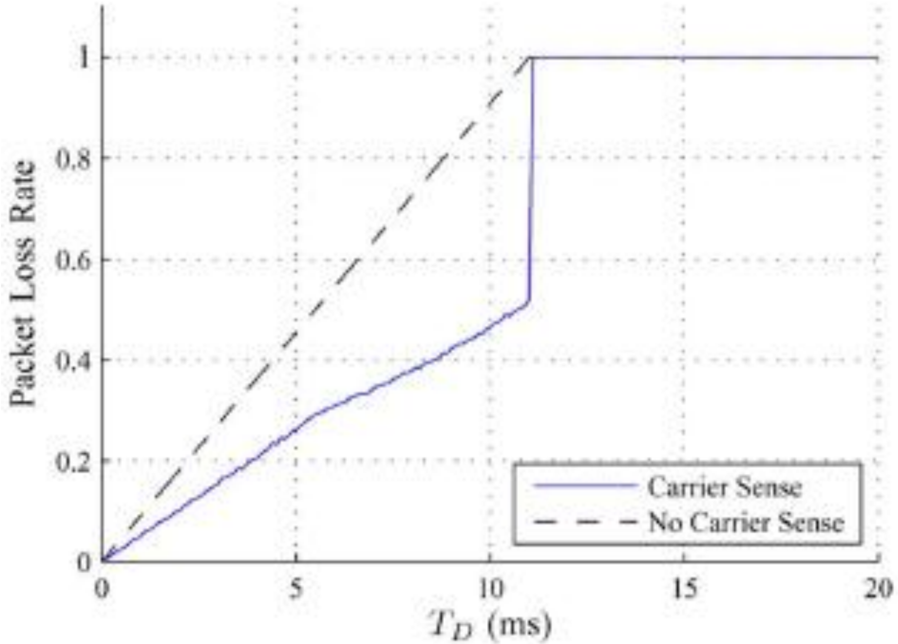
- Other causes of packet loss
- Want to isolate interference losses
- Two-packet bursts helpful for this

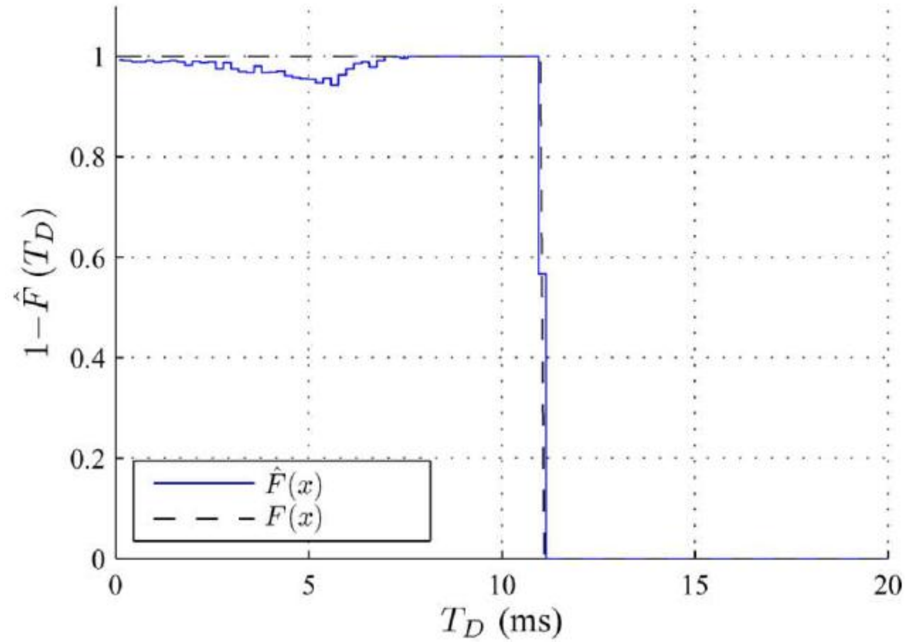
$$p_1\left(\frac{T_D}{2}\right) = 1 - \frac{1-p_c}{\mathbb{E}[S+\Delta]} \int_{\frac{T_D}{2}}^{\infty} \left(x - \frac{T_D}{2}\right) dF(x)$$

$$p_2\left(\frac{T_D}{2}\right) = 1 - \frac{1}{\left(1 - p_1\left(\frac{T_D}{2}\right)\right)\mathbb{E}[S+\Delta]} \int_{T_D}^{\infty} (x - T_D)\,dF(x)$$

$$p(T_D) = 1 - \left(1 - p_2\left(\frac{T_D}{2}\right)\right)\left(1 - p_1\left(\frac{T_D}{2}\right)\right)$$

Carrier Sense

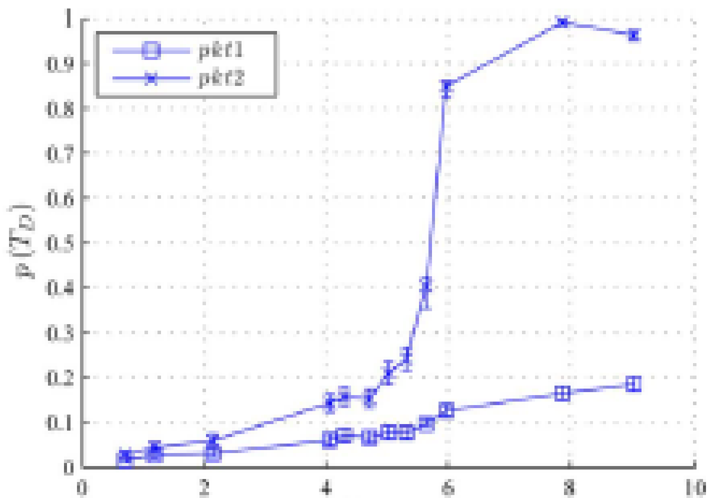


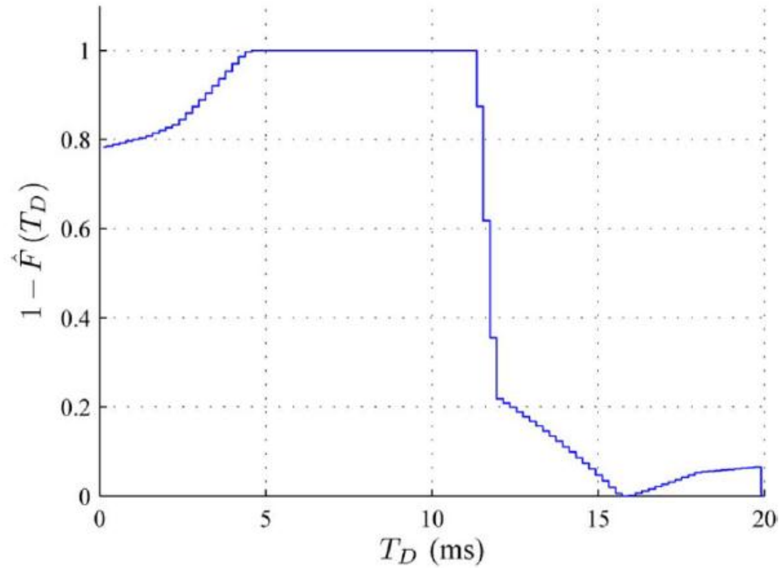


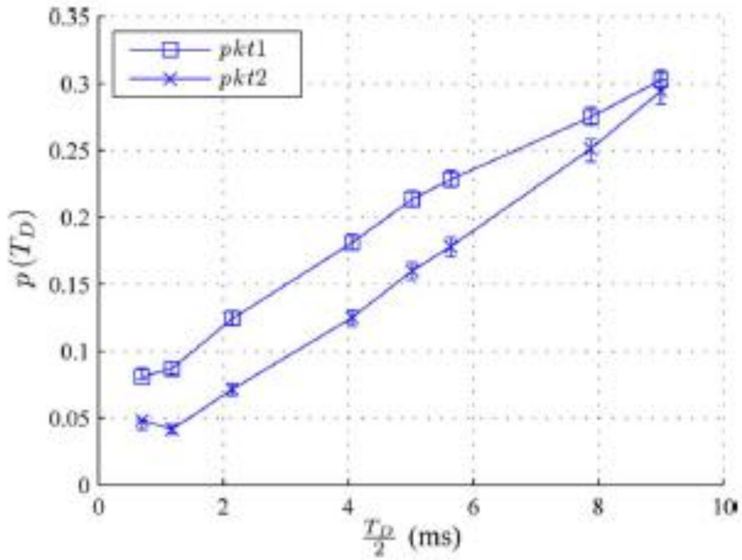
$$\tilde{U}_{T_\mathrm{D}}(X_t) = \begin{cases} 1, & t \in [T_k + T_\mathrm{D}, T_{k+1}) \text{ for some } k \\ 0, & \text{otherwise.} \end{cases}$$

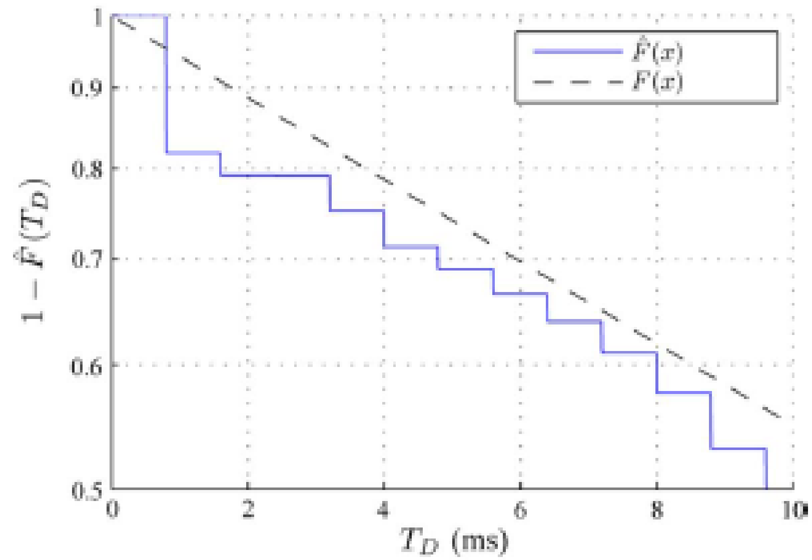
$$\tilde{p}(T_\mathrm{D}) = 1 - \frac{\mathbb{E}[S]}{\mathbb{E}[S] + \mathbb{E}[\Delta]} F_c(T_\mathrm{D}) + \frac{1}{\mathbb{E}[S] + \mathbb{E}[\Delta]} \int_{T_\mathrm{D}}^{\infty} F_c(x)\,dx.$$

Experimental Results







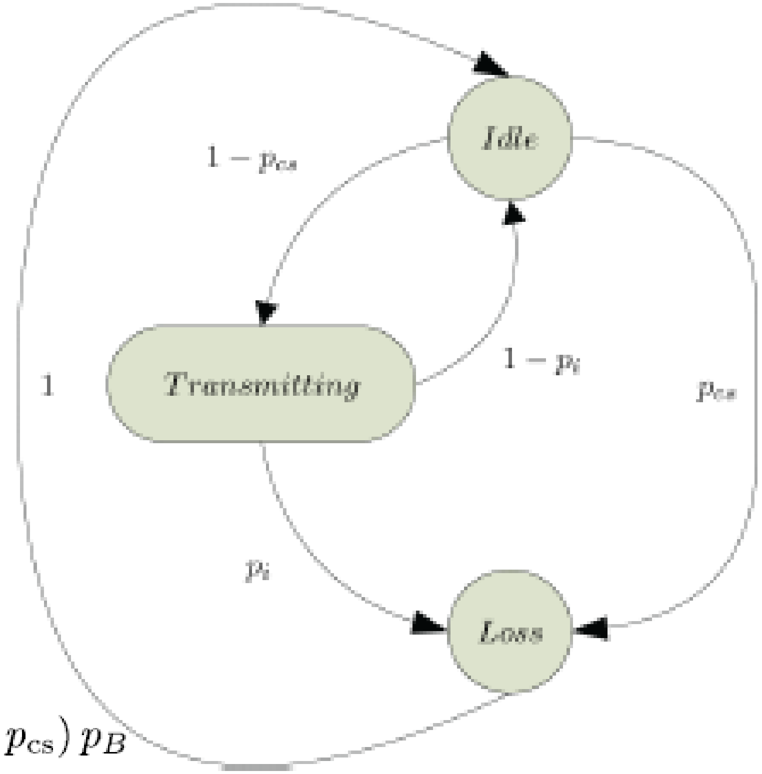


Parameterized Model

$$Q = \begin{bmatrix} -\lambda_B & \lambda_B \\ \lambda_G & -\lambda_G \end{bmatrix} \quad \Pi = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

$$\text{Prob}[Y_{n+1} = j | Y_n = i] = \Pi_{ij}$$

$$p_{\text{cs}} = \text{Prob}\left[t_n \in \left[T_{k(n)}, T_{k(n)} + \Delta_{k(n)}\right]\right] := \alpha \frac{\lambda_G}{\lambda_G + \lambda_B}$$



$$p_1(T_\text{D}) = (1 - p_\text{i}(T_\text{D}))\,(1 - p_\text{cs})p_G + (p_\text{i}(T_\text{D})(1 - p_\text{cs}) + p_\text{cs})\,p_B$$

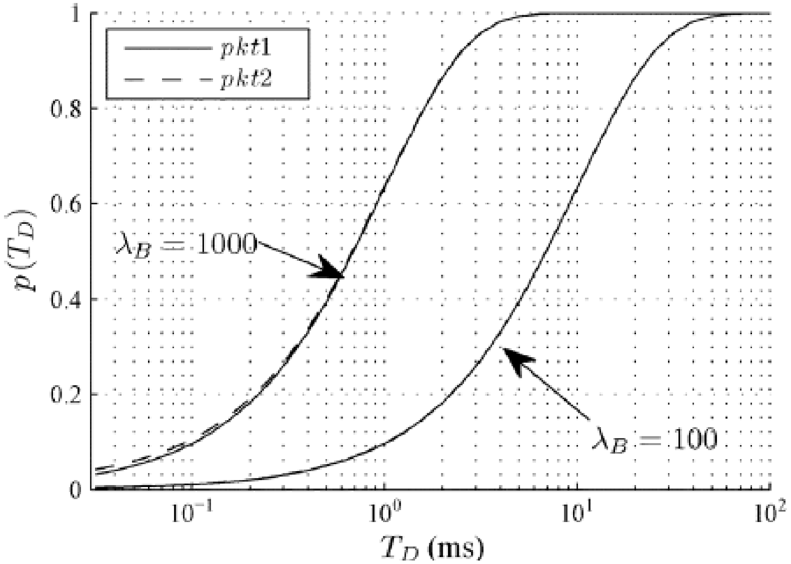
$$p_2(T_\text{D}) = (1 - p_\text{i}(T_\text{D}))\,\frac{\lambda_B}{\lambda_B + \lambda_G} p_G + \left(1 - (1 - p_\text{i}(T_\text{D}))\,\frac{\lambda_B}{\lambda_B + \lambda_G}\right) p_B$$

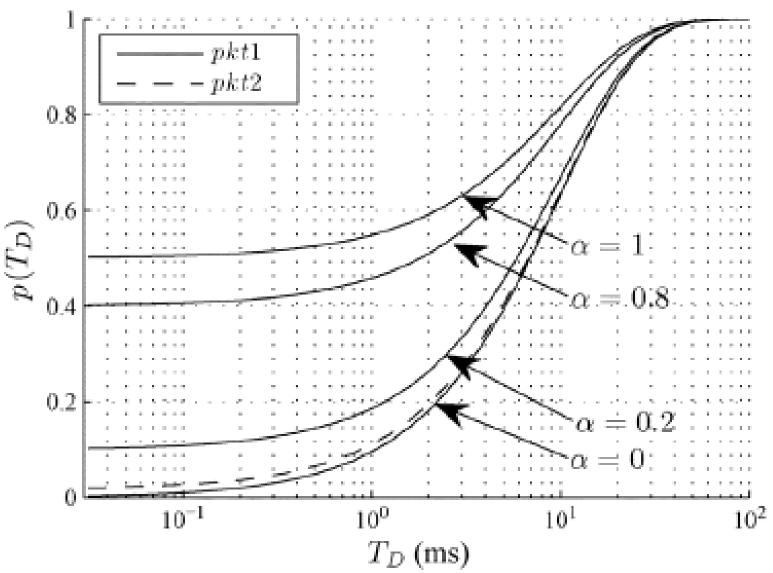
$$\mathbf{P} = \begin{bmatrix} 0 & 1 - p_\text{cs} & p_\text{cs} \\ 1 - p_\text{i}(T_\text{D}) & 0 & p_\text{i}(T_\text{D}) \\ 1 & 0 & 0 \end{bmatrix}$$

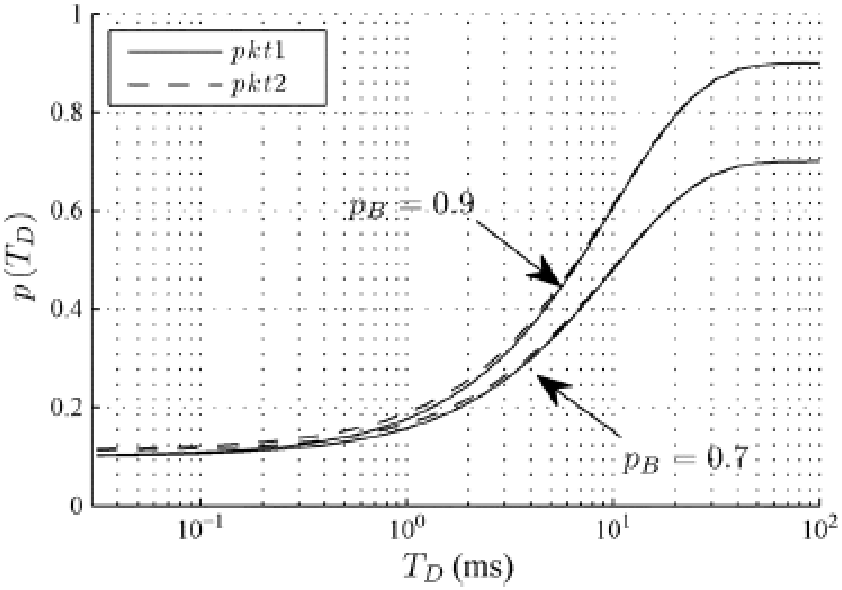
$$1 - p_\text{i}(T_D) = \exp(-\lambda_B T_\text{D})$$

Effect of Parameter Variation

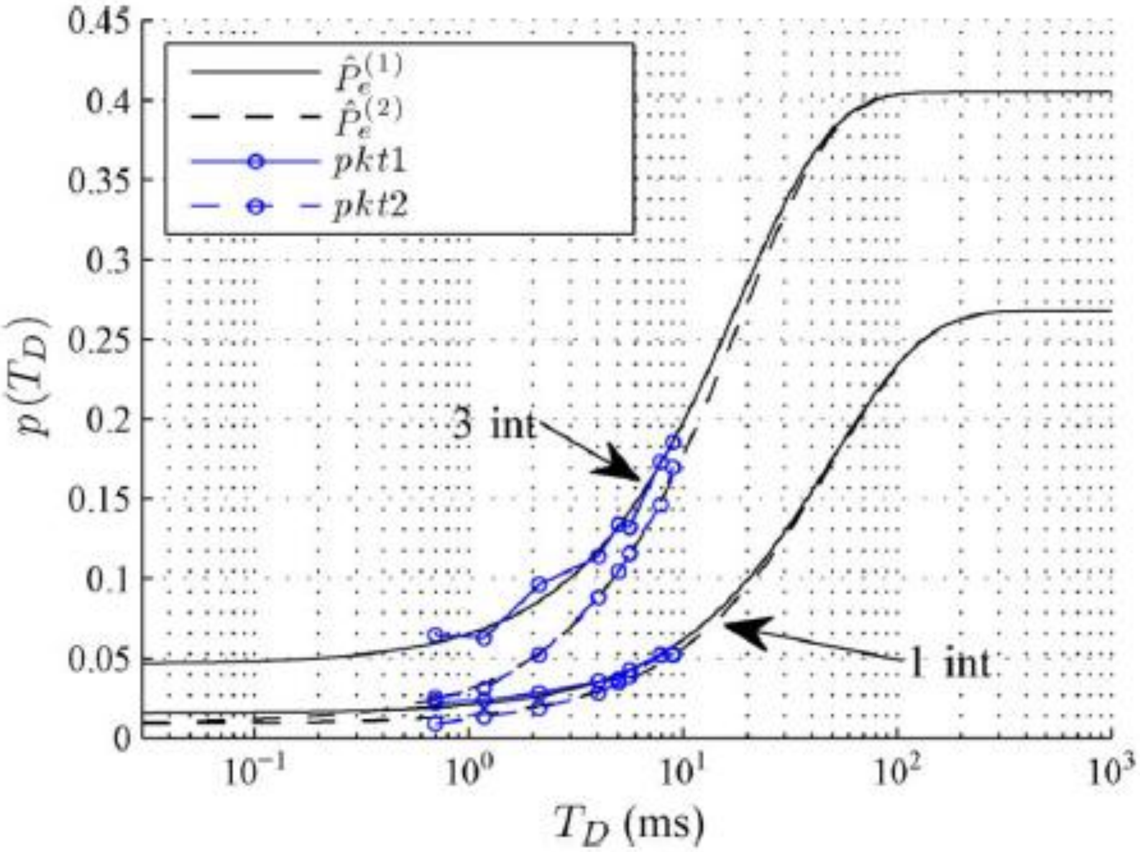
- Left: Varied λ
- Bottom Left: Varied p_B
- Bottom Right: Varied α







Experimental Results



Number of interferers	$\hat{\lambda}_B$	$\hat{p}_{cs}$	$\hat{p}_G$	$\hat{p}_B$
1	19.9932	0.0286	0.0080	0.2678
3	54.7173	0.1011	0.0055	0.4055

Conclusions

- Both nonparametric and parametric approaches allow inference of interferer statistical data
- Parametric approach converges to useful data more quickly
- Ability of a system to deduce cause of packet loss demonstrated