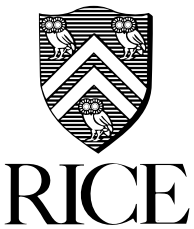


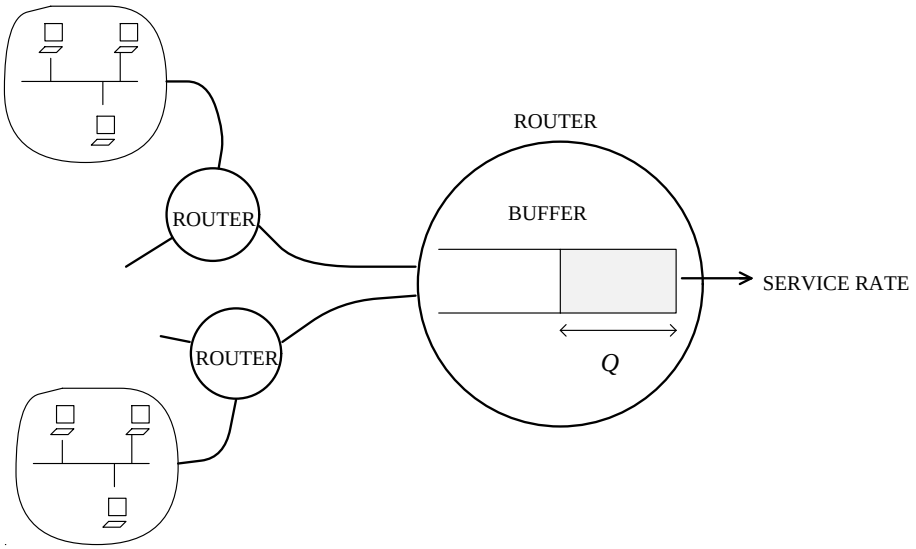
MULTISCALE QUEUING ANALYSIS OF LONG-RANGE-DEPENDENT TRAFFIC

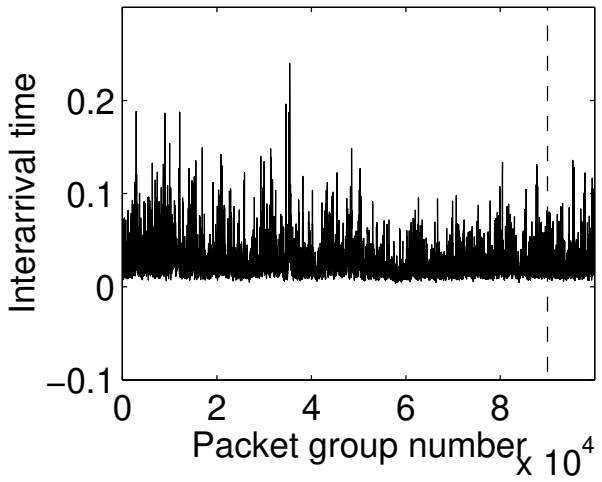
Vinay Ribeiro

Rudolf Riedi, Matthew Crouse,
Richard Baraniuk

Supported by
NSF, DARPA, Texas Instruments

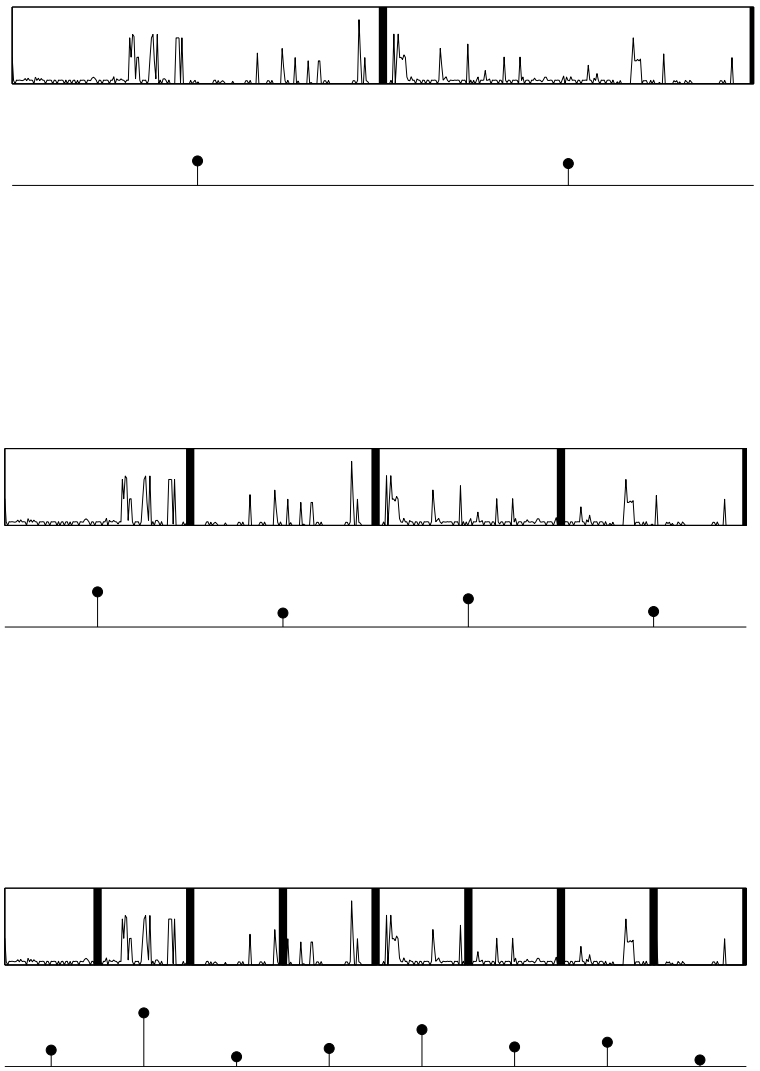
Network Traffic Modeling



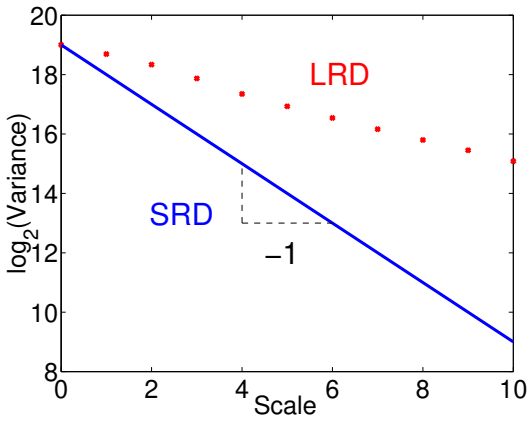


- Traffic is bursty
- Need statistical tools
  - understand implications of burstiness
  - improve performance

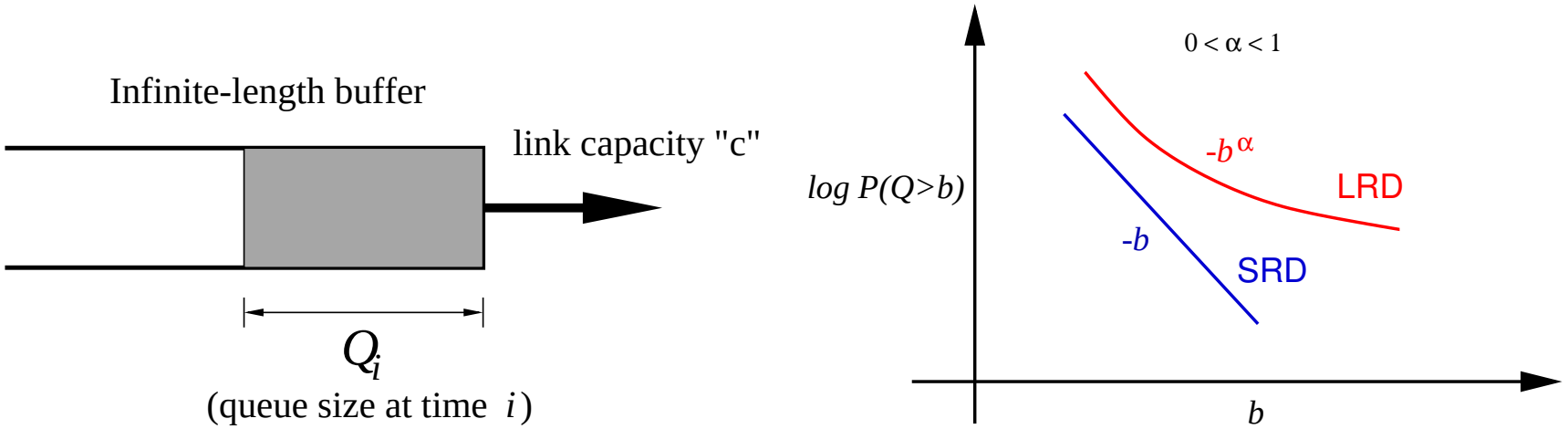
Long-Range Dependence (LRD): Multiscale Phenomenon



Variance-Time Plot (VTP)

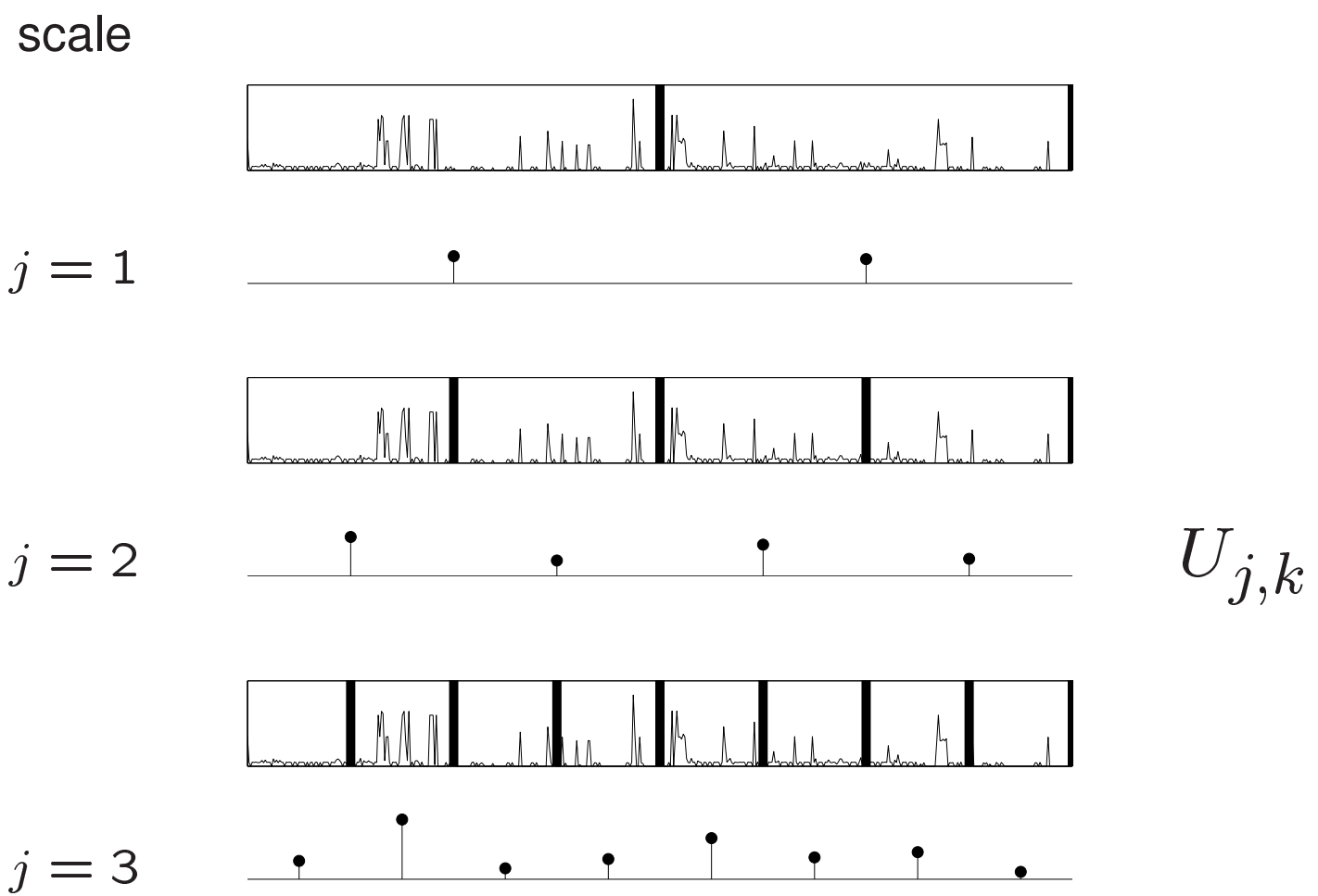


LRD and Queuing



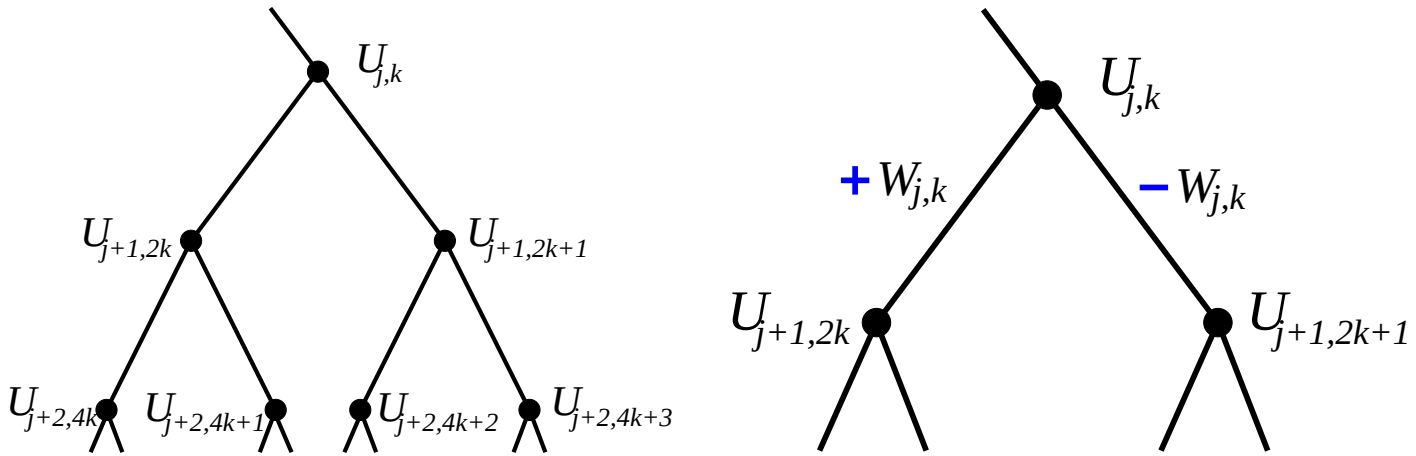
- Classical models (SRD) are overly optimistic
- LRD leads to larger queues
- Will show: LRD models can also be overly optimistic

Multiscale Tree Structure



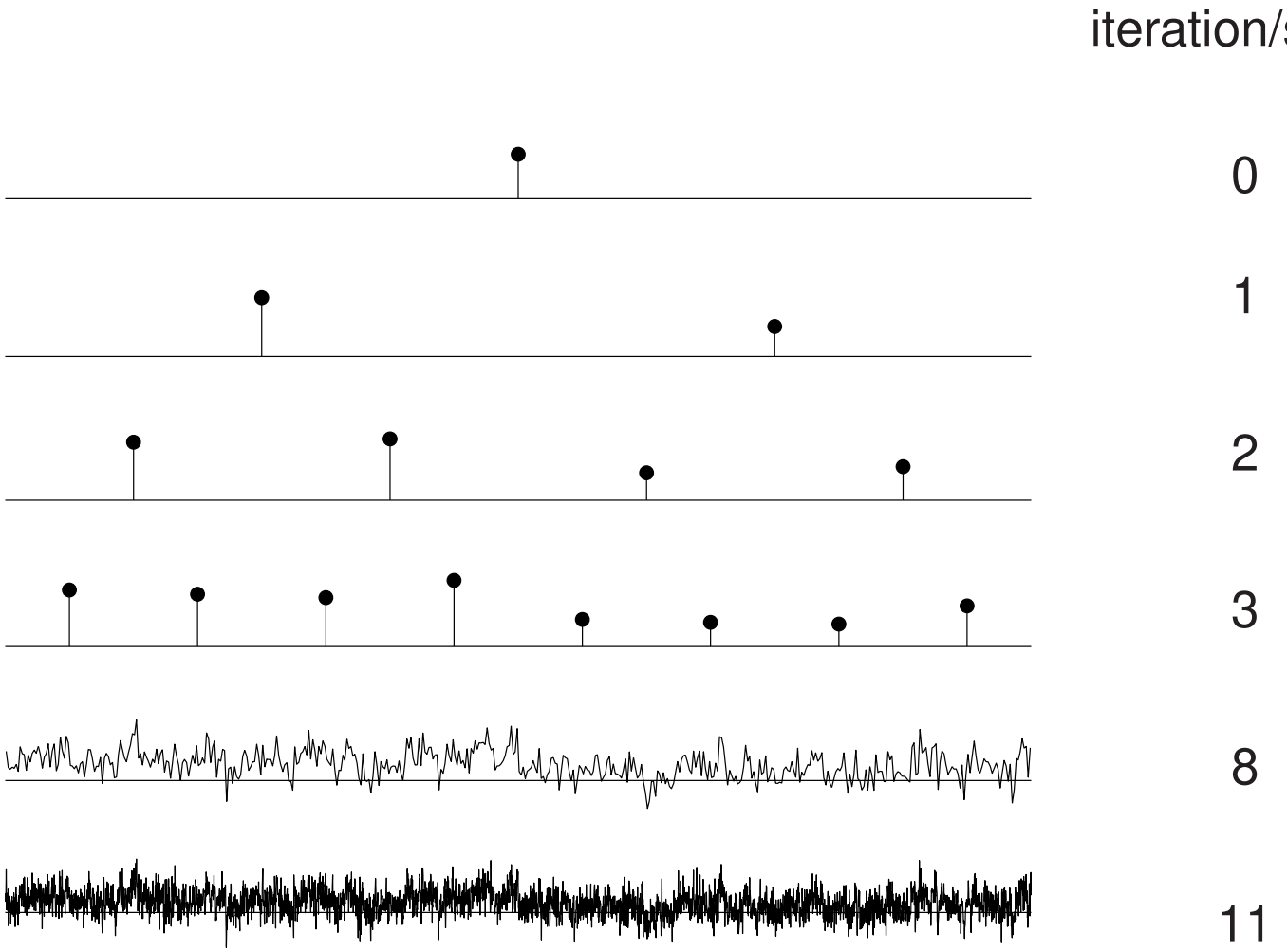
The Wavelet-domain Independent Gaussian (WIG) Model

Coarse-to-fine multiscale synthesis



- Generate independent additive innovations: $W_{j,k} \sim N(0, \sigma_j^2)$
- set σ_j^2 to match Variance-Time Plot (LRD)
- special case: fractional Gaussian noise (fGn)
- Rapid, $O(N)$ algorithm

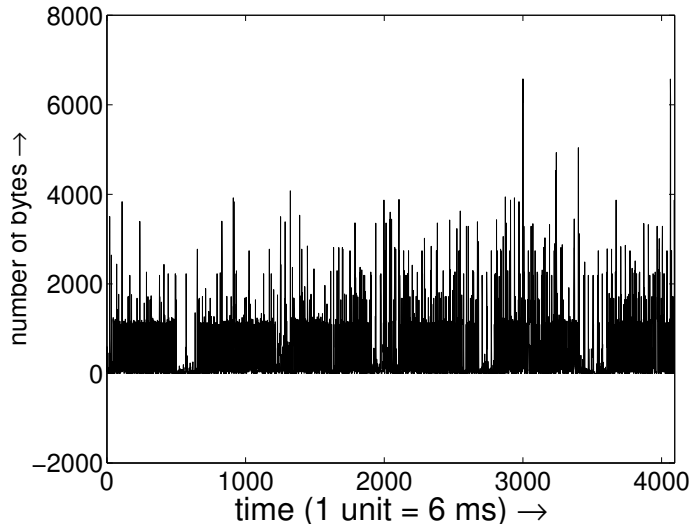
WIG Sample Realization



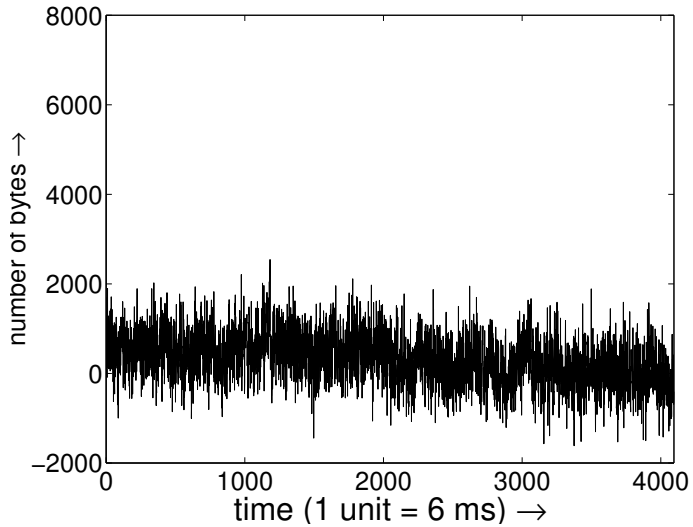
Limitations of Gaussian Network Traffic Models

- Gaussian $\Rightarrow$ takes negative values; but network traffic is positive
- Gaussian not spiky, real traffic is spiky

Network traffic



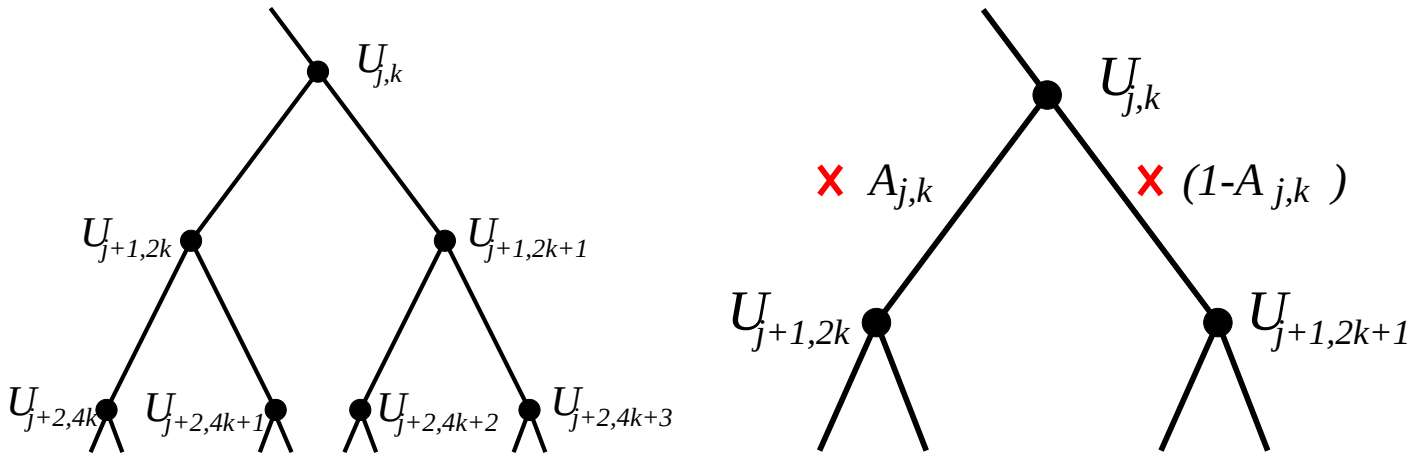
WIG synthesis



- Goal: positive bursty LRD processes

The Multifractal Wavelet Model (MWM)

Coarse-to-fine multiscale synthesis



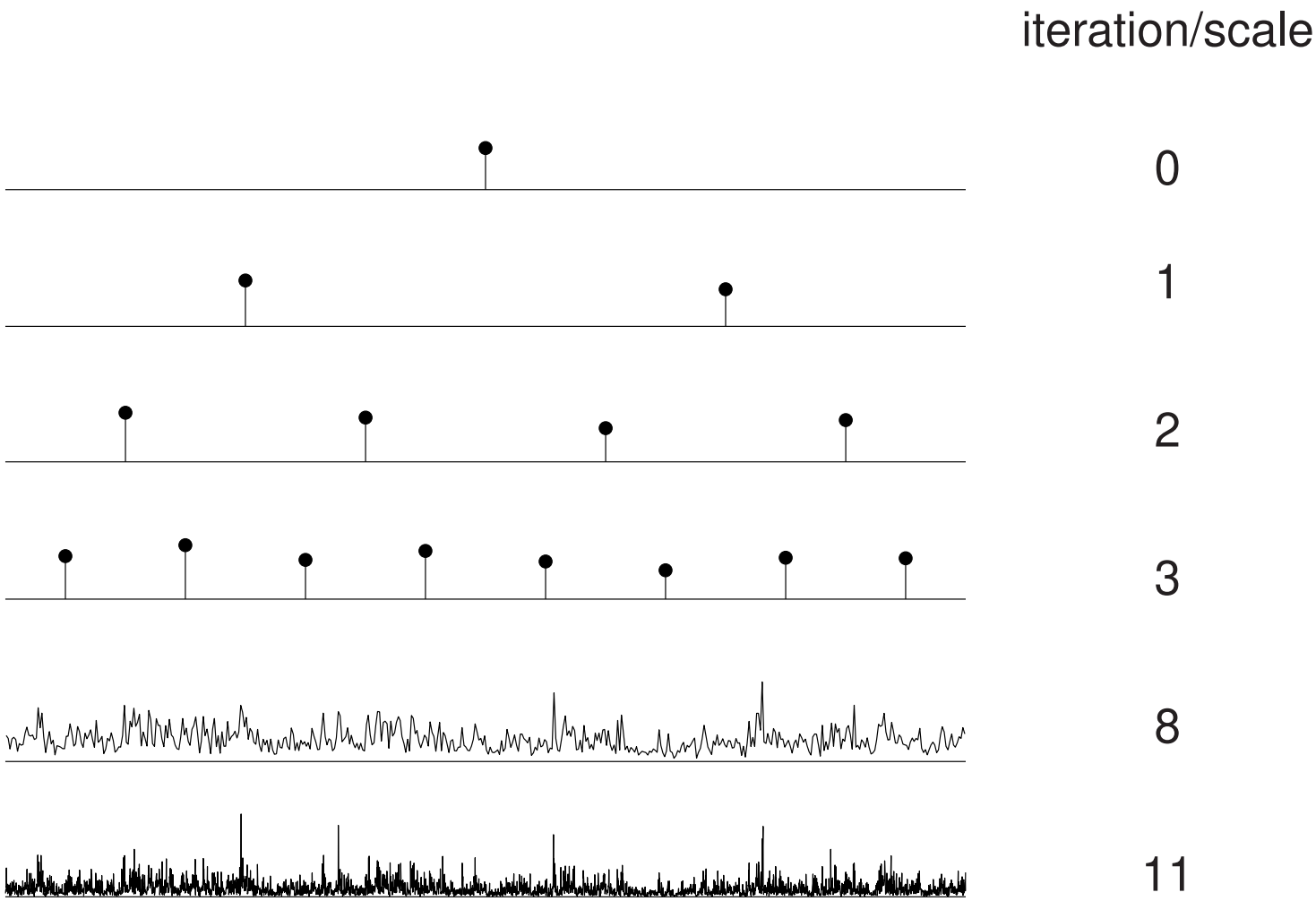
- Generate independent positive multiplicative innovations:

$$A_{j,k} \in [0, 1]$$

- set Var($A_{j,k}$) to match Variance-Time Plot (LRD)

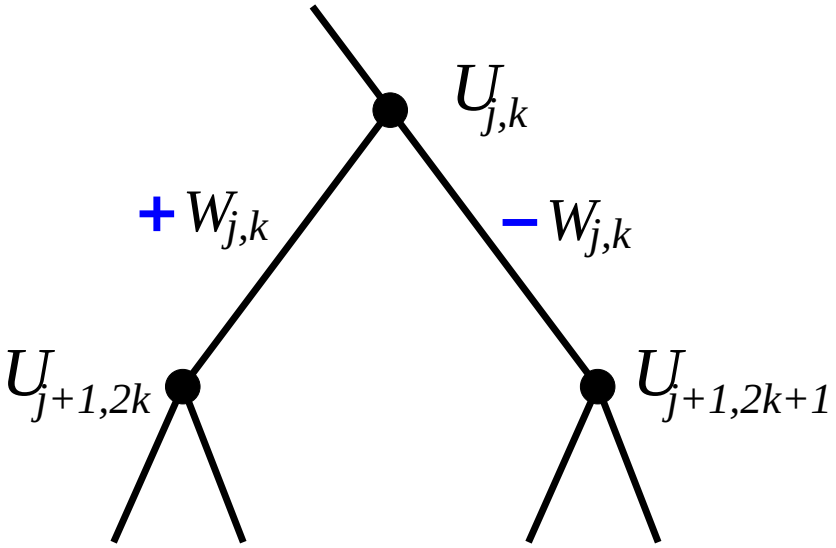
- Rapid, $O(N)$ algorithm

MWM Sample Realization



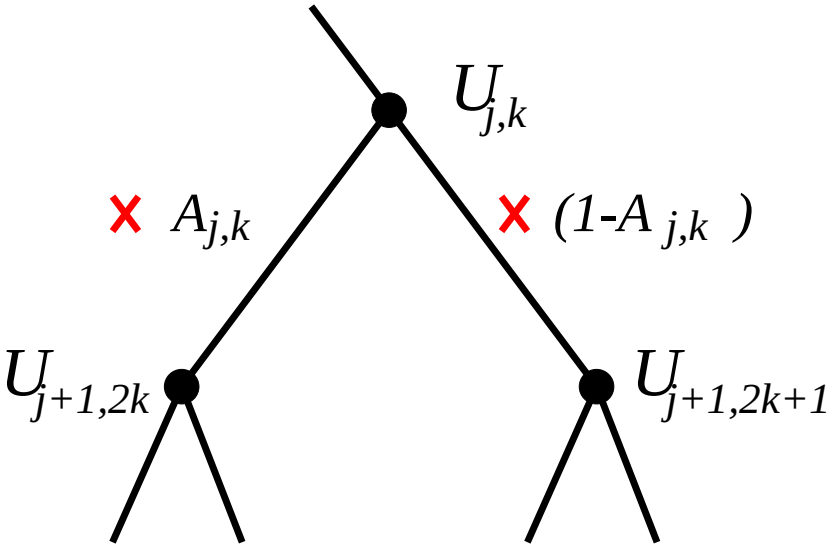
Additive vs. Multiplicative Innovations

WIG



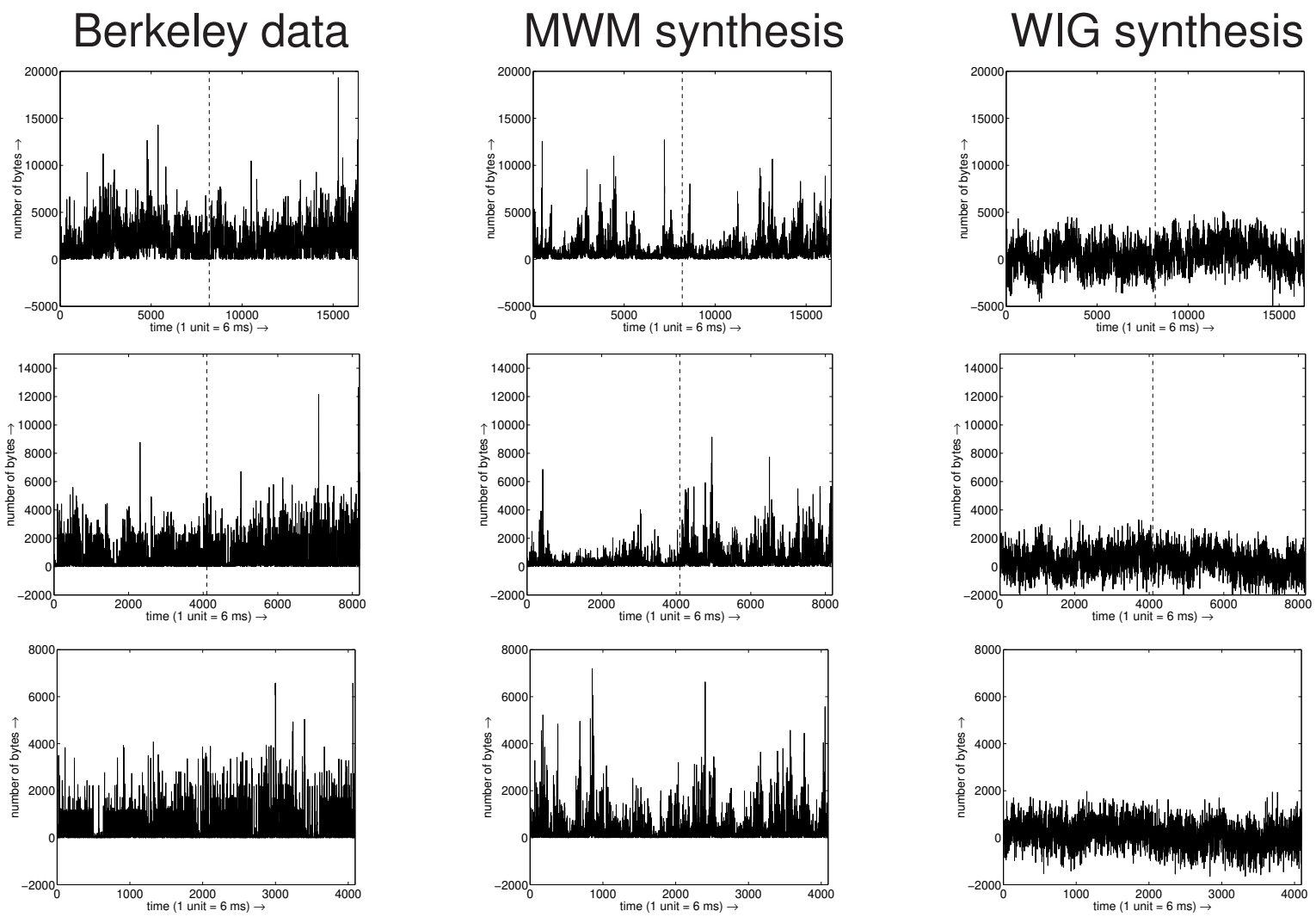
additive
Gaussian
matches VTP
monofractal
$O(N)$

MWM

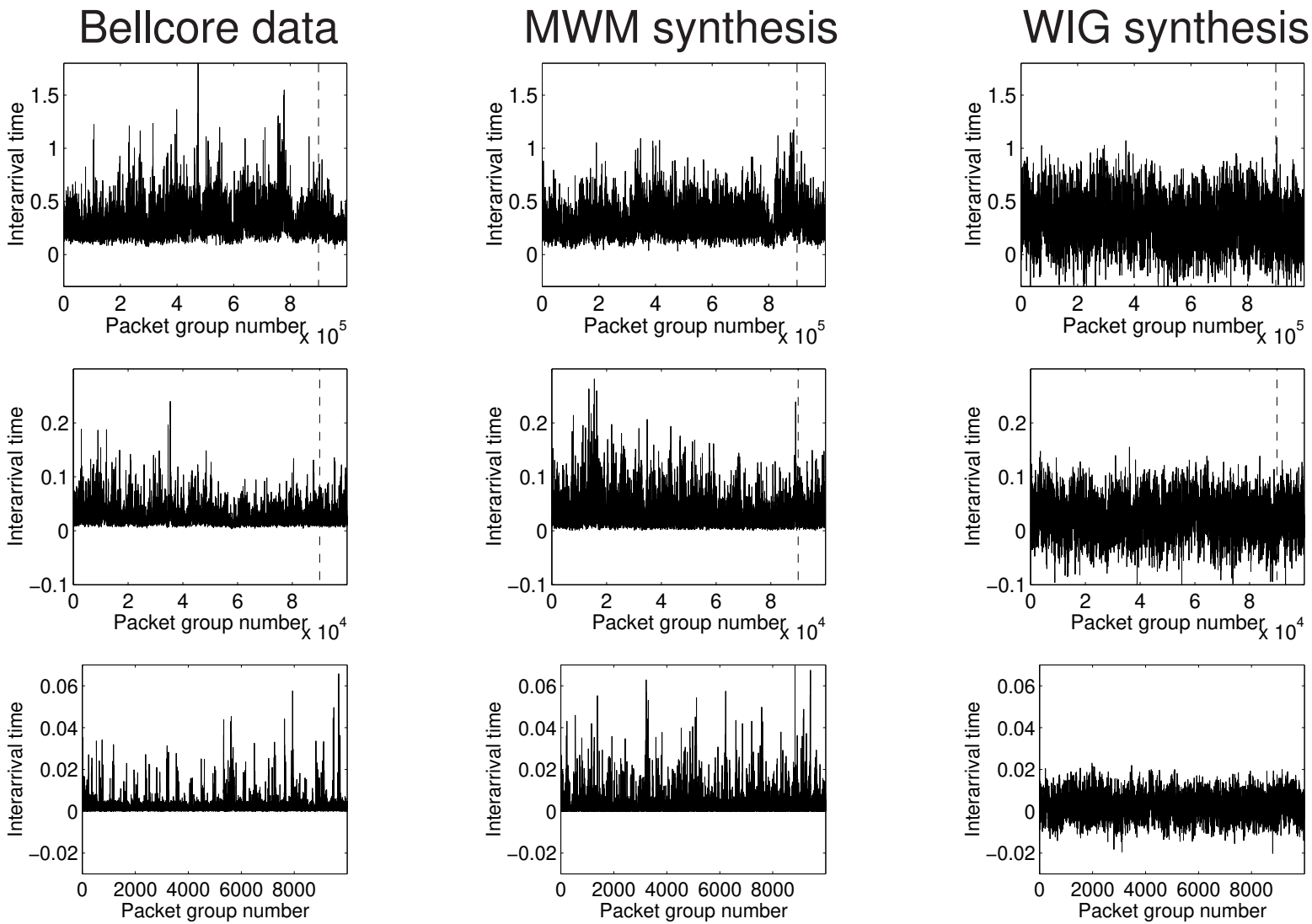


multiplicative
non-Gaussian
matches VTP
multifractal
$O(N)$

Lawrence Berkeley Labs 1994 WAN Bytes-per-Time

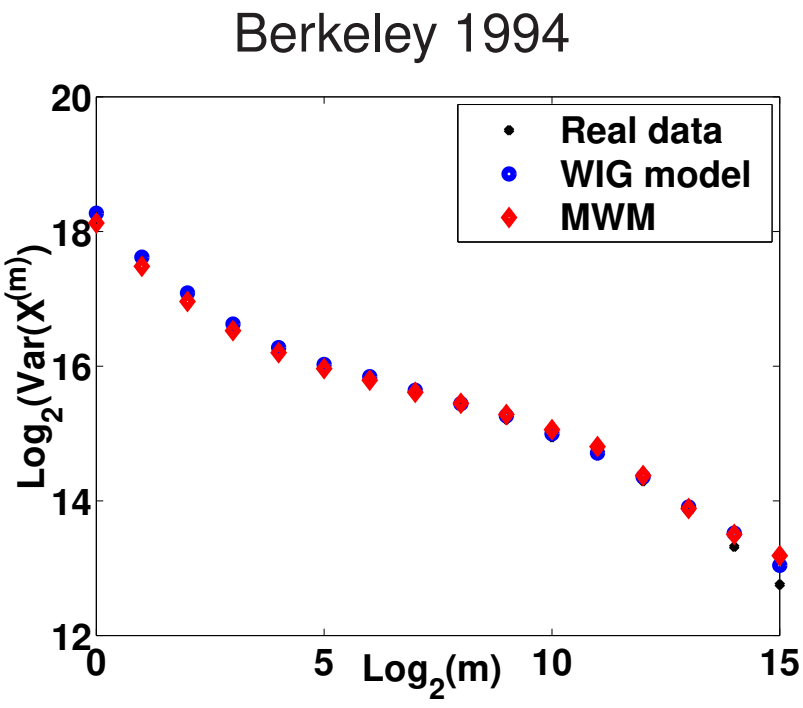


Bellcore August 1989 Ethernet Interarrival Times

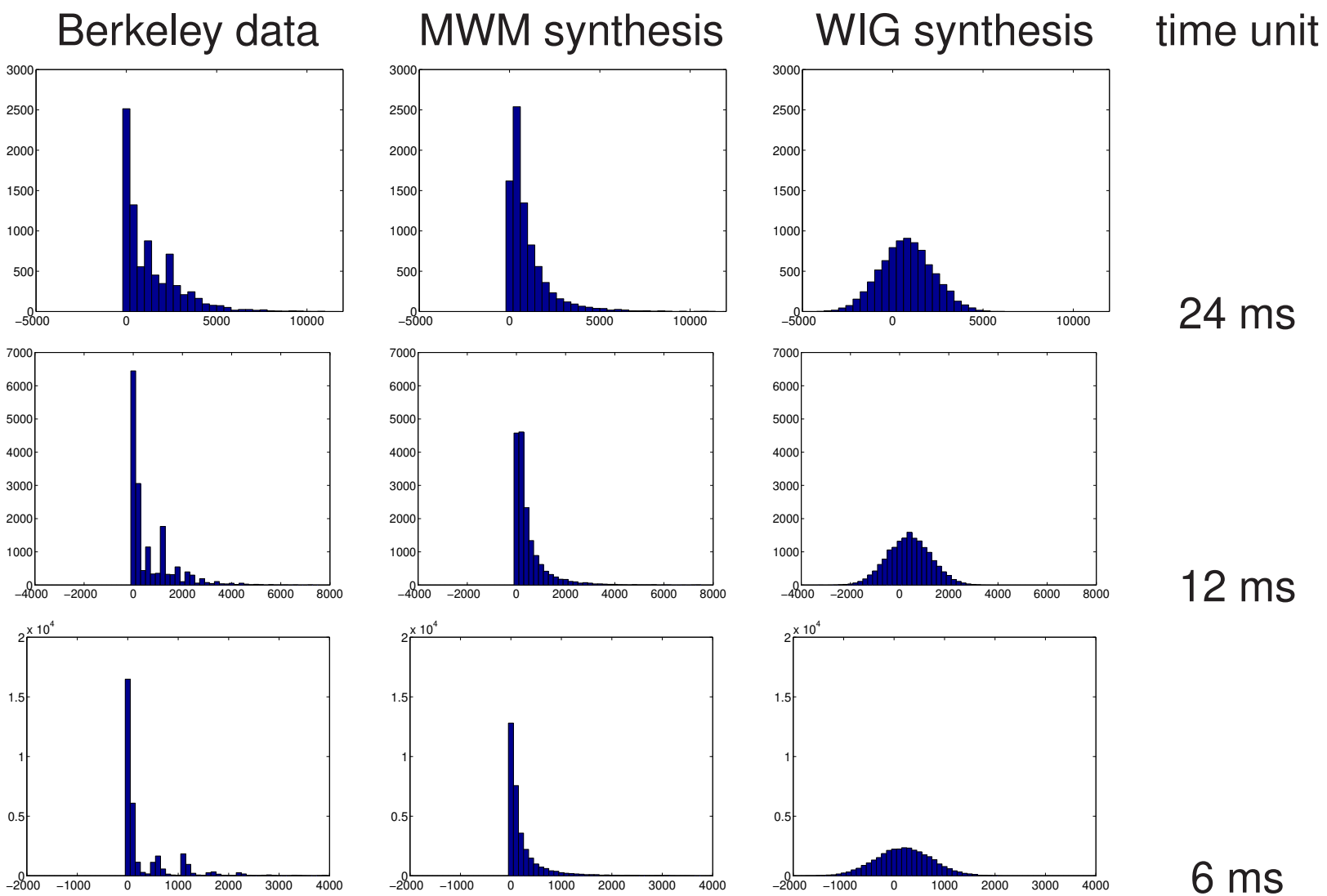


Variance-Time Plots (LRD)

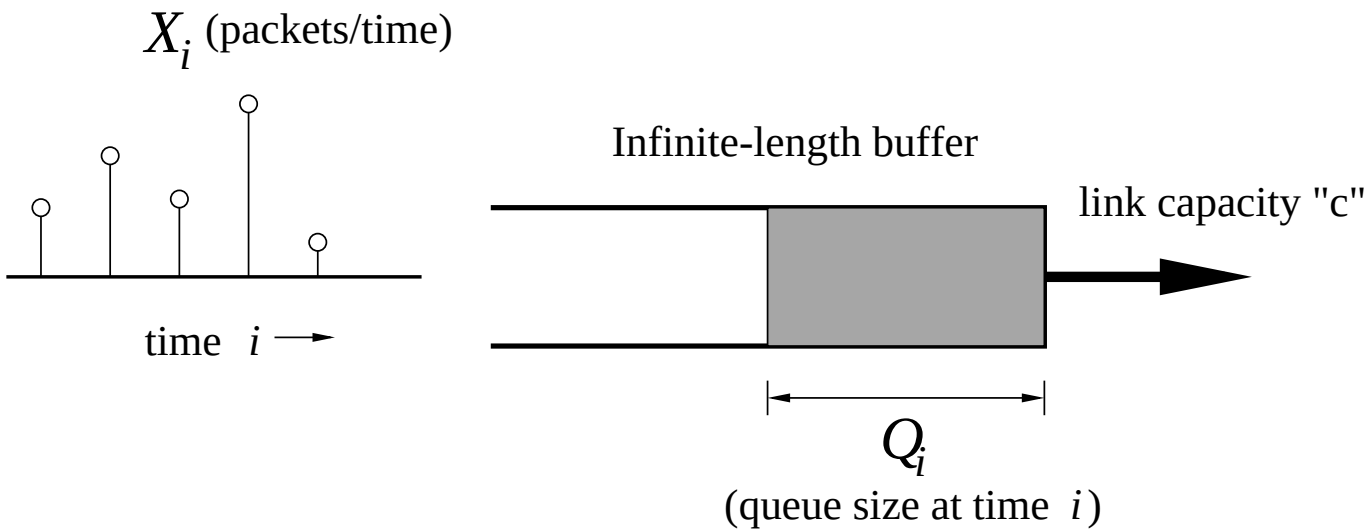
- Both WIG and MWM match multiscale 2nd-order statistics (LRD)



Berkeley 1994 WAN Bytes-per-Time (Marginals)



Queuing Simulations

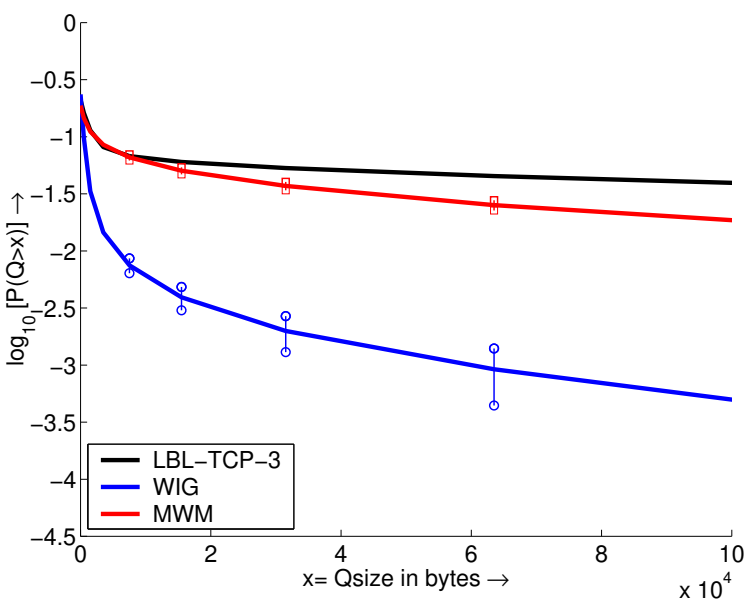


- Study tail queue probability: $P(Q > b)$

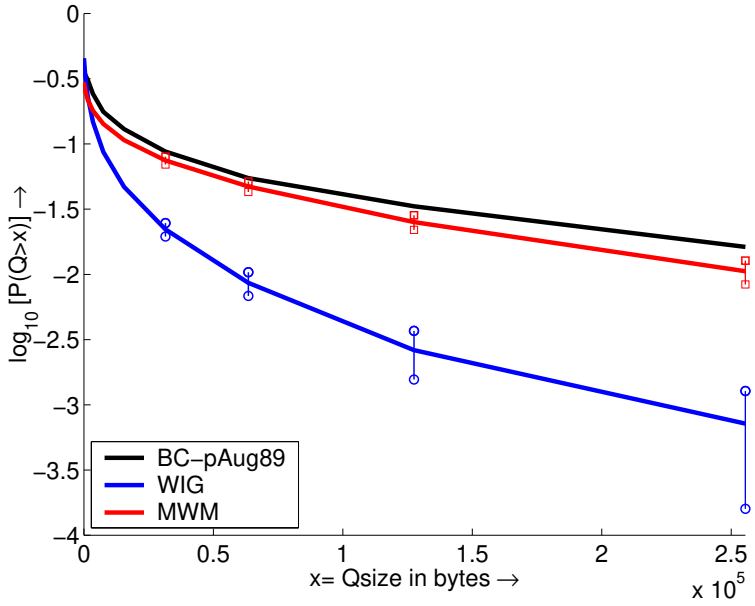
Queuing Simulations

- Plot $\log P(Q > b)$ vs. b

Berkeley 1994 WAN



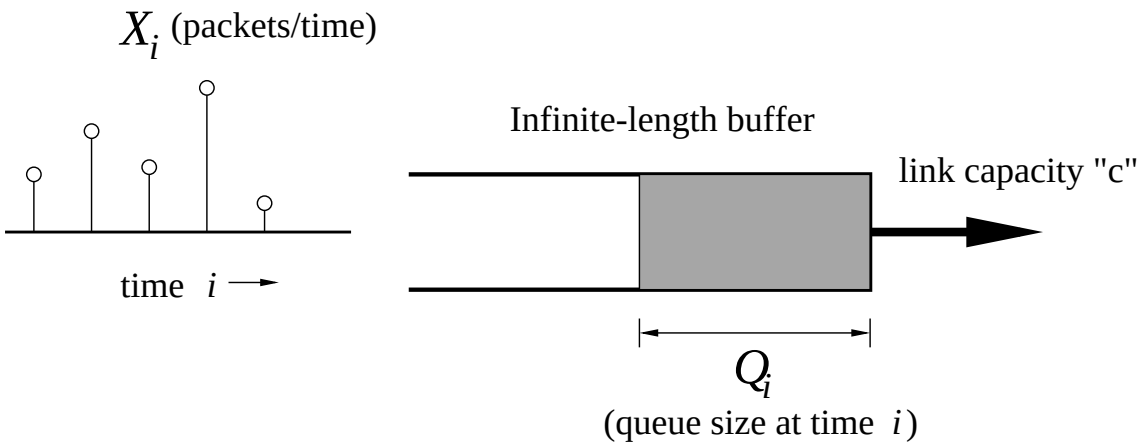
Bellcore 1989 Ethernet



- Queuing not entirely determined by LRD (2^{nd} order statistics)

- Matching multiscale marginals improves queuing match

Queuing: Multiscale Phenomenon

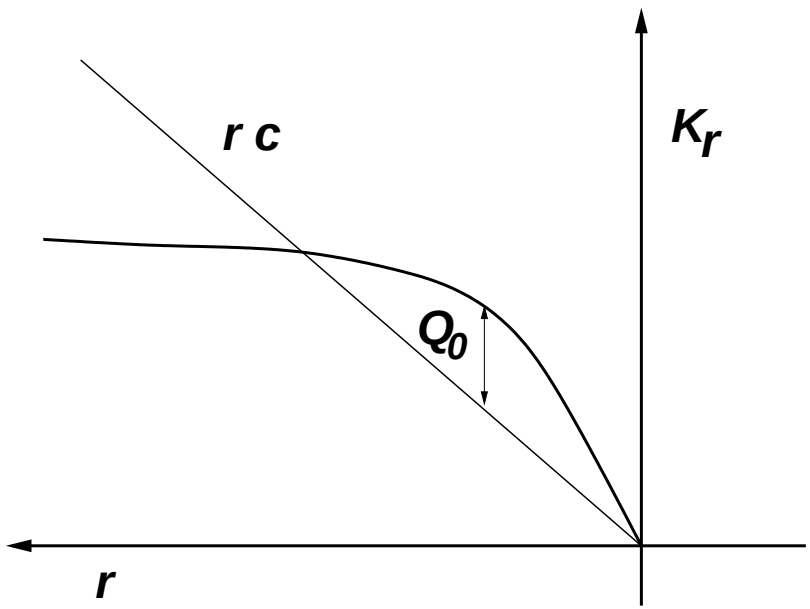


- Study Q_0, determined by X_i, $i \leq 0$

$$K_r := \sum_{i=-r+1}^{0} X_i$$

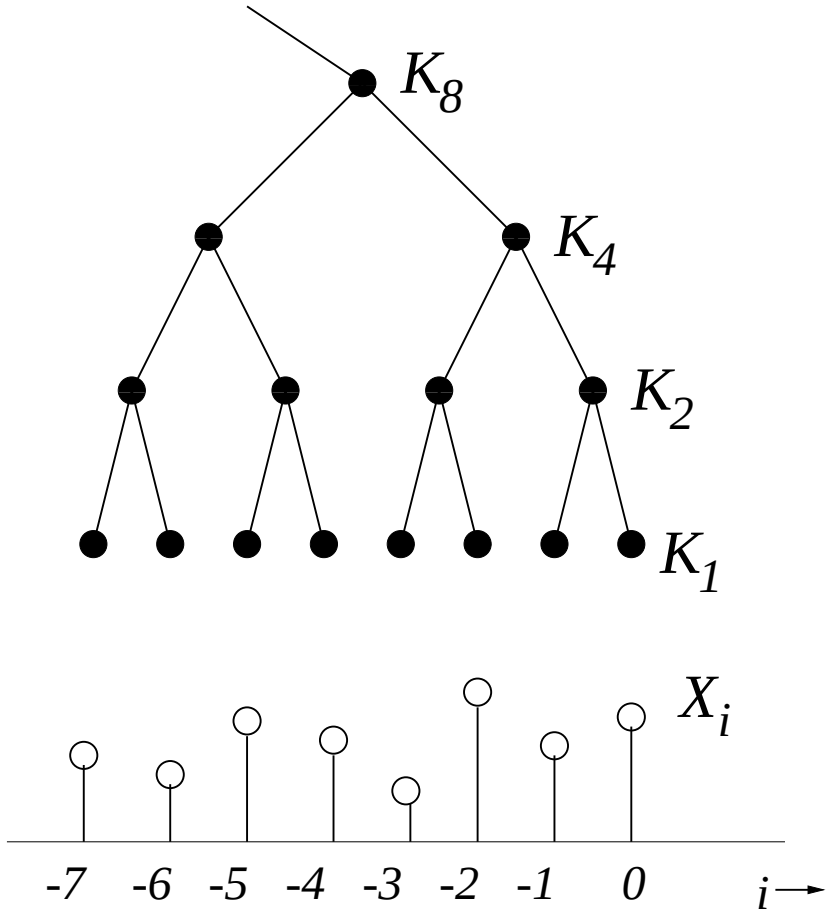
$$= \text{packets arrived in last } r \text{ instants}$$

$$Q_0 = \sup_r (K_r - rc)$$



Limit analysis to dyadic scales

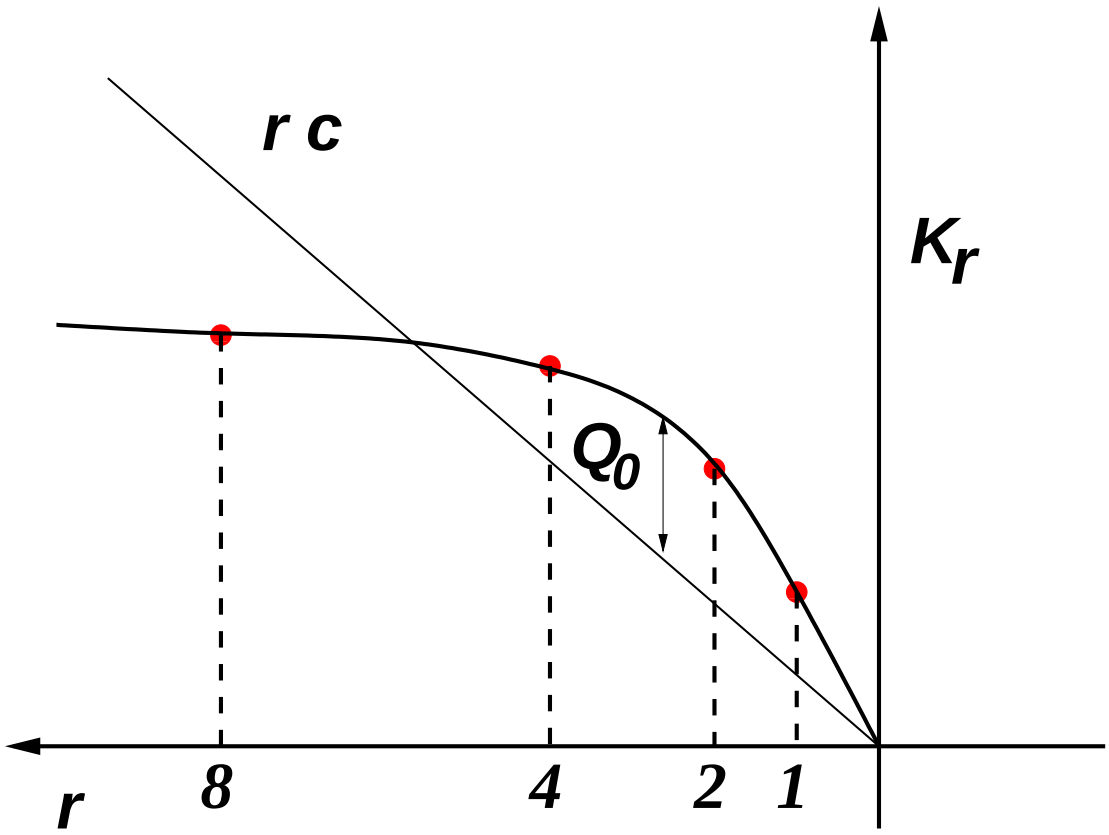
- K_r for $r = 2^j$ (dyadic time scales) are nodes on multiscale tree



Multiscale Queuing Formula

- Sample dyadically $r = 2^j$

$$Q_D := \sup_j (K_{2^j} - c2^j) \approx Q_0$$



Multiscale Queuing Formula

- $Q_D := \sup_j (K_{2^j} - c2^j)$

- For both WIG and MWM

$$P(Q_D < b) = P(\cap_{j=0}^{n} \{K_{2^j} < b + c2^j\}) \geq \prod_{j=0}^{n} P(K_{2^j} < b + c2^j)$$

- Multiscale Queuing Formula

$$\text{MSQ}(b) := 1 - \prod_{j=0}^{n} P(K_{2^j} < b + c2^j) \geq P(Q_D > b)$$

$$\text{MSQ}(b) \approx P(Q_0 > b)$$

Multiscale Queuing Formula

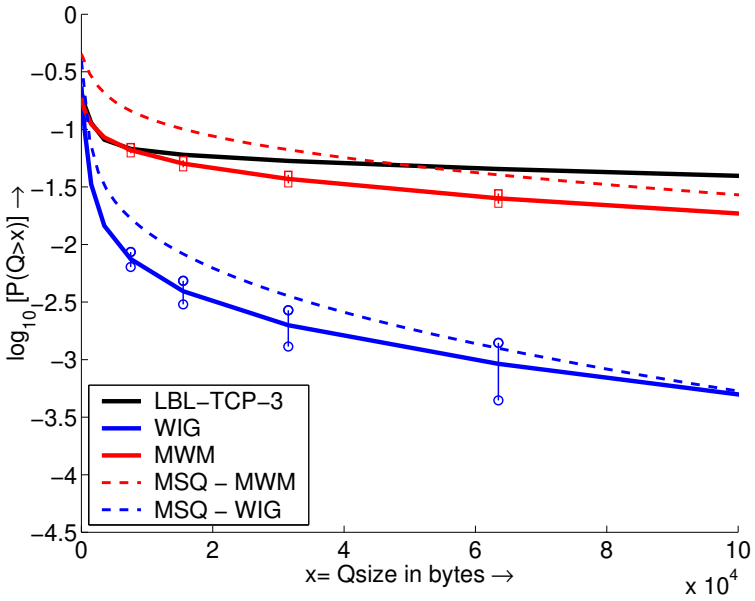
$$MSQ(b) := 1 - \prod_{j=0}^{n} P(K_{2^j} < b + c2^j)$$

- Simple to compute tail probabilities: $P(K_{2^j} < b + c2^j)$
- Valid for any b, not asymptotic
- requires few statistics

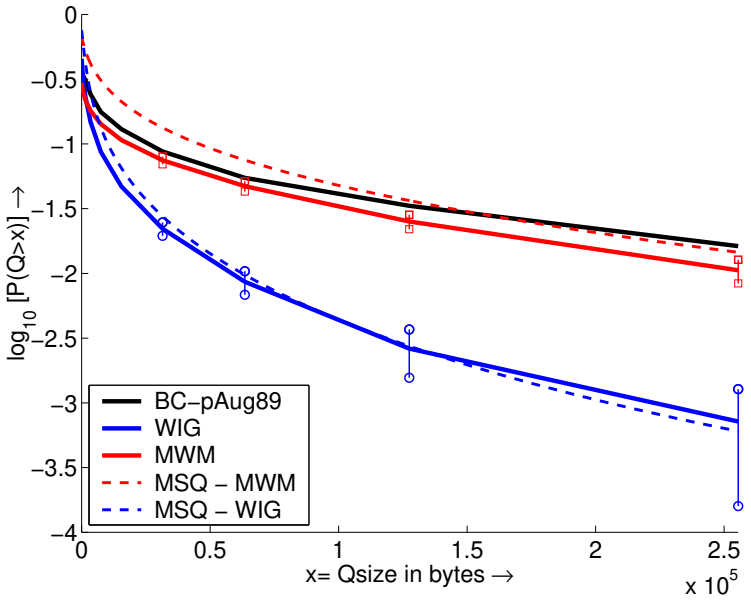
Queuing Results

- Plot $\log P(Q > b)$ vs. b

Berkeley 1994 WAN

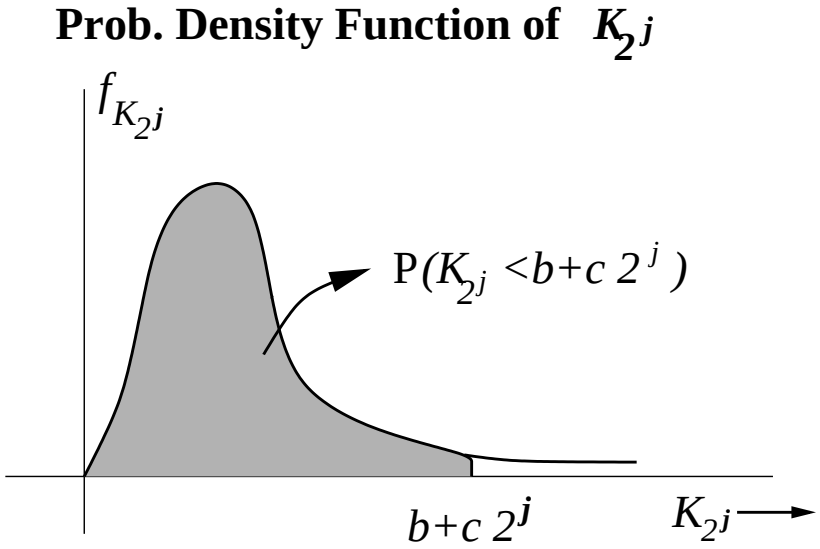


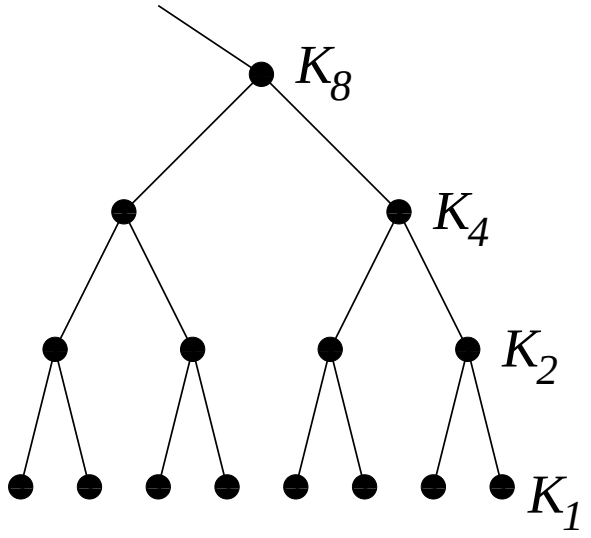
Bellcore 1989 Ethernet



- MSQ is a close approximation

Multiscale Marginals affect Queuing





$$\text{MSQ}(b) = 1 - \prod_{i=0}^{n} P(K_{2^j} < b + c2^j)$$

- $P(K_{2^j} < b + c2^j)$ only roughly characterized by Var(K_{2^j}) (LRD)
- marginal tails influence MSQ

Main Contributions

- **Multifractal wavelet model (MWM):**
  - Fast synthesis of bursty positive LRD traffic
- **Multiscale queuing formula for WIG and MWM**
  - is a close approximation and valid for any buffer size, is not asymptotic
  - requires few statistics
- **Multiscale marginals affect queuing, LRD insufficient**

Papers and Matlab code: www.dsp.rice.edu