MULTIFRACTAL CROSS-TRAFFIC ESTIMATION

Vinay J. Ribeiro

Mark Coates, Rolf Riedi, Shriram Sarvotham, Brent Hendricks
Richard Baraniuk

Rice University

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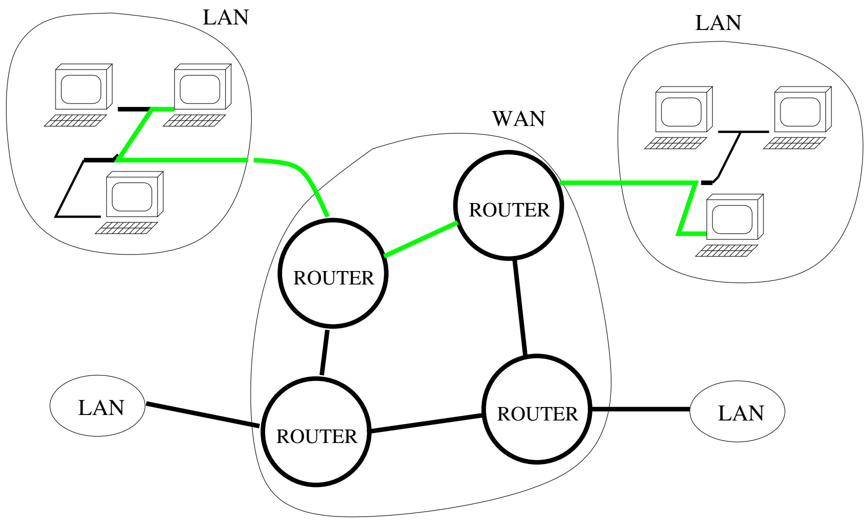
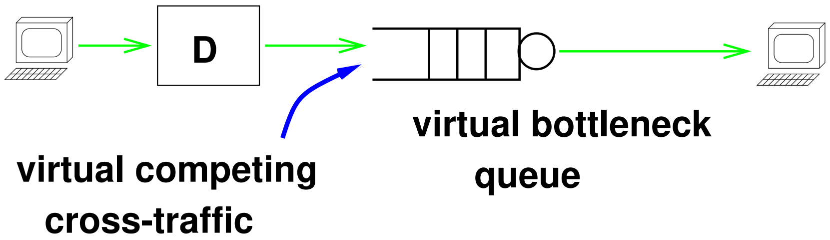
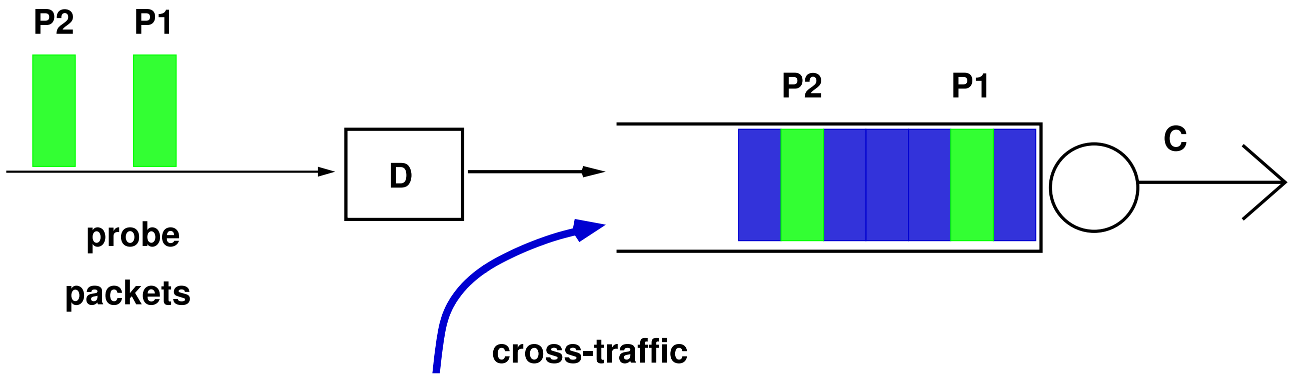
End-to-End Path Modeling



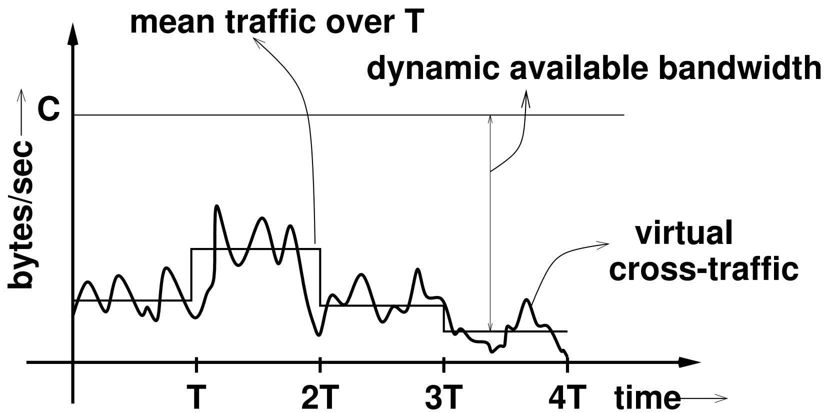


- **Model:** single bottleneck queue
- **Goal:** estimate competing cross-traffic

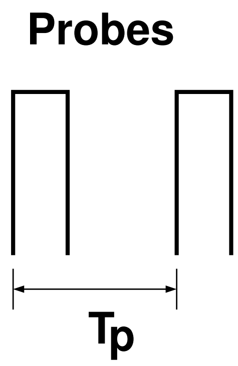
Probing



- delay $\Rightarrow$ queue length $\Rightarrow$ volume of cross-traffic



Probing Uncertainty Principle



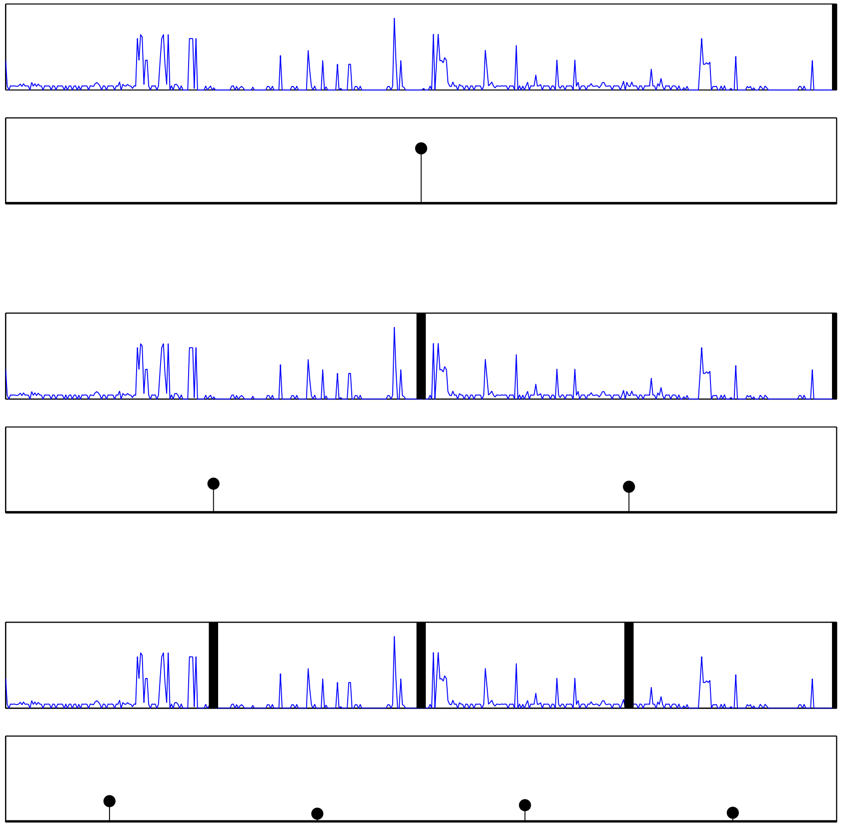
- $T_{\text{crit}} = P/C$, P probe packet size, C link cap.

Probe spacing T_p	Measurements	Impact on cross-traffic
$< T_{\text{crit}}$	exact	strong
$> T_{\text{crit}}$	not exact	less strong

- uncertainty $\Rightarrow$ must estimate cross-traffic intelligently
- exploit traffic statistics via traffic model: Multifractal Wavelet Model

Multiscale Tree Structure

time unit

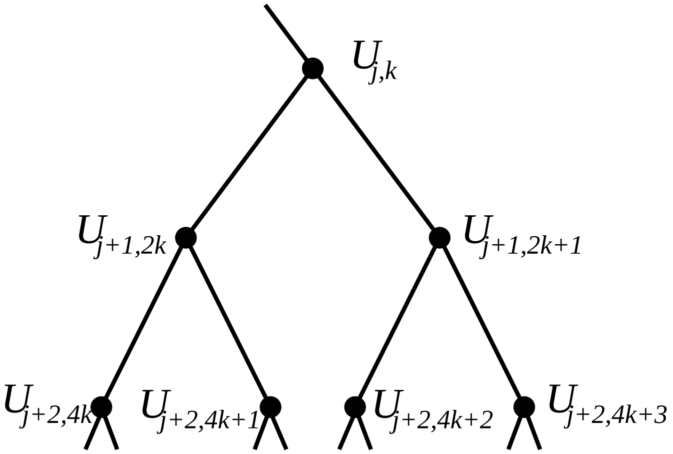


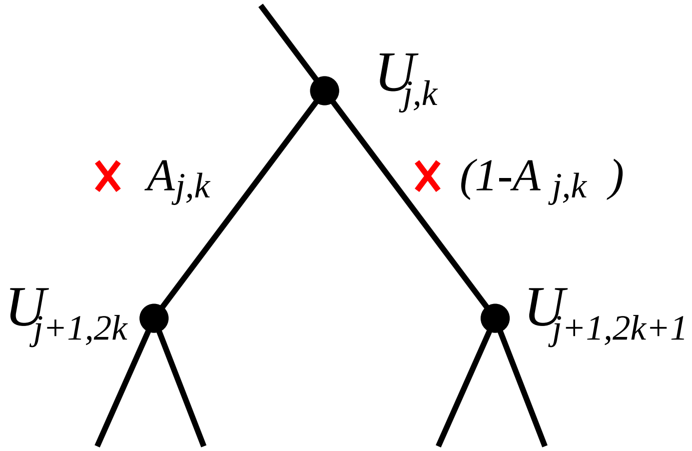
400 ms

200 ms

100 ms

Multifractal Wavelet Model (MWM)

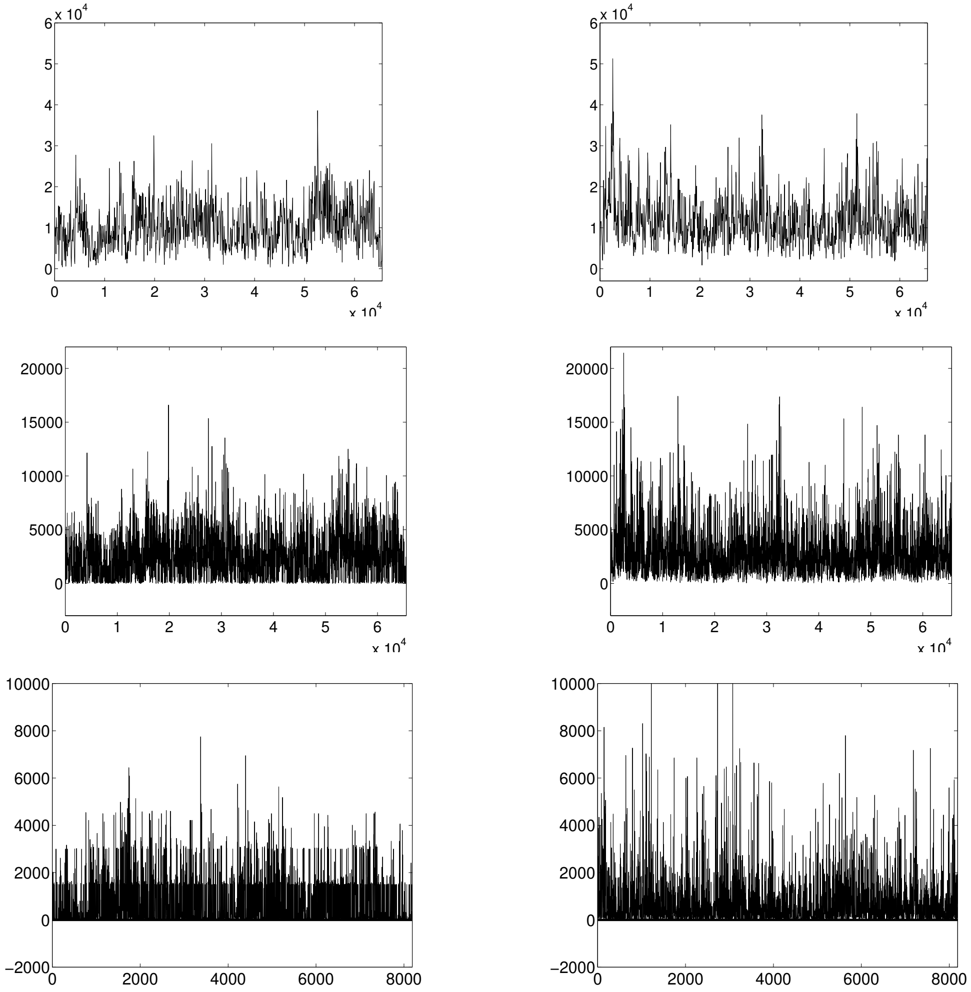




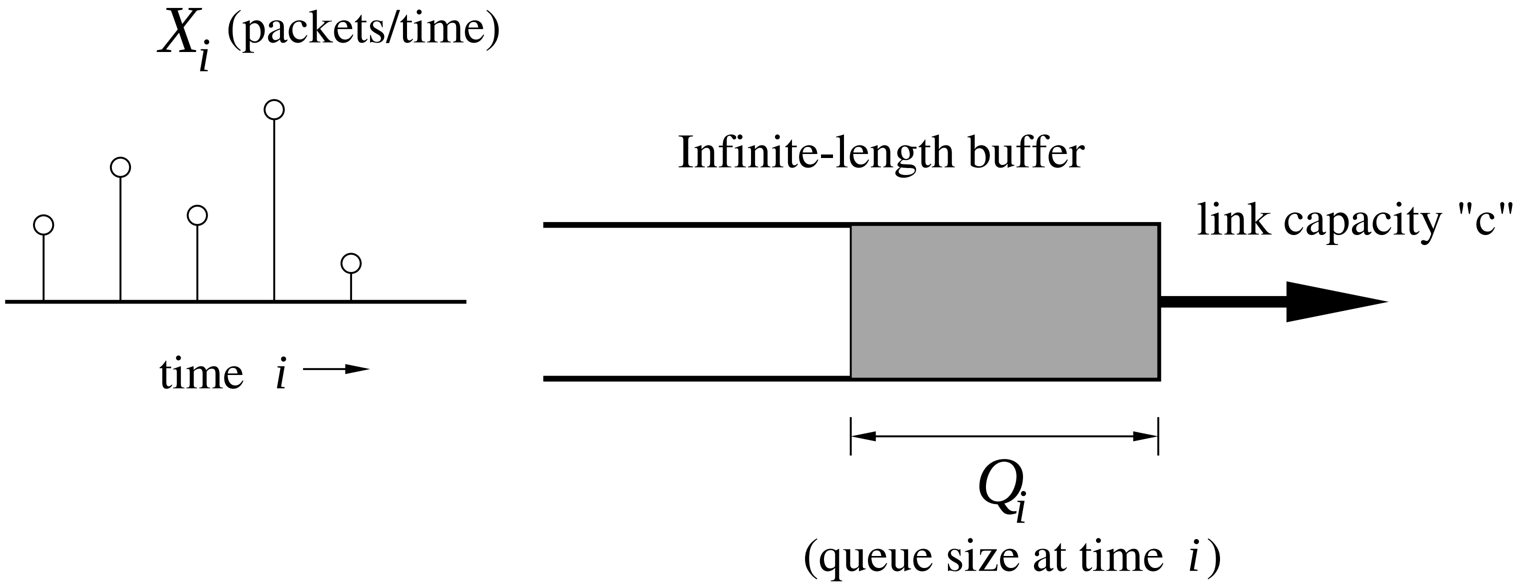
- multiplicative innovations: $A_{j,k} \in [0,1]$, ex: beta random variable
- model parameters: var$(A_{j,k})$ (one parameter per scale)
- multifractal cascades

Auckland 2000 WAN Bytes-per-Time (NLANR)

time unit	Auckland 2000	MWM
64 ms		
16 ms		
4 ms		



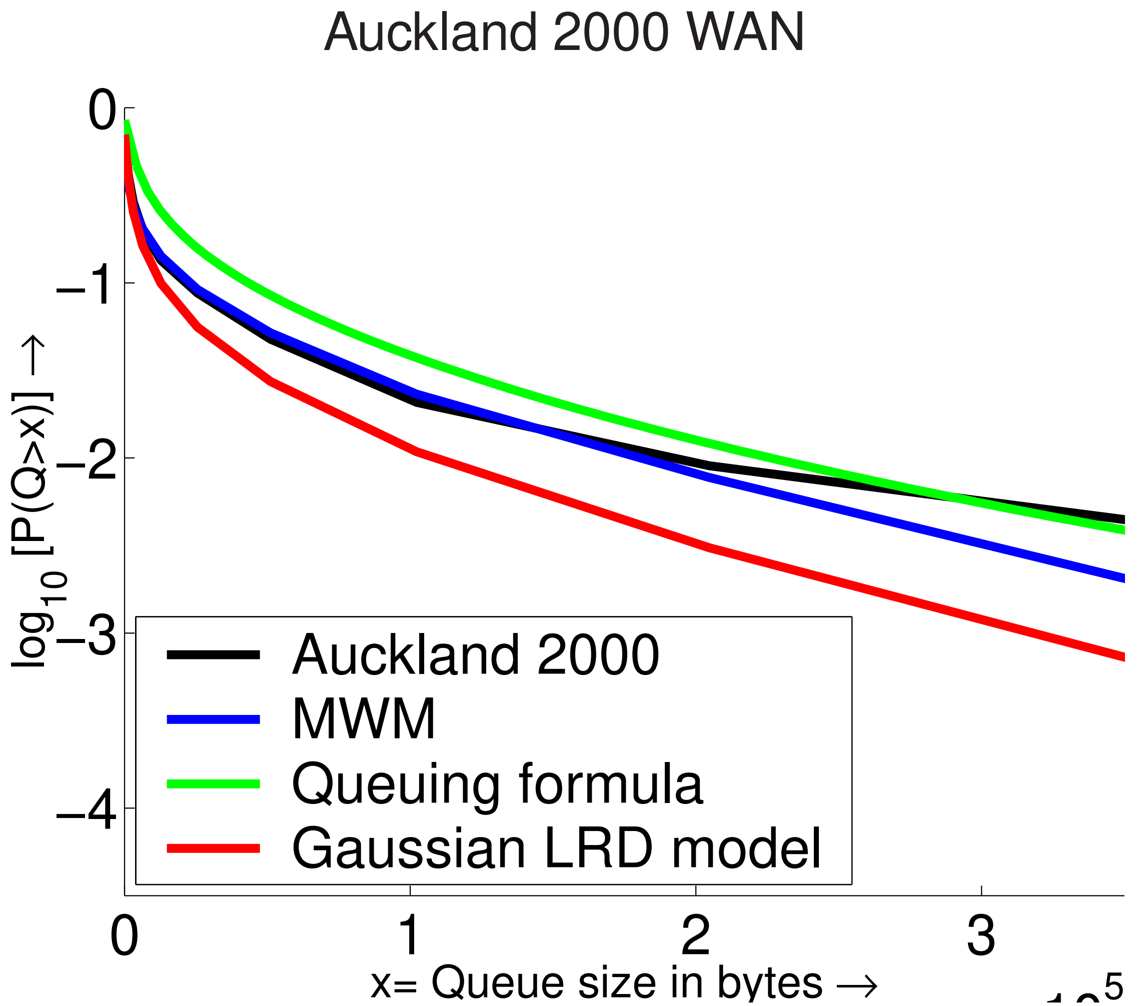
Queuing Simulations



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

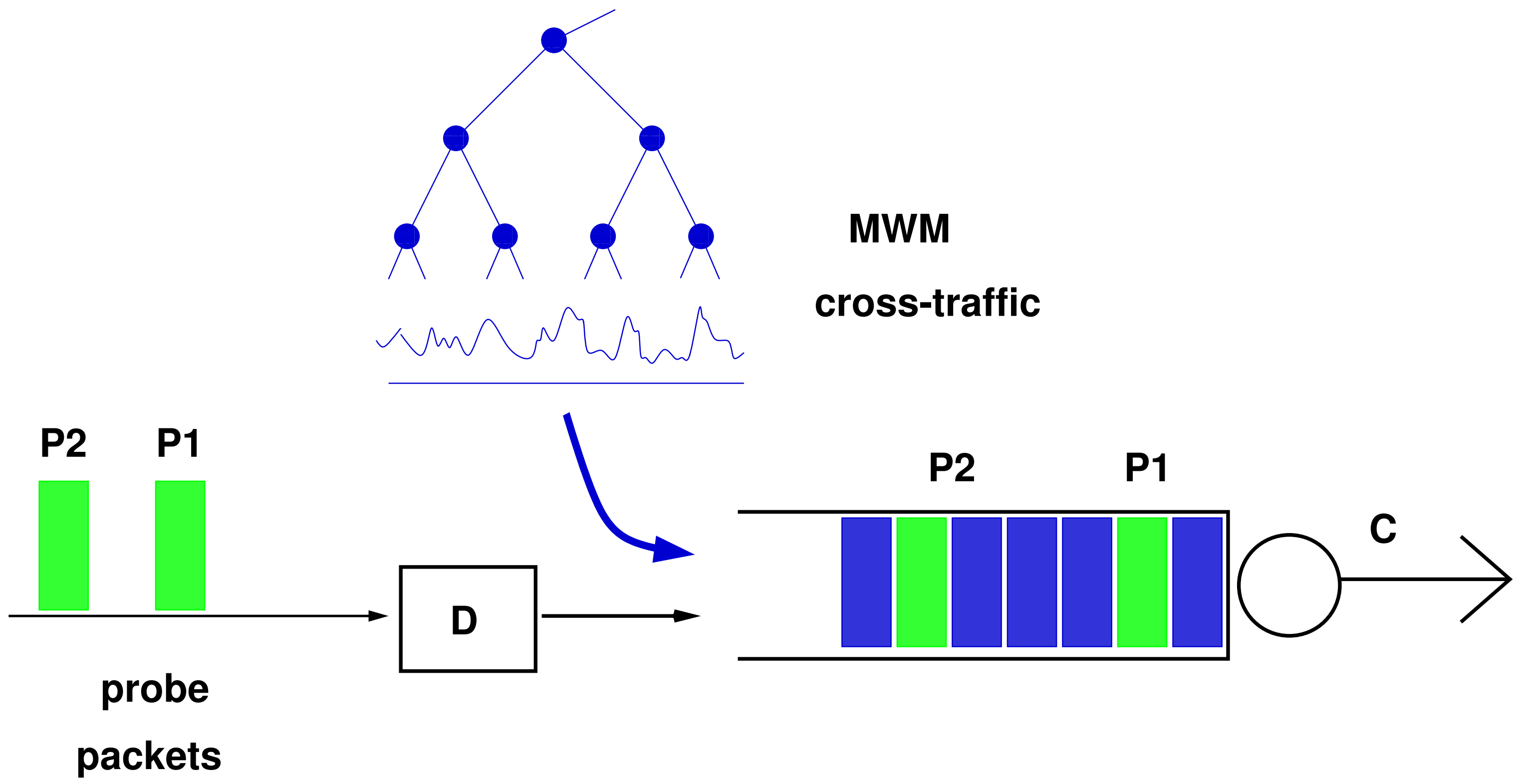
Queuing Simulations

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



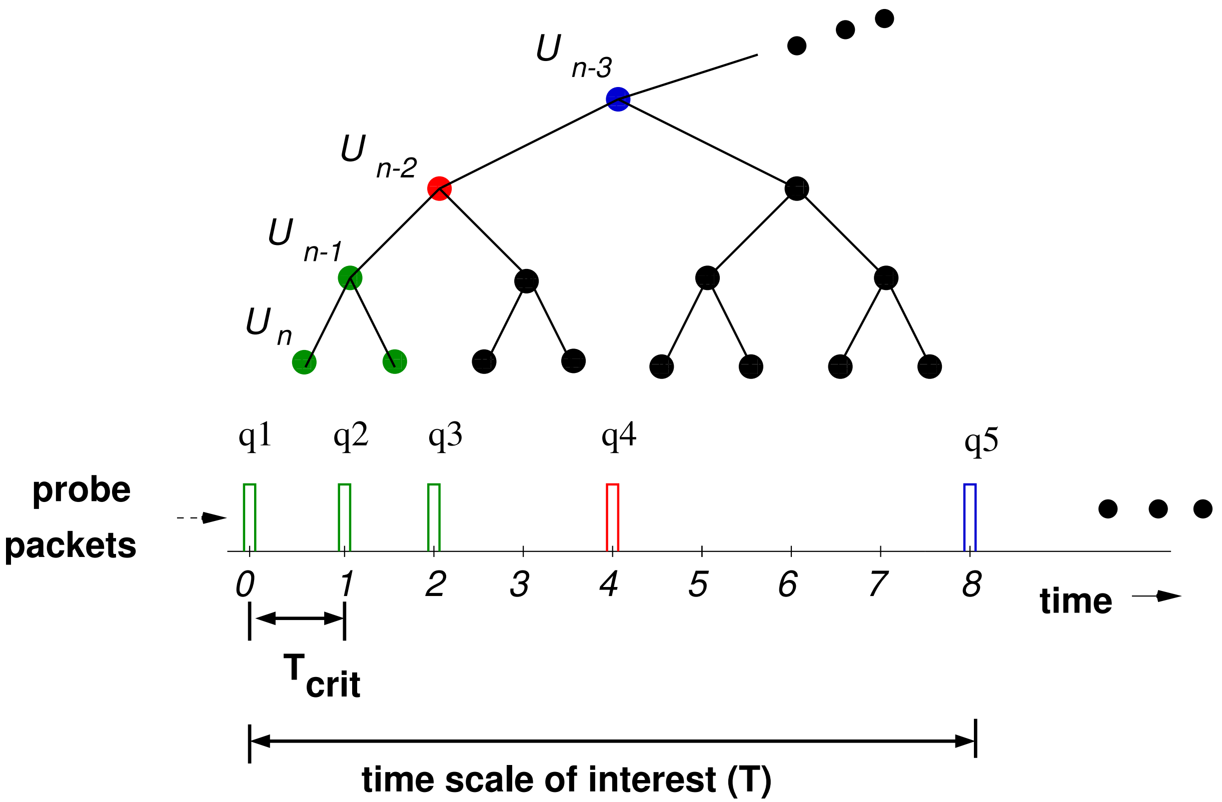
- Accurate analytical queuing formula for MWM

MWM Cross-Traffic Model



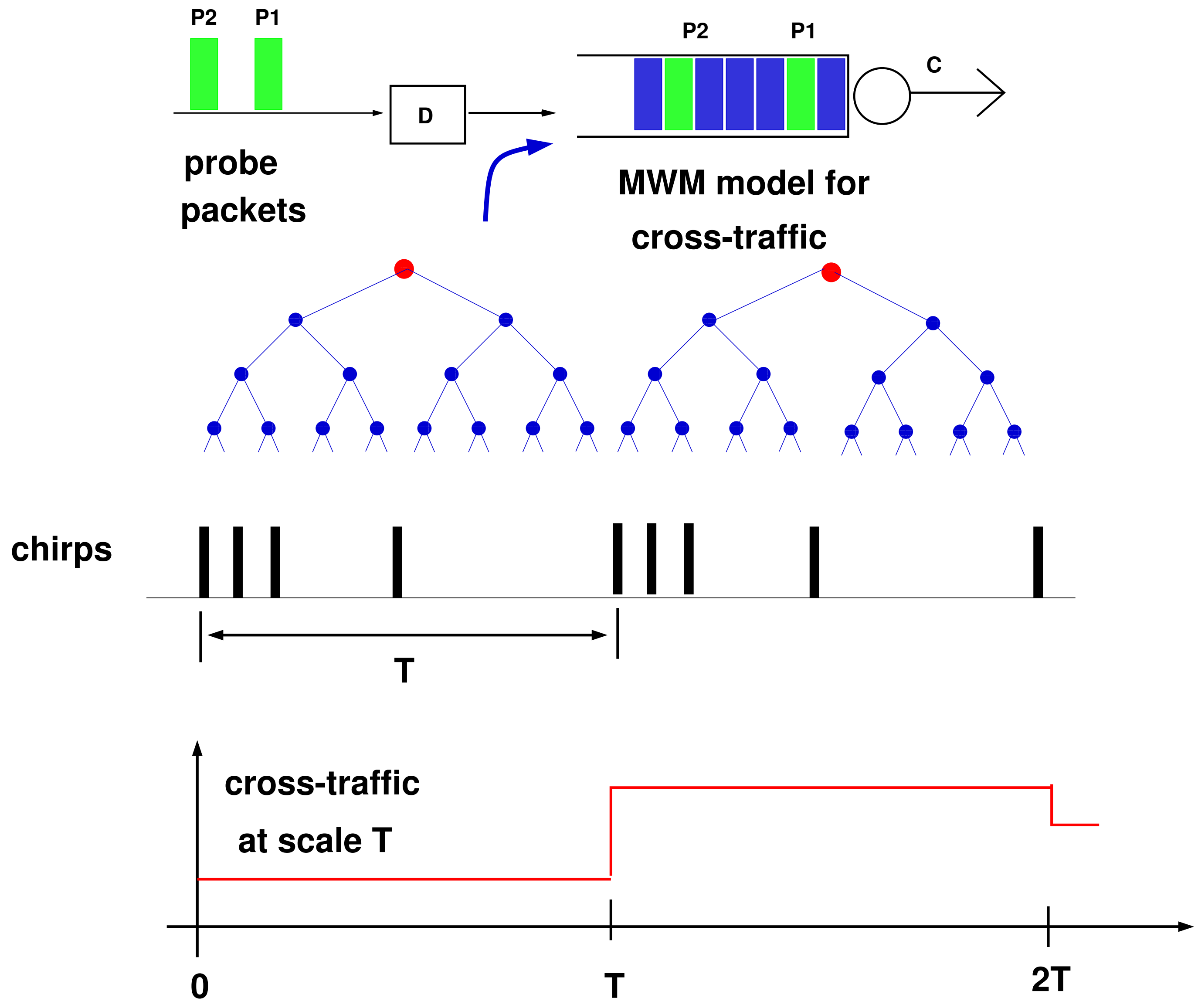
- **Goal:** probe path to estimate cross-traffic volume

Efficient Probing: Chirps of Packets



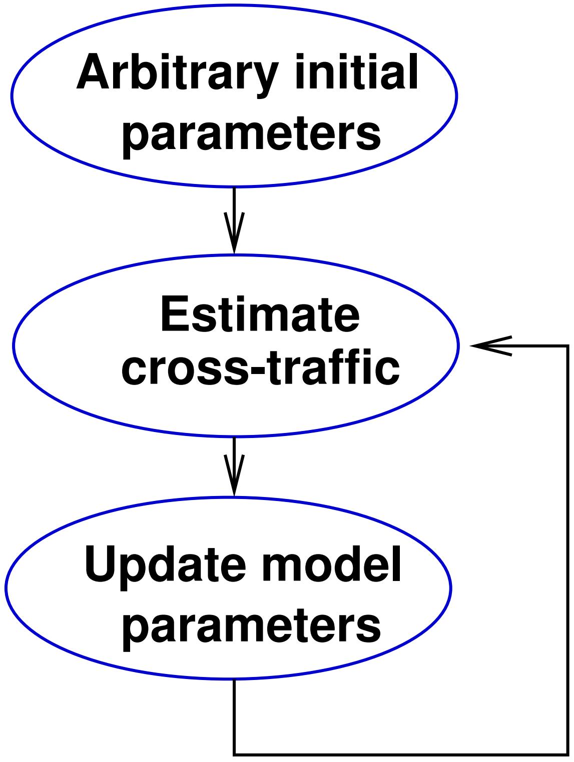
- balance accuracy vs. impact on cross-traffic
- estimator: $\widehat{u}_{n-2} = \arg\max_{u_{n-2}} P(\widehat{u}_{n-1}, q_4 | u_{n-2})$
- recursive fine-to-coarse scale estimation

Cross-Traffic Estimation

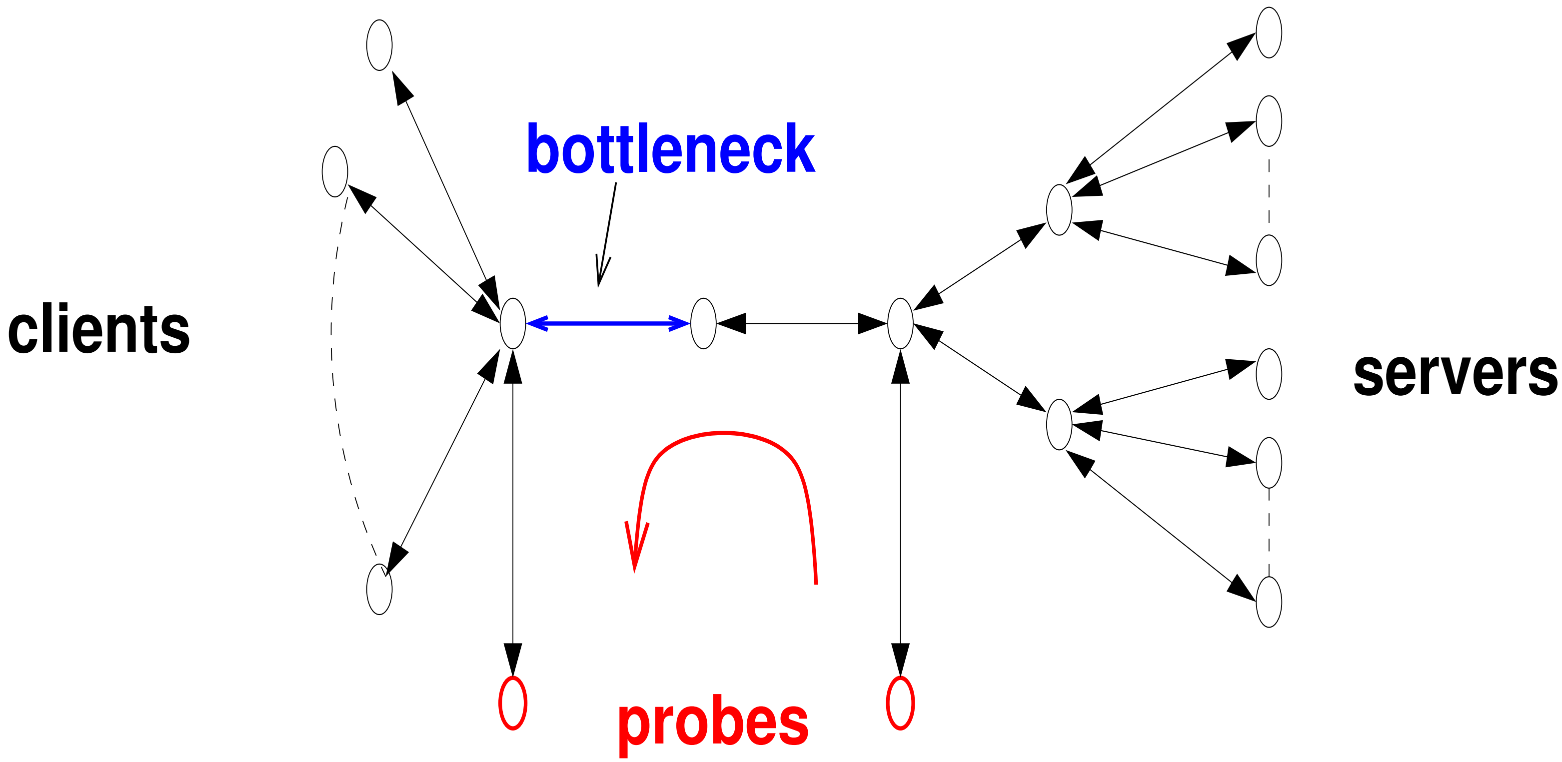


Vinay Ribeiro Rice University

Adaptive Algorithm for MWM Parameters



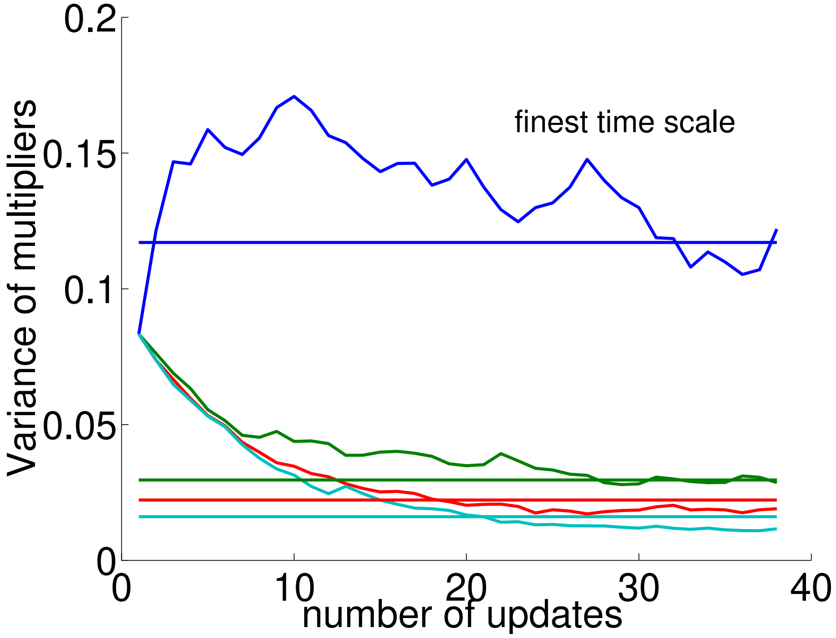
ns-2 Experiments



- web traffic simulation
- heavy-tailed connections $\Rightarrow$ LRD cross-traffic

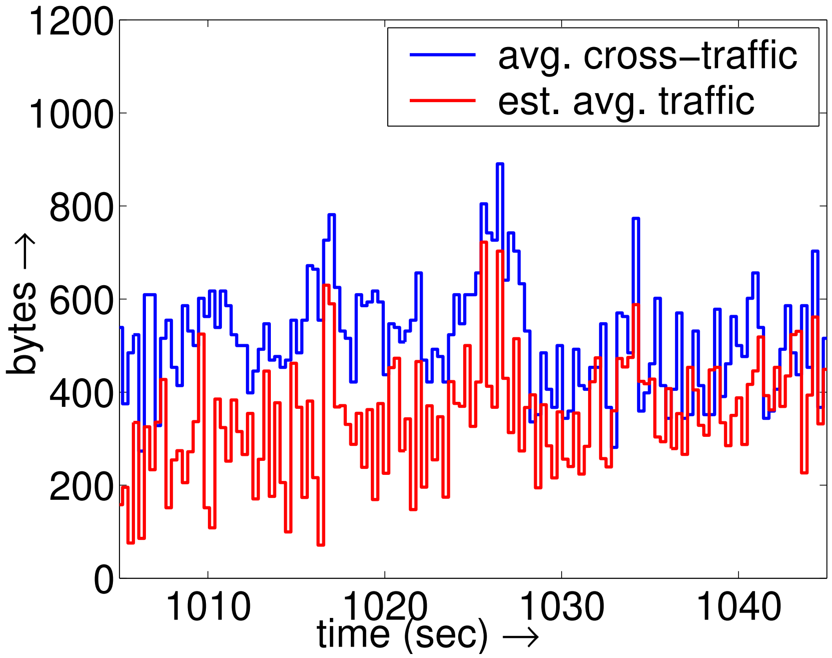
Adaptive Algorithm (ns-2 experiments)

MWM model parameters



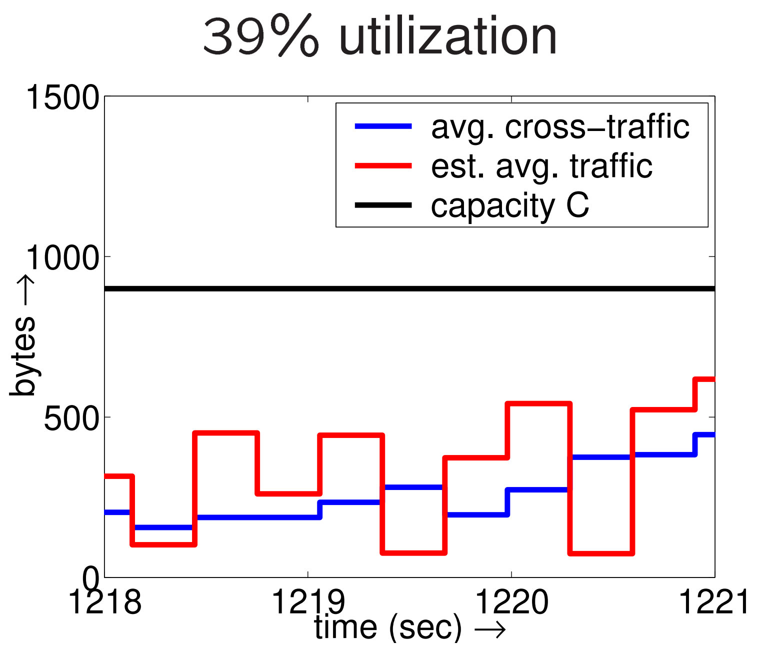
adapt with time

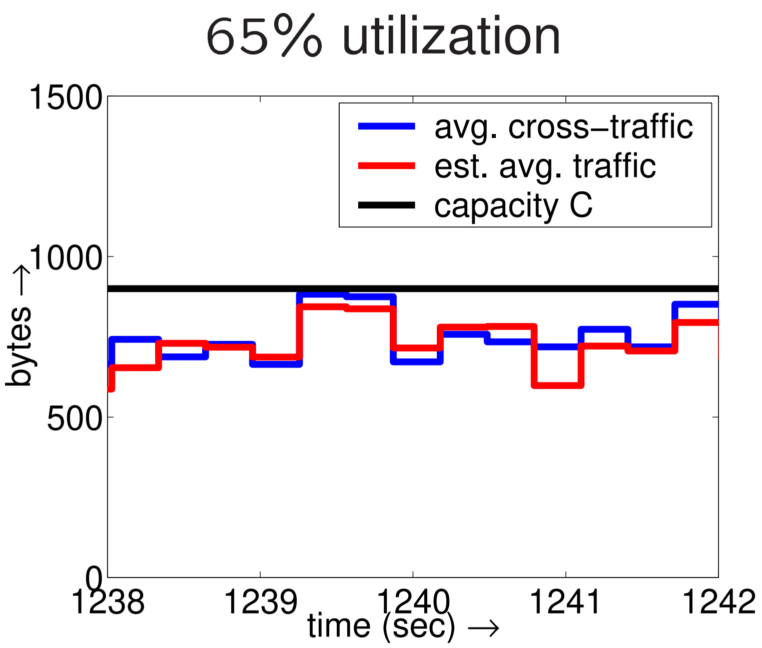
Cross-traffic estimates



improve with accuracy of parameters

Varying Utilization

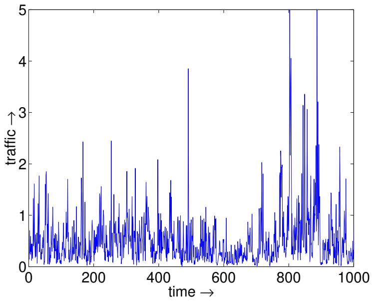




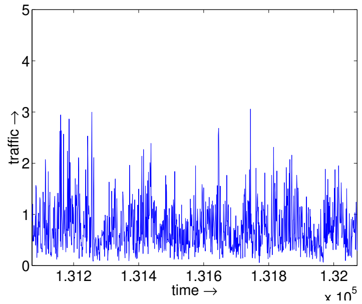
- estimates improve with increasing utilization

Tracking Non-stationarity (MWM Cross-Traffic)

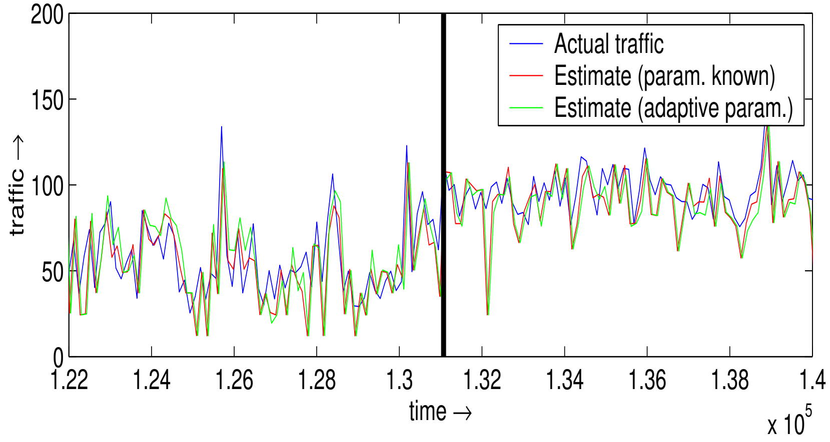
Xtraffic earlier



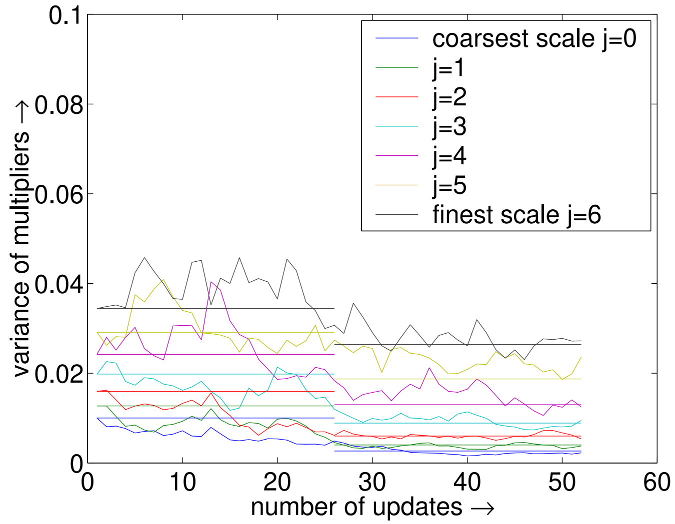
Xtraffic later



Inferred Xtraffic



Parameter estimates



Algorithm adapts to changing network conditions

Conclusions

- probing based cross-traffic estimation algorithm
  - novel probe chirps: balances accuracy vs. impact on the network
  - model based: MWM accounts for LRD, burstiness
  - adaptive
    - ⋆ requires no prior traffic statistics
    - ⋆ tracks changing traffic conditions
  - primarily sender based
- estimates improve with increasing utilization

Future Work

- understand convergence of adaptive algorithm
- real network deployment
- extend to passive probing

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