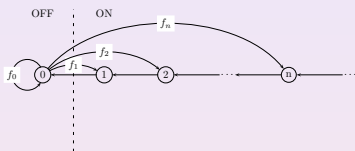


# Markov modelling for queues of Internet traffic

UK Performance Engineering Workshop (2007)



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— UK Performance Engineering Workshop, 2007  
(Prepared using L<sup>A</sup>T<sub>E</sub>X and beamer.)

# Talk Overview

## Motivation

- Mathematically appealing Markov models of internet data in literature.
- Models capture Long-range dependence of real data (plus other parameters).
- Would like a simple queuing model to do maths with.
- How useful are these models in practice?

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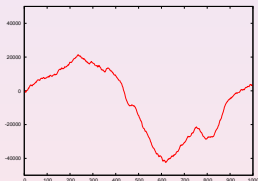
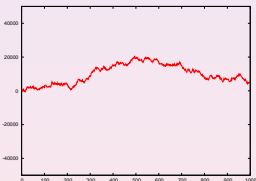
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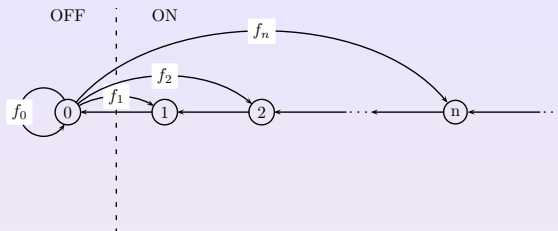
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  - 4 Compare with freely available real internet data sets.

# Irresponsibly hasty guide to Long-Range Dependence

- LRD (also known as long memory) occurs when a data has significant correlations over a number of time scales.
- Imagine that data at a particular time  $t$  having some significant effect on the data at time  $t + k$  even if  $k$  becomes very large.
- This data might, therefore, have large peaks (or troughs) which cause queuing problems.
- Measured in packets/unit time on internet data [Leland et al '93]. Can cause problems with queuing/delay [Erramilli etc al 96].



# The Markov Model

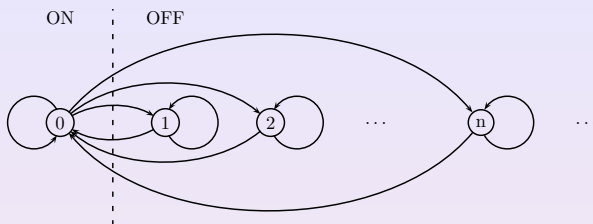


- This is topology of Wang and Clegg/Dodson models.
- If  $\{X_t : t \in \mathbb{N}\}$  is generated by chain then generate

$$Y_t = \begin{cases} 0 & X_t = 0 \\ 1 & \text{otherwise.} \end{cases}$$

- Choose  $f_i$  so return times have heavy-tails and get binary series with LRD [Heath et al 1998].
- Both models set mean and  $H$  parameter.
- Exact solution to discrete queuing model exists.

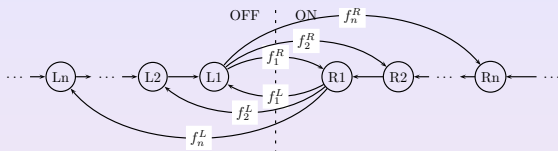
# Pseudo-Self-Similar Traffic Model (PSST)



- Introduced in [Robert et al '97] no proof of LRD.
- Parameters:  $q$  relates to mean  $a$  has no obvious interpretation.

$$\mathbf{P} = \begin{bmatrix} \Sigma_0 & \frac{1}{a} & \frac{1}{a^2} & \cdots \\ \frac{q}{a} & \Sigma_1 & 0 & \cdots \\ \left(\frac{q}{a}\right)^2 & 0 & \Sigma_2 & \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix}.$$

# Arrowsmith/Barenco Model



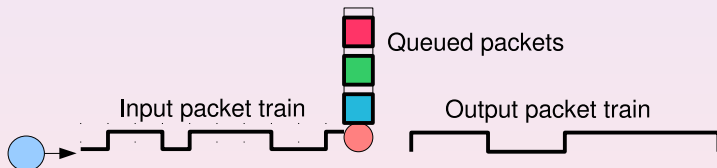
- General class of models described in [Barenco & Arrowsmith '04] proof of strong result giving LRD.
- Think of as double-sided version of Wang topology.
- Could set model to use LRD with Wang or Clegg/Dodson probabilities but theoretical issues cause problem with mean and stability.
- Instead use on/off length distributions for real data.
- Results here **not** be a criticism of this family of models.

# Models Used

- Simple and tractable packet generation models.
- Models are “clocked” and “binary”. Fixed width packets generated at times  $n\Delta t : n \in \mathbb{N}$ .
- Generating Models (listed in chronological order):
  - ① Poisson process (strictly speaking Bernoulli process) (mean only).
  - ② Fractional Brownian Motion model (mean and Hurst parameter).
  - ③ Wang model [Wang '89] — Markov Modulated process (mean and  $H$ ).
  - ④ Pseudo Self-Similar Traffic (PSST) [Robert et al '97] — MMP (mean and ?).
  - ⑤ Arrowsmith/Barenco [Barenco & Arrowsmith '04] — MMP (mean and on/off dist).
  - ⑥ Clegg/Dodson [Clegg & Dodson '05] — MMP (mean and  $H$ ).
  - ⑦ UH model (Bernoulli–Zeta) [Conversation in pub '07] — MMP (mean and  $H$ ).

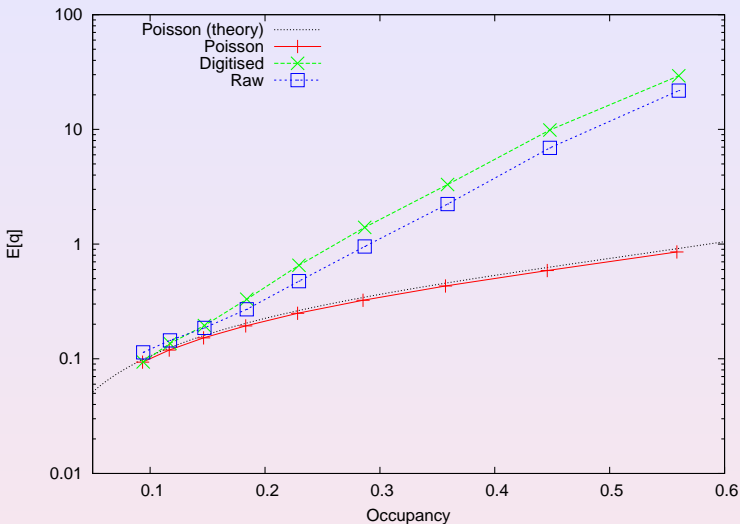
# Queuing Model

- Assume a single FIFO server with an infinite buffer and output bandwidth  $b$ .
- Takes time  $l/b$  to process a packet of length  $l$ .
- If  $l$  is constant then this is a G/D/1 type queue.
- Measure  $E[q]$  the expected queue length (in packets or in bits) as function of  $b$ .
- Input to the queue maybe from “real” traffic traces or from models.

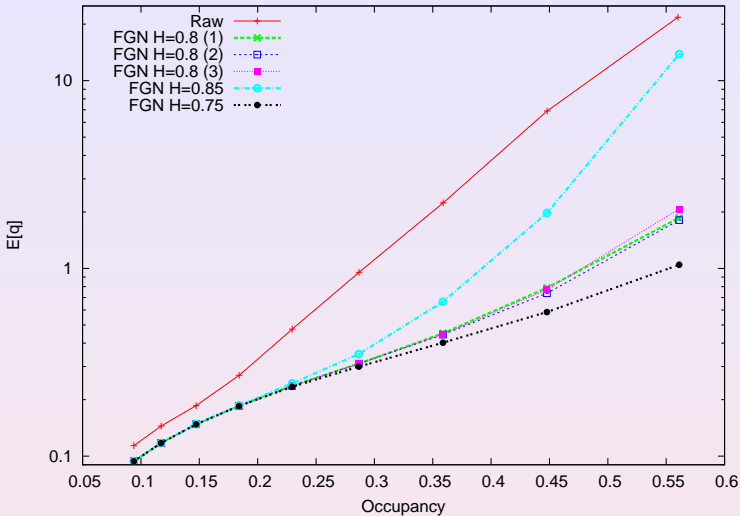


# Real Traffic Traces

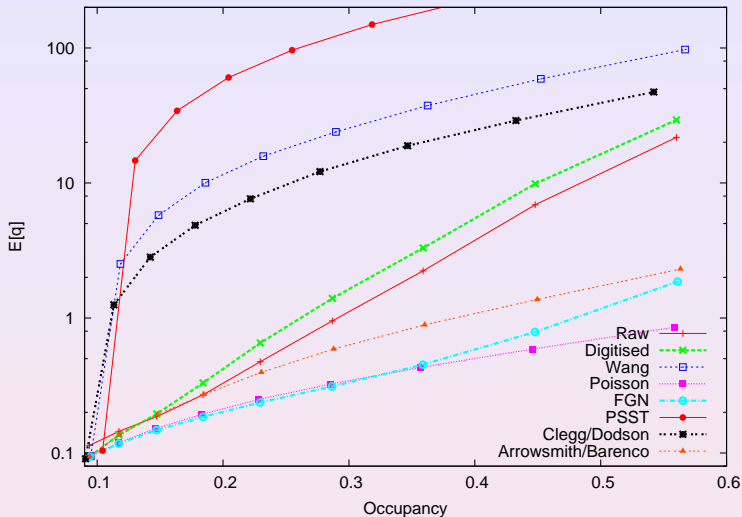
- 100,000 packets from real life traffic sources which give times and packet lengths.
- Establish base case — use arrivals times and lengths as input to queue. Pick  $b$  to get approx 10% occupancy.
- Get “digitised” version of real data by only allowing output of fixed  $l$  bit packets at times  $n\Delta t$ .
- CAIDA OC48 data, two sets ( $H = 0.6$ ) ( $H = 0.65$ ) from spring 2003. High speed link (2.45 Gb/s). Available from CAIDA website.
- Bellcore data ( $H = 0.8$ ) ( $H = 0.9?$ ) much beloved historic data from autumn 1989. Available from Internet Traffic Archive.



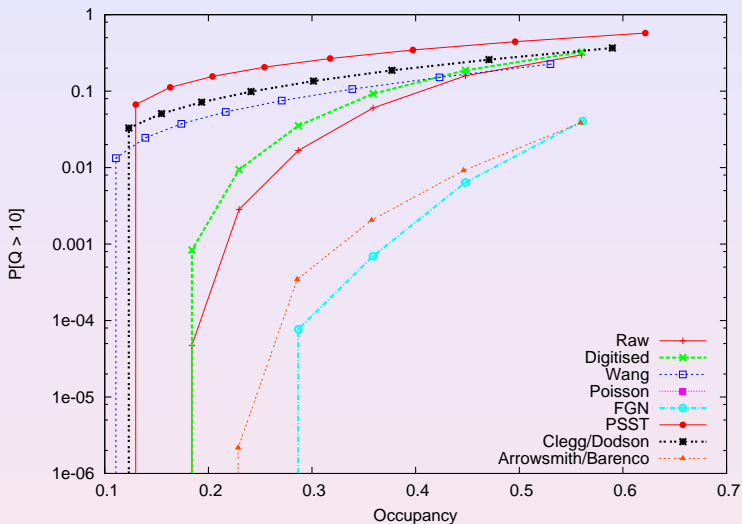
Poisson vs Bellcore (theory line is from P-K theorem).



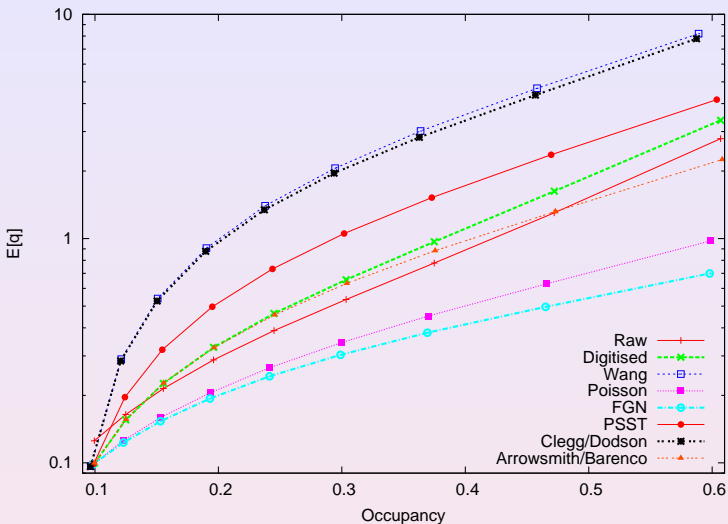
Bellcore vs FGN (several realisations with  $H = 0.8$  and one each of  $H = 0.75$  and  $H = 0.85$ ).



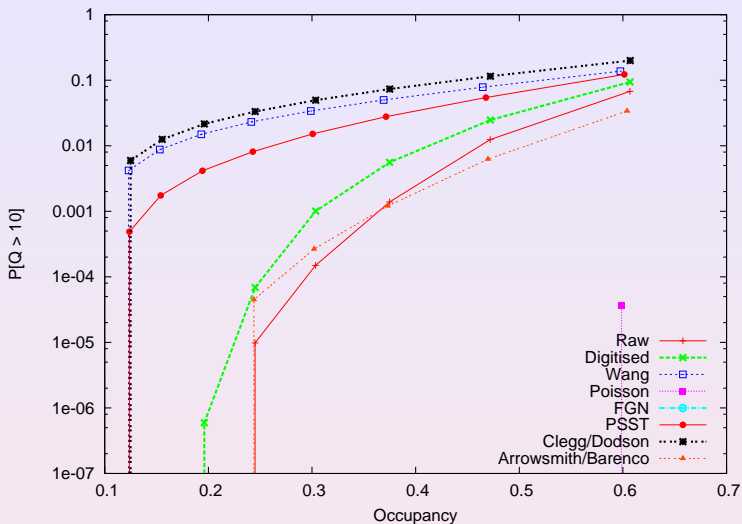
Bellcore – All models compared with real data.



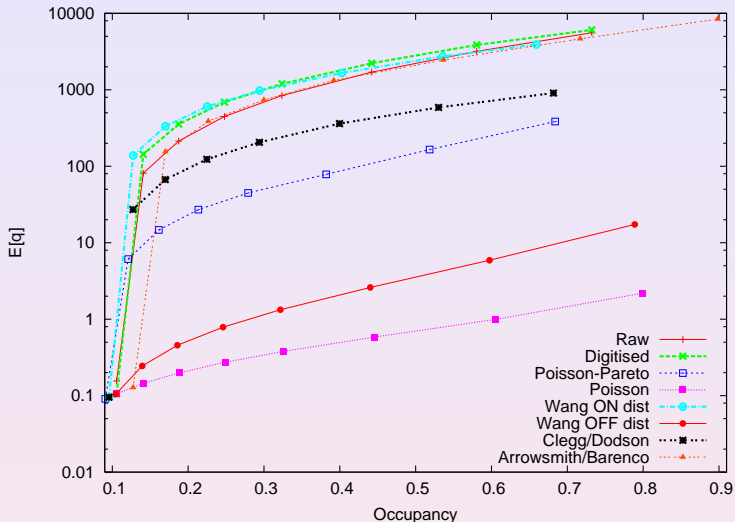
Bellcore –  $\mathbb{P}[Q > 10]$ .



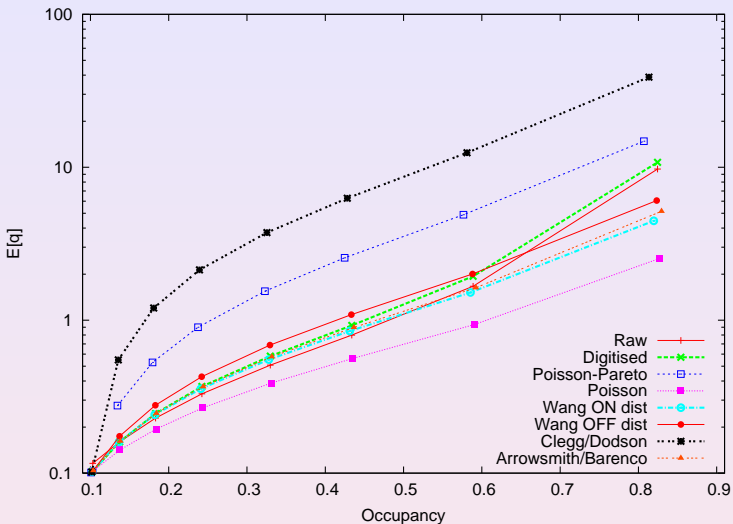
CAIDA – All models compared with real data.



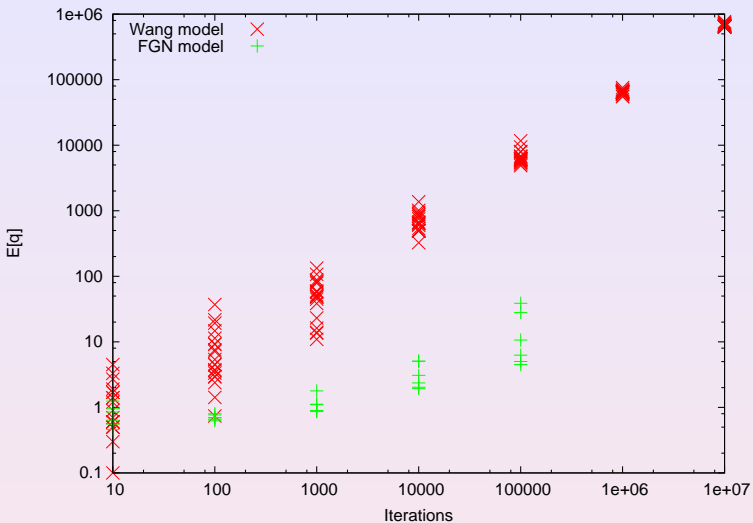
CAIDA –  $\mathbb{P}[Q > 10]$ .



Bellcore trace 2 – Selected models compared with real data.



CAIDA trace 2 – Selected models compared with real data.



The effect of increasing the number of iterations on  $E[q]$  in two LRD models.

# Conclusions (general conclusions)

- No models were always close to matching queuing behaviour.
- Getting a simple model to match queuing performance is **very** difficult.
- The “digitisation” in these models is not the reason for the difference.
- Real traffic is variable in ways which simple models cannot be.
- Modelling the distribution of on and off periods is not sufficient in the high Hurst case but may be for low Hurst.
- Models which took the distribution of ON burst lengths were sometimes “good enough”.
- I need more data and fewer parameters (good models have many parms).

# Conclusions (LRD modelling)

- LRD is a nuisance to work with (poor convergence of mean, hard to measure  $H$ ) is it fundamental anyway?
- All LRD models matched mean (sort of) and Hurst once aggregated (except PSST) but got different wrong answers.
- The PSST model is very peculiar. (Non-Hurst LRD?)
- Hurst parameter can be “naughty” or “nice” [Neidhardt '98].
- Different models which give the same mean and  $H$  give very different queuing performance.
- With an infinite buffer these models are predicting infinite queue and delay.
- **The very idea of LRD modelling may be fundamentally broken.**

# Where to now?

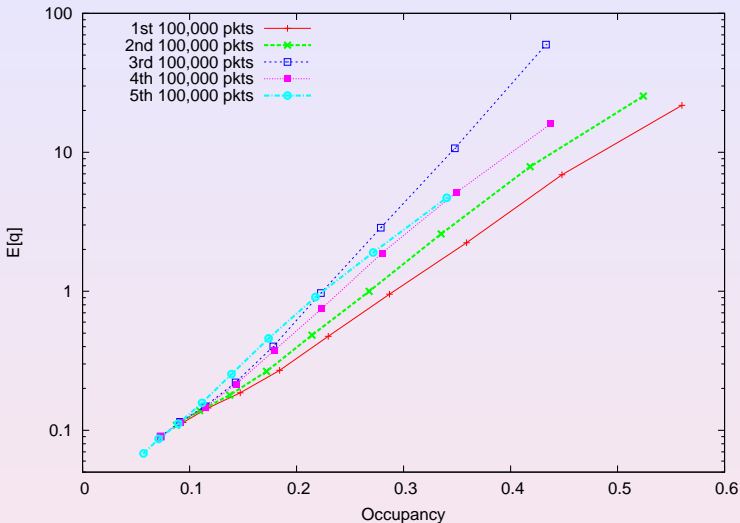
- Multi-parameter models? (Multi-fractal wavelet model? Variants of Arrowsmith/Barenco model? Capture ACF?)
  - Pro: Captures more parameters of traffic.
  - Pro: Mathematics is interesting.
  - Anti: Mathematics is much more difficult (accuracy versus understanding).
- Closed loop models?
  - Pro: Captures importance of TCP feedback mechanism.
  - Anti: Likely to be mathematically intractable.
  - Anti: Does complex simulation gain us understanding?
- What am I missing? (User behaviour? Network behaviour? Misunderstanding theory?)
- Definitely **more research required**.

# References

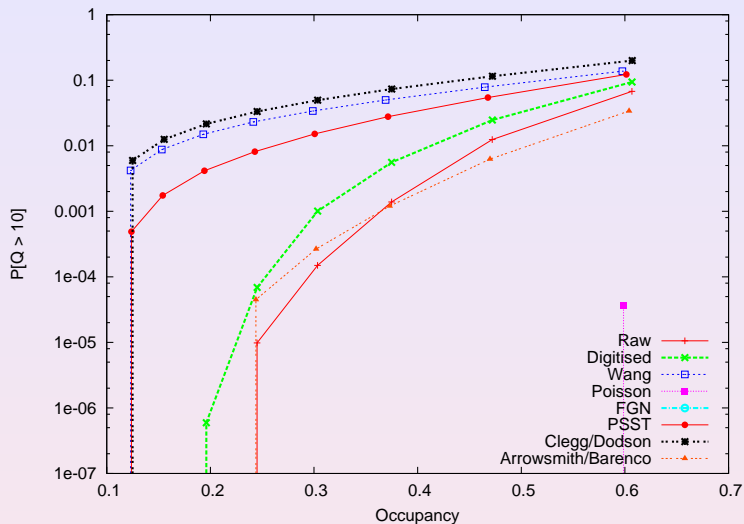
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This talk, the author's papers referred to above and the software used are all available online at:

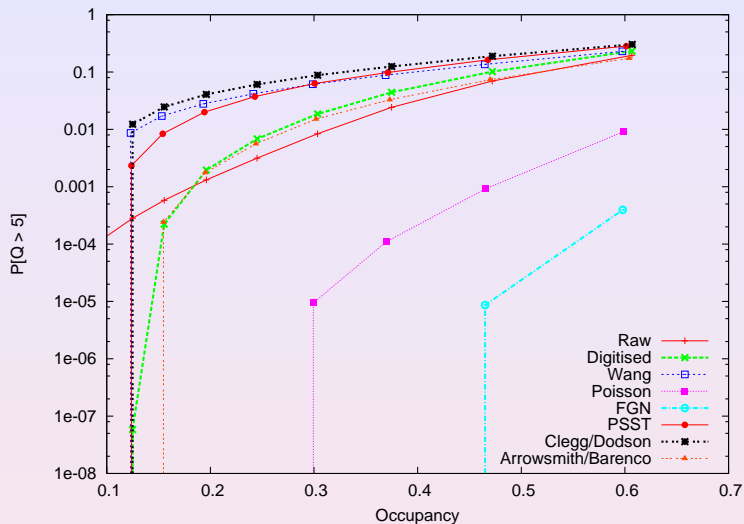
[www.richardclegg.org/](http://www.richardclegg.org/).



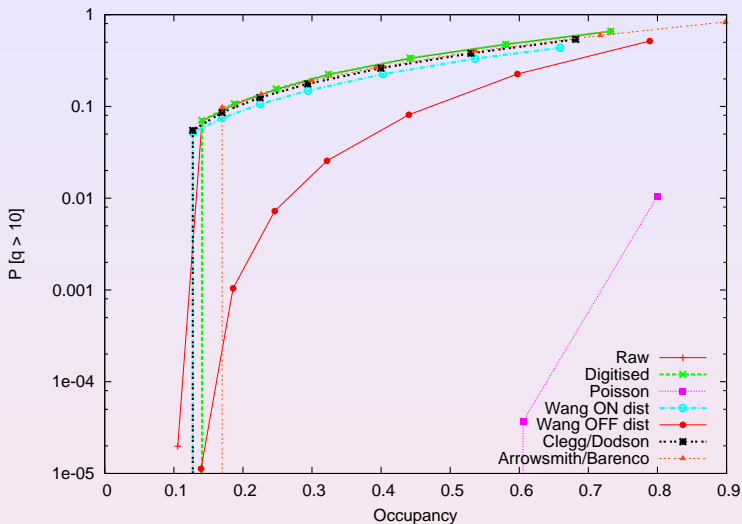
Bellcore – next four blocks of 100,000 packets.



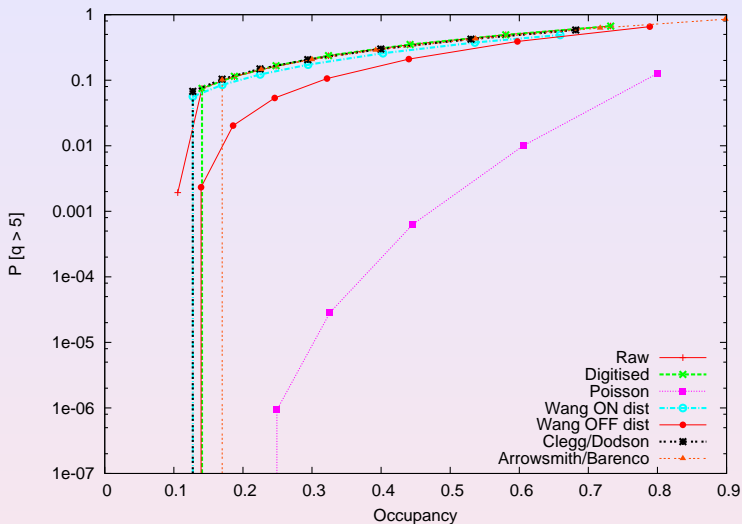
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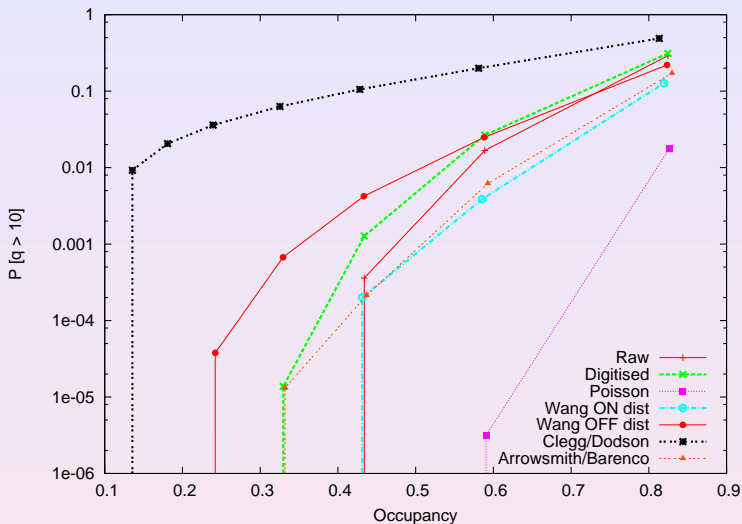
CAIDA -  $\mathbb{P}[Q > 5]$ .

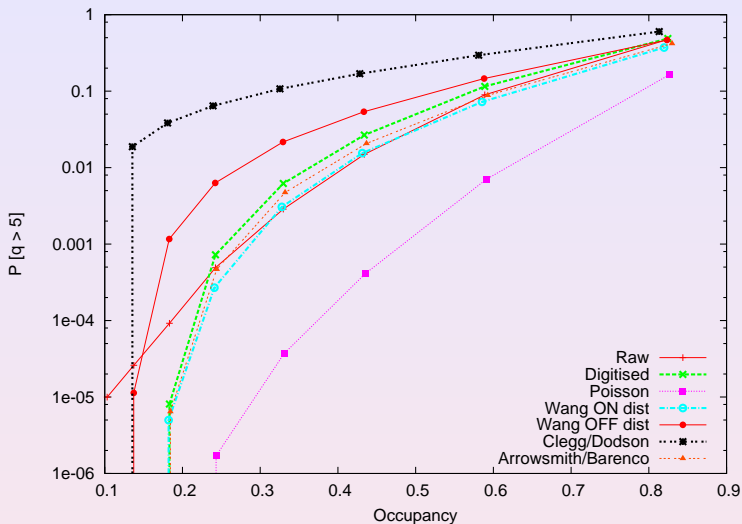


Bellcore 2 -  $\mathbb{P}[Q > 10]$ .



Bellcore 2 -  $\mathbb{P}[Q > 5]$ .





CAIDA 2 -  $\mathbb{P}[Q > 5]$ .