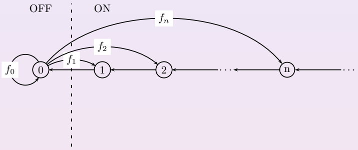
Markov modelling for queues of Internet traffic

Sixth Mathematics of Networks meeting



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(Prepared using LaTeX 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 "cheap and easy" queuing model to do maths with.

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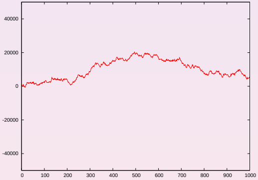
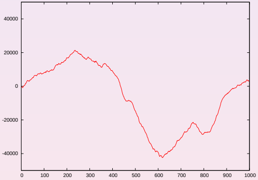
4. Compare with freely available real internet data sets.

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 signficant effect on the data at time $t + k$ even if k becomes very large.
- Sometimes when the data starts to go "up" (or down) it can continue to go "up" (or down) for a long time.
- This data might, therefore, have large peaks (or troughs) which cause queuing problems.





Long-Range Dependence

Definition of Long-Range Dependence

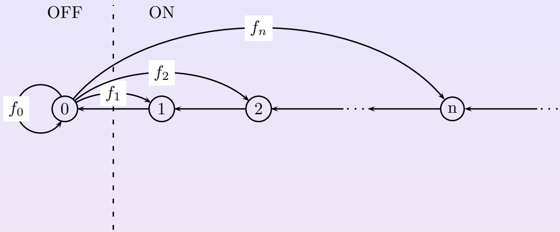
A weakly-stationary time series is said to be *long-range dependent* (LRD) if the sum $\sum_{k=-\infty}^{\infty} |\rho(k)|$ diverges where $\rho(k)$ is the autocorrelation function. Often a specific form is assumed

$$\rho(k) \sim Ck^{-\alpha},$$

where $\sim$ means asym. equal as $k \to \infty$, $C > 0$ and $\alpha \in (0, 1)$ are const. Hurst parameter $H = 1 - \alpha/2 \in (1/2, 1)$ is common measure of LRD.

- In 1993 LRD (and self-similarity) was found in bytes/unit time on LAN [Leland et al '93].
- The Hurst parameter is "a dominant characteristic for a number of packet traffic engineering problems" [Erramilli '96].
- Measuring H in real data is a real pain [Clegg '06].

The Markov Model

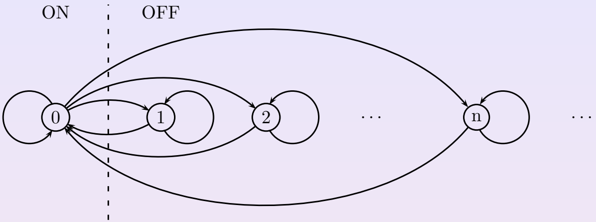


- This is topology of Wang and Clegg/Dodson models.
- If $\{X_t : t \in \mathbb{N}\}$ is generated by chain then generate

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

- The f_i are trans. prob. and the π_i equilibrium densities.
- Want simple values of f_i to work with.
- Choose f_i so return times have heavy-tails and get binary series with LRD [Heath et al 1998].

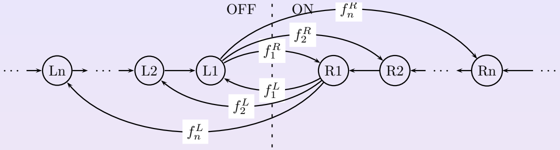
Pseudo-Self-Similar Traffic Model (PSST)



- 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



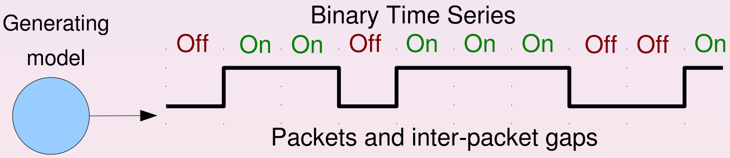
- General class of models described in [Barenco & Arrowsmith '04] proof of strong result giving LRD.
- Think of as double-sided version of Wang topology.
- Can set heavyness of tail for ON and OFF periods.
- Could use Wang or Clegg/Dodson probabilities but theoretical issues cause problem with mean of traffic and stability.
- Instead use on/off length distributions for real data.
- This should not be taken as 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.

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 $\mathrm{E}[q]$ 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 two 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 $n\Delta t$.
- All models are two parameter (except Bernouilli) — try to match base μ (and hence var) and H.

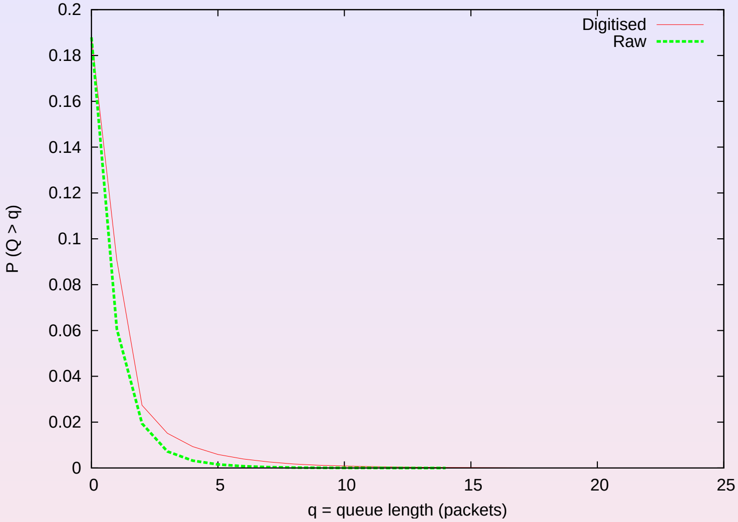
CAIDA OC48 data ($H = 0.6$)

- Data from April 2003.
- High speed link (2.45 Gb/s).
- Available from: `www.caida.org/data/passive`.

Bellcore data ($H = 0.8$)

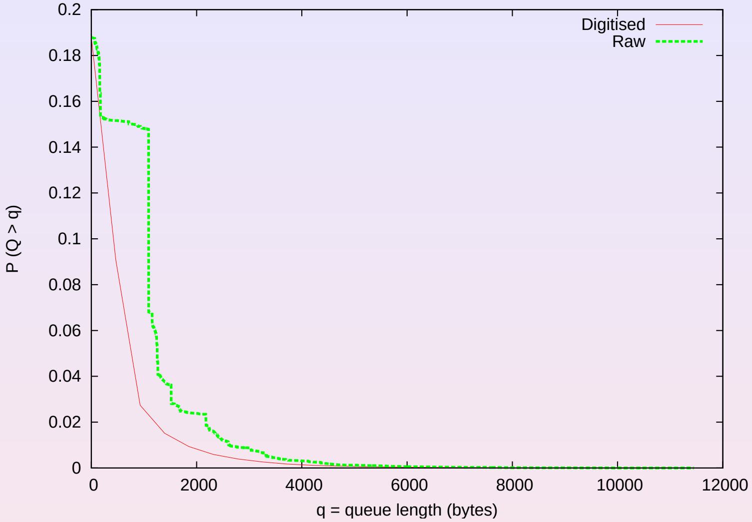
- Much beloved historic data (Aug 1989).
- Available from: `ita.ee.lbl.gov/html/contrib/BC.html`

Bellcore digitisation (by packet)



1 - PDF of queue size in packets before and after digitisation of the Bellcore data (queued at half bw).

Bellcore digitisation (by bits)



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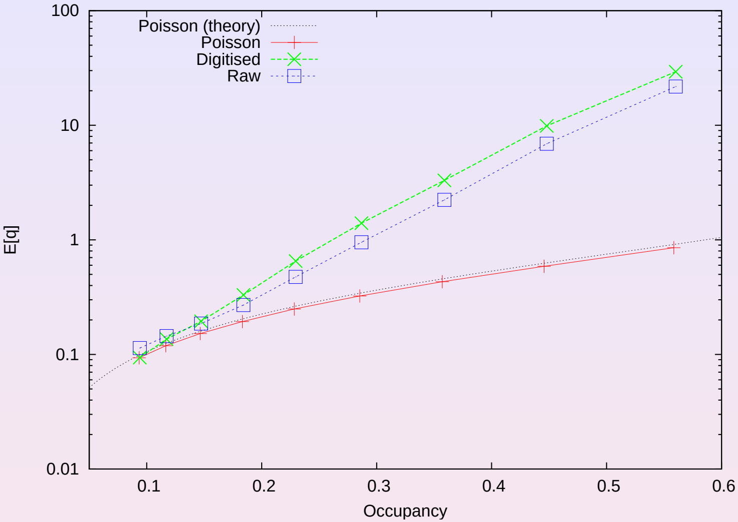
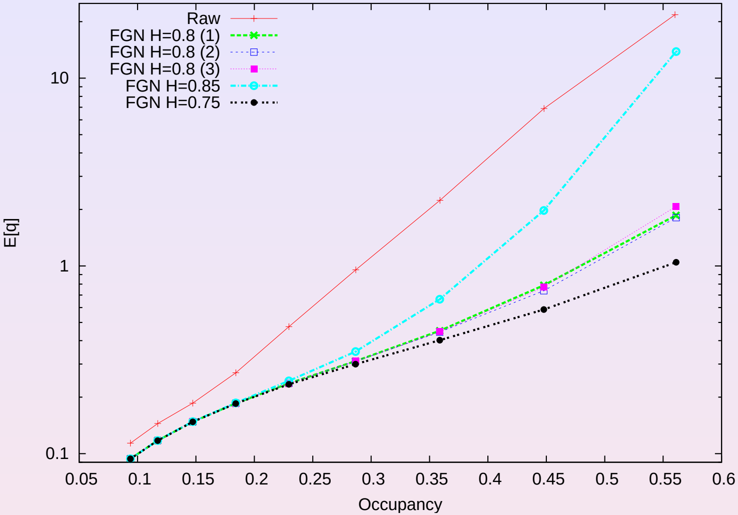
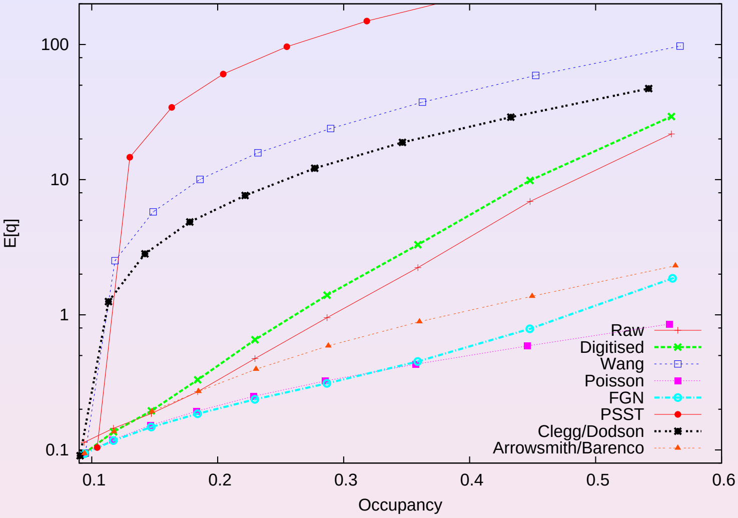


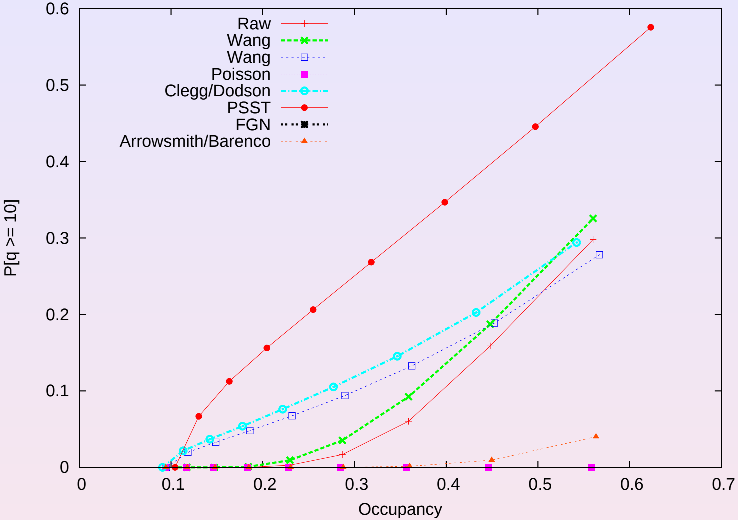
Poisson versus real data (theory line is from P-K theorem).



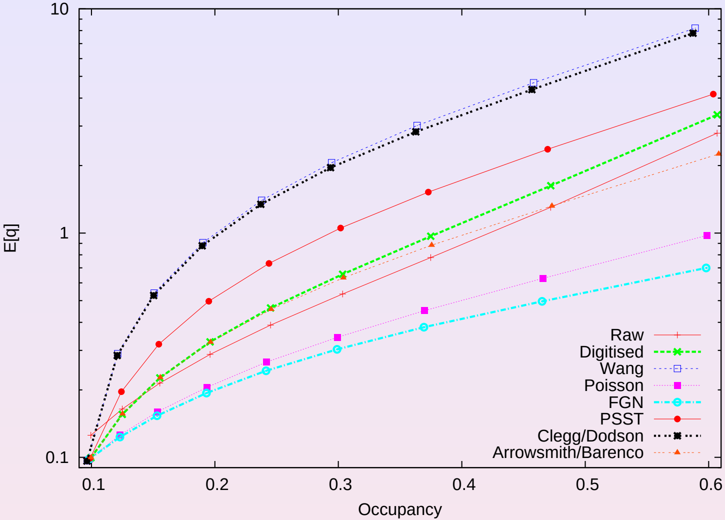
FGN (several realisations with $H = 0.8$ and one each of $H = 0.75$ and $H = 0.85$).



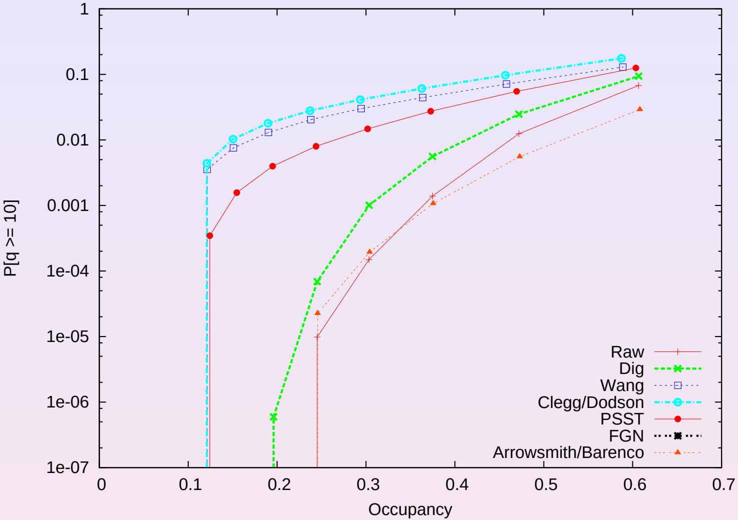
Bellcore – All models compared with real data.



Bellcore – Probability $q > 10$.



CAIDA – All models compared with real data.



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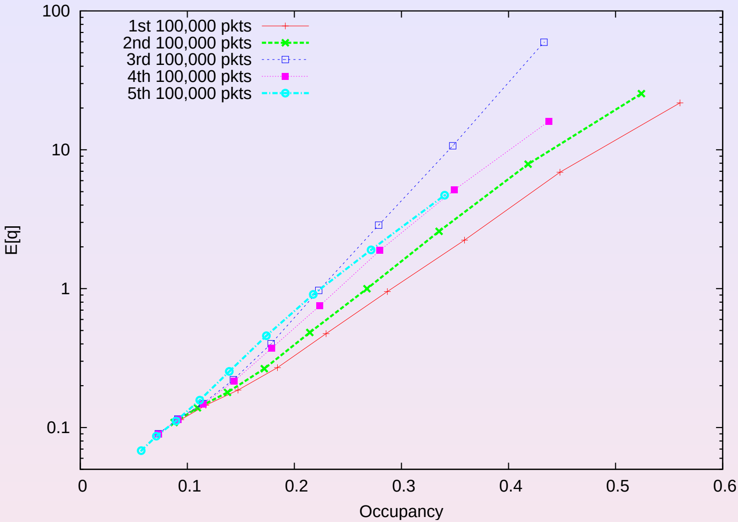
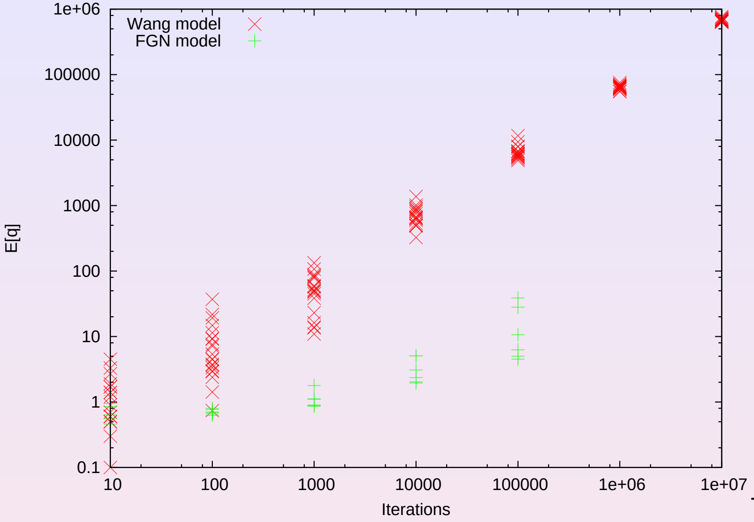


The next four blocks of 100,000 packets on Bellcore (raw data queuing performance).



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

Conclusions (general conclusions)

- No models were very 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.
- I can find no good Markov model of internet traffic in the literature.

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 — I needed to use the reverse of it anyway. (Non-Hurst LRD?)
- Hurst parameter can be "naughty" or "nice" [Neidthardt '98].
- Different models which give the same mean and H give very different queuing performance.
- 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.

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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/`.