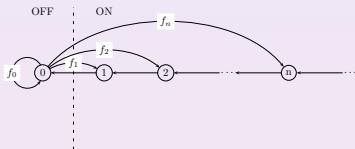


# Markov modelling for queues of Internet traffic

## Multi Service Networks (2007)



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— Multi-service networks, 2007  
(Prepared using L<sup>A</sup>T<sub>E</sub>X and beamer.)

## 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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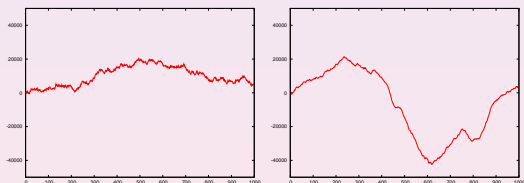
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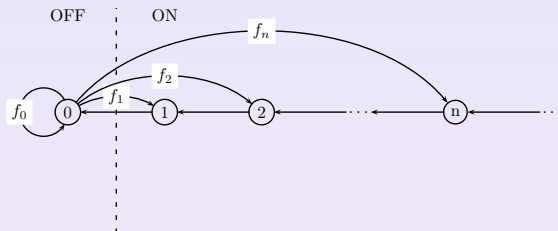
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- 1 Seven simple ways to model internet traffic (usually with MCs).
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  - 3 Compare with freely available real internet data sets.

# 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

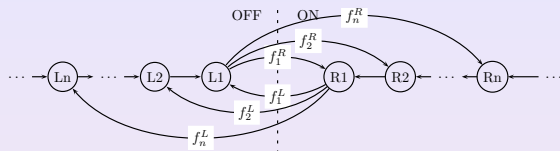


- This is topology of Wang and Clegg/Dodson models.
- If  $\{X_t : t \in \mathbb{N}\}$  is generated by chain then generate

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

- 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.

# Arrowsmith/Barenco Model



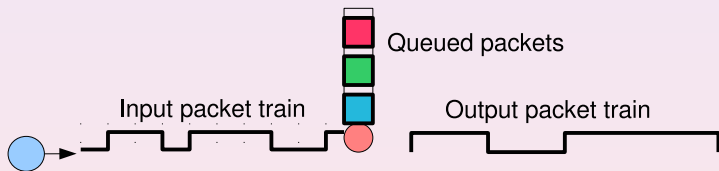
- General class of models described in [Barenco & Arrowsmith '04] proof of strong result giving LRD.
- Think of as double-sided version of Wang topology.
- Could set model to use LRD with Wang or Clegg/Dodson probabilities but theoretical issues cause problem with mean and stability.
- Instead use on/off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

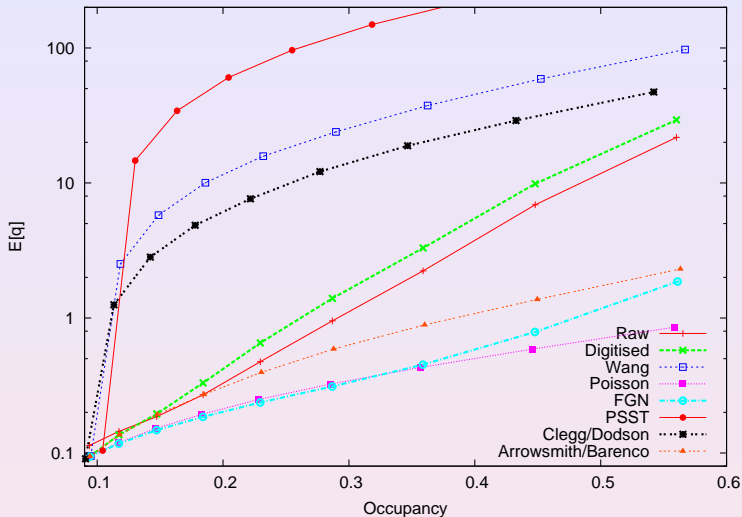
# Models Used

- 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  $H$ ).

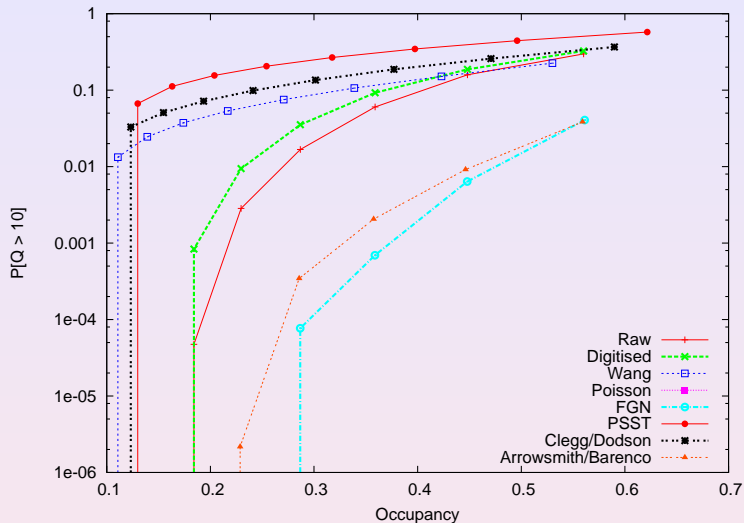
# Queuing Model

- Assume a single FIFO server with an infinite buffer and output bandwidth  $b$ .
- Takes time  $l/b$  to process a packet of length  $l$ .
- 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 is 2 x Bellcore (1989) and 2 x CAIDA (2003) data.

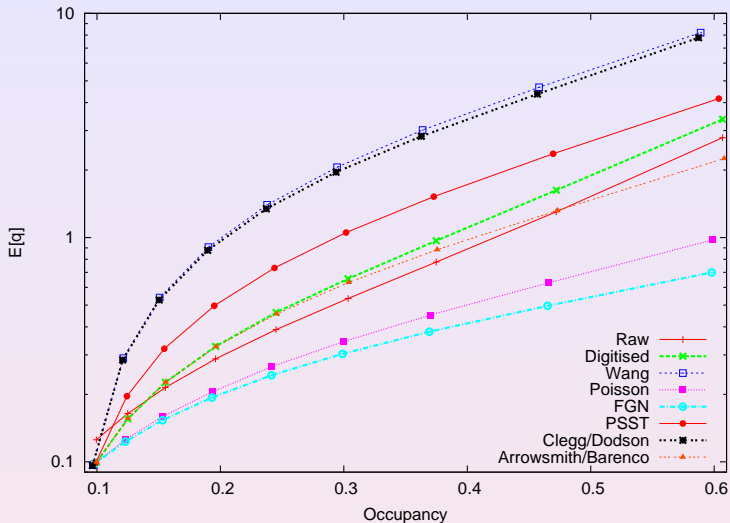




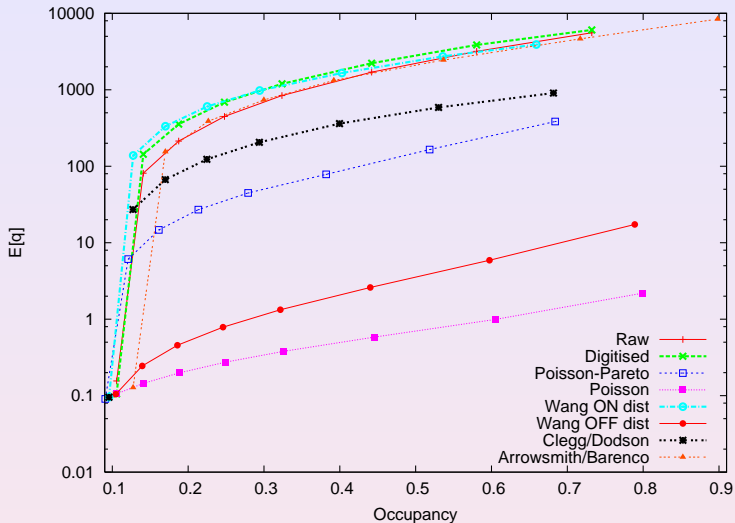
Bellcore – All models compared with real data.



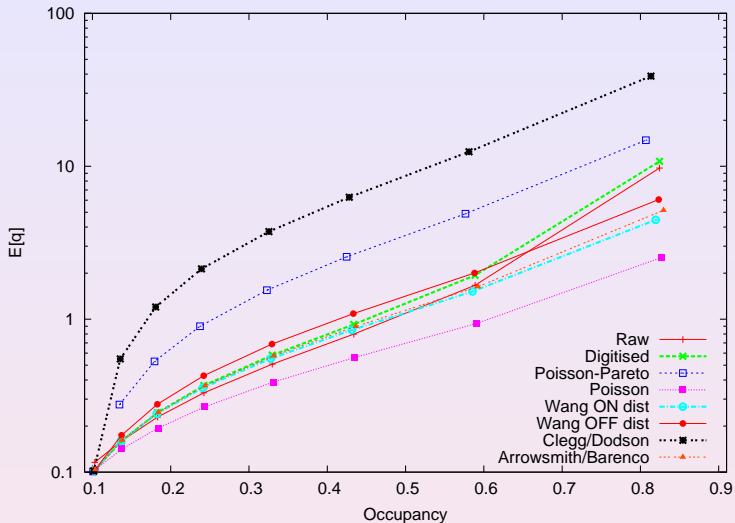
Bellcore –  $\mathbb{P}[Q > 10]$ .



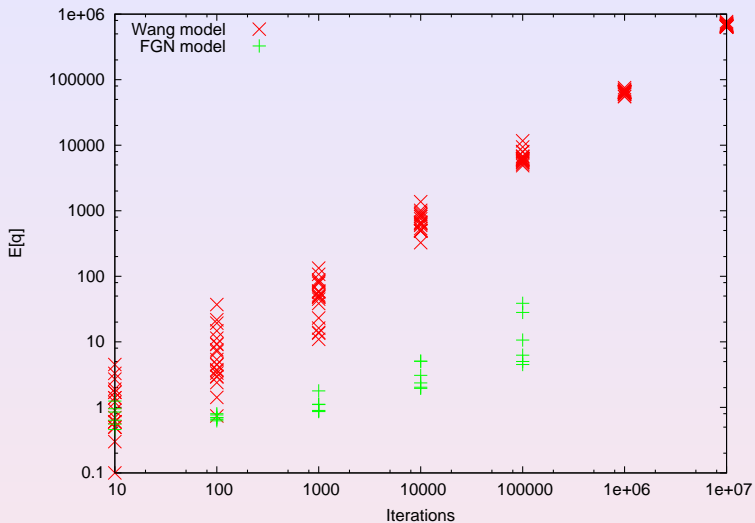
CAIDA – All models compared with real data.



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

- No models were always close to matching queuing behaviour.
- The “digitisation” in these models is not the reason for the difference.
- 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).
- LRD is a nuisance to work with (poor convergence of mean, hard to measure  $H$ ) is it fundamental anyway?
- 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?

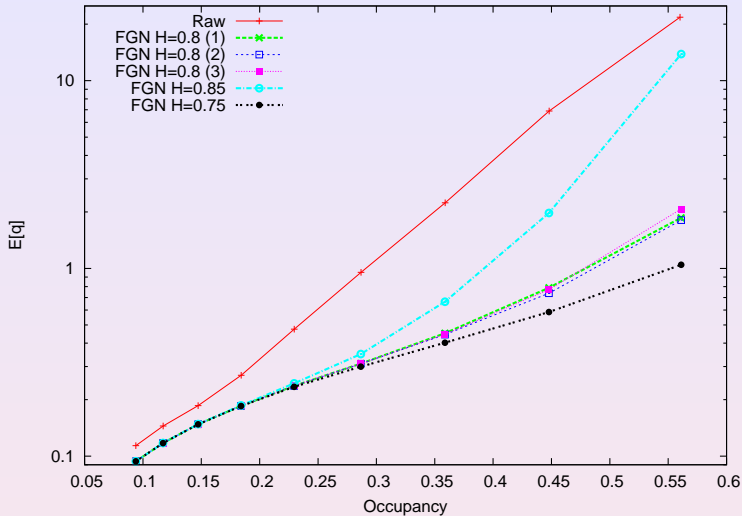
- Multi-parameter models? (Multi-fractal wavelet model? Variants of Arrowsmith/Barenco model? Capture ACF?)
  - Pro: Captures more parameters of traffic.
  - Pro: Mathematics is interesting.
  - Anti: Mathematics is much more difficult (accuracy versus understanding).
- Closed loop models?
  - Pro: Captures 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

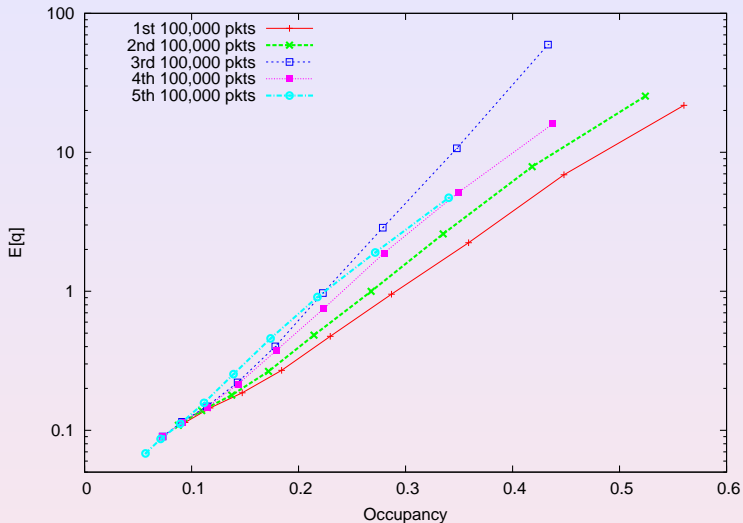
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This talk, the author's papers referred to above and the software used are all available online at:

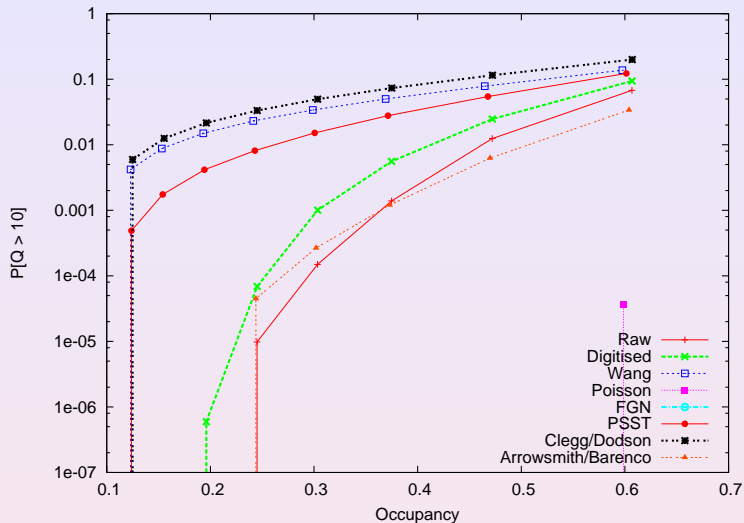
[www.richardclegg.org/](http://www.richardclegg.org/).



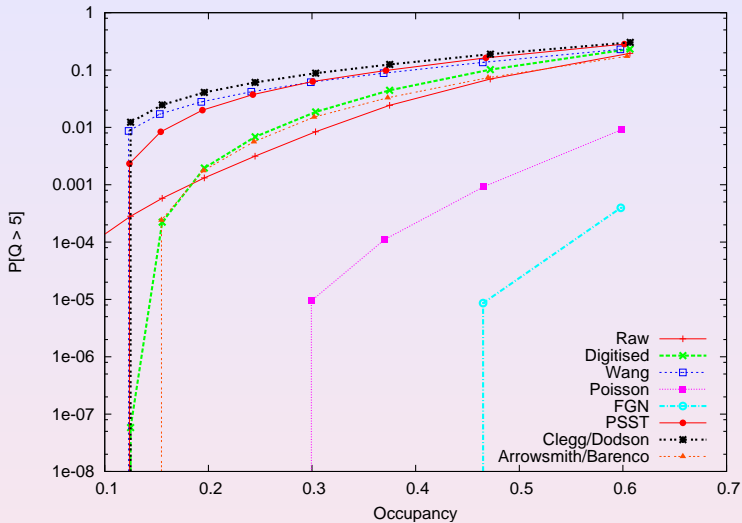
Bellcore vs FGN (several realisations with  $H = 0.8$  and one each of  $H = 0.75$  and  $H = 0.85$ ).



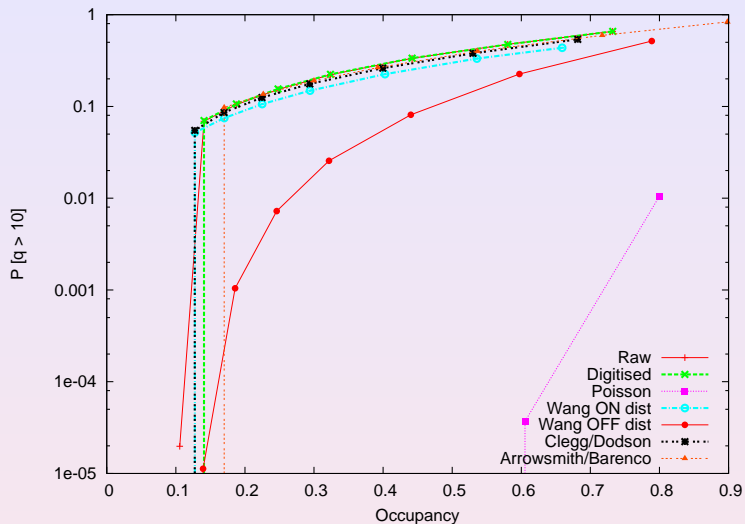
Bellcore – next four blocks of 100,000 packets.



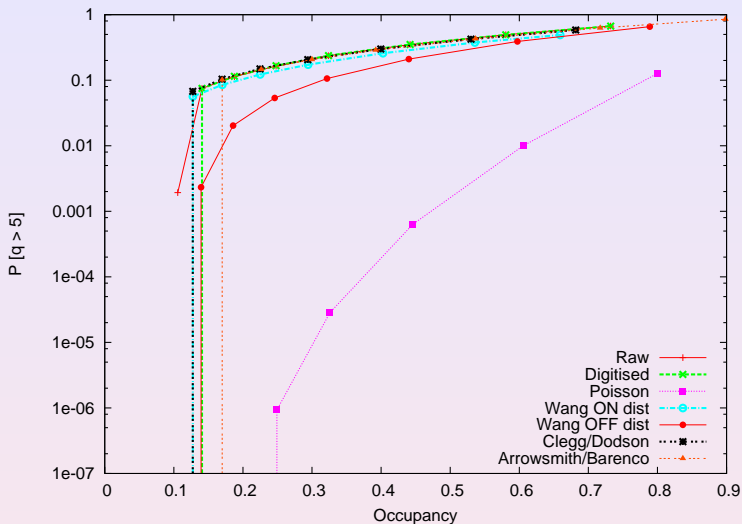
CAIDA –  $\mathbb{P}[Q > 10]$ .



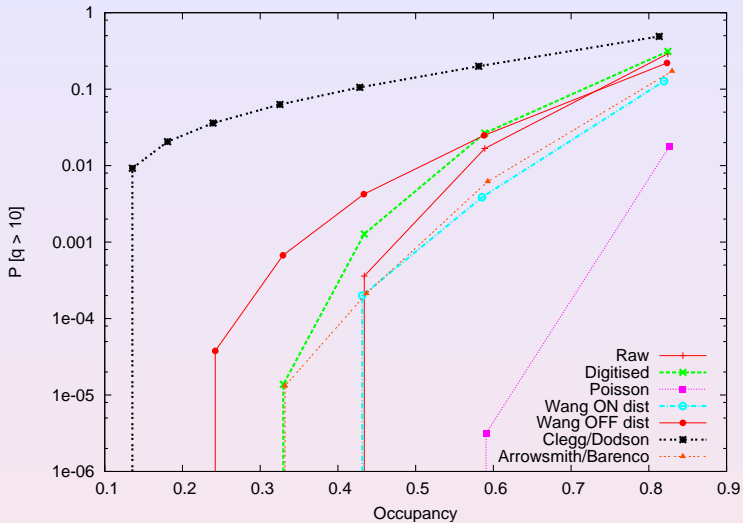
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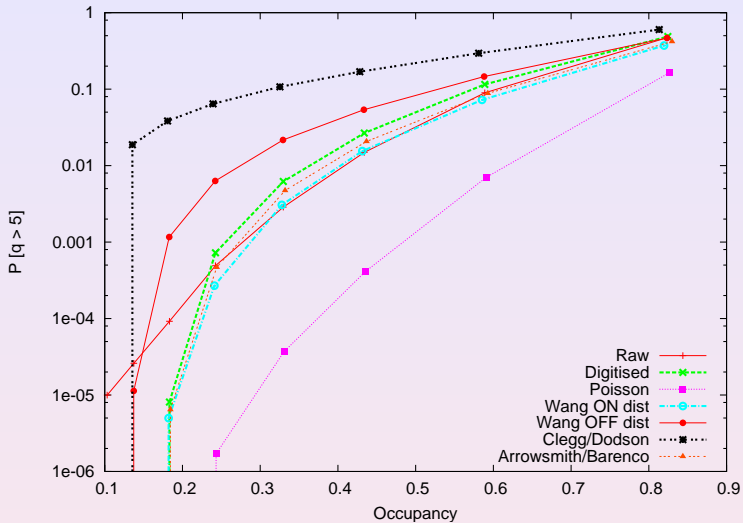
Bellcore 2 -  $\mathbb{P} [Q > 10]$ .



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CAIDA 2 –  $\mathbb{P} [Q > 10]$ .



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