Investigating self-similarity and heavy-tailed distributions on a large-scale experimental facility

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Global objective – Develop a metrology activity on a grid environment for a better understanding of the traffic in order to improve Quality of Service.

TCP-IP protocols were designed for the internet: are they adapted to a grid environment, for distributed computation?

A grid is a great testbed to perform experiments in order to understand the traffic characteristics and their links to the QoS.

→ focus on the LRD parameter: $H$
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Metrology – Relevant parameters

- **Long Range Dependence** has been observed on internet traffic

**Theorem (Taqqu, Willinger, Sherman, 1997)**

*A simple ON/OFF source model with heavy tail distributed periods generates LRD in the aggregated throughputs.*

**Tail index** $\alpha$ and **LRD parameter** $H$ rely according to:

$$H = \frac{3 - \alpha}{2}$$

- What is the influence of LRD on the QoS?
  - force the flow size distribution to impose a given $H$
  - prescribe the LRD index $H$ and measure the QoS

- We need to validate Taqqu’s relation in a real large scale environment
Long Range Dependance: definition

Model — fractional Gaussian noise (fGn – derivative of fractional Brownian motion fBm) with Hurst exponent $0 < H < 1$:

- $H < 1/2$ short range correlation
- $H = 1/2$ white Gaussian noise
- $H > 1/2$ long range correlation
Long Range Dependence: definition

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Long Range Dependance and QoS

- Quality of service – The correlation decrease slowly: big values of the bandwidth increase the probability to observe bigger values ⇒ Congestion
- Impact of the LRD on the QoS observed by Park, Kim and Crovella, 1997
- The study was performed using ns2 simulator
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**Heavy Tails and LRD**

- \( f_i \) : frequency of \( i \)-size flows (\( \propto P(S = i) \))
- **Heavy Tail**: \( f_i \sim \frac{1}{i^{\alpha+1}} \), tail index \( \alpha \)
- \( X_i \) : number of packets in time interval \([i\Delta, (i+1)\Delta]\)
- **LRD**: \( \mathbb{E}X_iX_{(i+\tau)} \sim |\tau|^{2H-2} \)
  LRD param \( H \)
Parameters estimation

$\alpha$: wavelet based method
- never used in the internet community
- efficient and robust estimation, even with small samples
- Possible to predict theoretical bounds of scaling range

$\log \mathbb{E} \Psi(2^j S) \sim \alpha j + \log C$

$H$: wavelet based method
- massively used in the internet community
- efficient estimation
- supplies error bars

$\mathbb{E} |\langle \psi_{j,k}, X \rangle|^2 \sim 2^j (2^H + 1)$
Experimental methodology

- Use a large scale facility: Grid5000
- Generate fully controlled traffic based on the ON/OFF scheme with 100 sources (with limited rate to avoid congestion)
- Impose HT flow size distributions: controlled tail index $\alpha$
- Measure the aggregated traffic at packet-level on a core link
- Estimate the parameters $\hat{H}$ and $\hat{\alpha}$
- Study the validity domain of Taqqu’s relation with respect to some potentially influential parameters:
  - the protocol used (TCP or UDP)
  - the rate limitation mechanism used (TCP, HTB, PSP)
  - the mean flow duration (mean ON period)
  - the OFF period distribution
GtrcNet-1 performs 52-Bytes header extraction with 60 ns accurate timestamp on a 1 Gb/s link

- Captured headers train are processed with original tools to:
  - retrieve flow size distributions and estimate $\alpha$
  - form packet count series and estimate $H$
## Experiments description

- Experiments time: 8 hours of *stationary* traffic

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<thead>
<tr>
<th>Proto.</th>
<th>Rate limit.</th>
<th>$\alpha_{ON}$</th>
<th>$\alpha_{OFF}$</th>
<th>mean flow size</th>
<th>measured parameter</th>
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<tbody>
<tr>
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<td>TCP</td>
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</table>
**Results – LD description**

- Series A: mean flow size = 100 → $\mu^{\text{ON}} = 0.24$ s
Results – coarse scaling range: the "knee"

- **Series B:**
  - mean flow size = 100 → $\mu^{ON} = 0.24$ s
  - mean flow size = 1000 → $\mu^{ON} = 2.4$ s
- average normalized LDs over different values of $\alpha$

Location of the "knee" introduced by Hohn et al., 2003
Results – Influence of the protocol and of the source rate limitation: Coarse scales

- Series A: mean flow size = 100 → $\mu^{ON} = 0.24$ s
Results – H versus $\alpha_{ON}$

- Series A: mean flow size $= 100 \rightarrow \mu^{ON} = 0.24$ s
- With heterogeneous RTT

- Study of the relation between $H$ and $\alpha_{ON}$ by Park, Kim and Crovella, 1996, on ns2
Results – $H$ versus $\alpha_{ON}$

- Series A: mean flow size $= 100 \rightarrow \mu^{ON} = 0.24$ s
- With heterogeneous RTT

Study of the relation between $H$ and $\alpha_{ON}$ by Park, Kim and Crovella, 1996, on ns2
Results – $H$ versus $\alpha_{\text{OFF}}$

- Series C: mean flow size $= 1000 \rightarrow \mu^{\text{ON}} = 2.4$ s

- Study of the relation between $H$ and $\alpha_{\text{OFF}}$ by Park, Kim and Crovella, 1996, on ns2
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Results – Influence of the protocol and the rate limitation: Fine scales

- Series D: mean flow size = 100 $\Rightarrow \mu^{ON} = 0.24$ s

Scaling behavior in fine and intermediate scales:
- Guo, Crovella and Matta, 2001
- Figueiredo, Feldmann et al., 2005
Conclusion and future work

Conclusion:

- In our experimental conditions (no congestion), Taqqu’s relation between LRD (coarse scales) and HT is well verified independently of:
  - the protocol used
  - the rate limitation mechanism
- We also checked that the relation is verified when OFF periods are HT distributed instead of ON periods

Future work:

- Study Taqqu’s relation in congested situations and in lossy contexts
- Study the impact of LRD on queuing delays and dynamics
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Results with Loss

- mean flow size = 1000 → $\mu^{ON} = 2.4$ s
- Lossy link with three loss rates: 0% (black), 0.7% (red) and 5% (blue)
References

- Guo, Crovella and Matta, *How does TCP Generate Pseudo-Self-Similarity?*, MASCOTS 2001