Improving Confidence in Network Simulations

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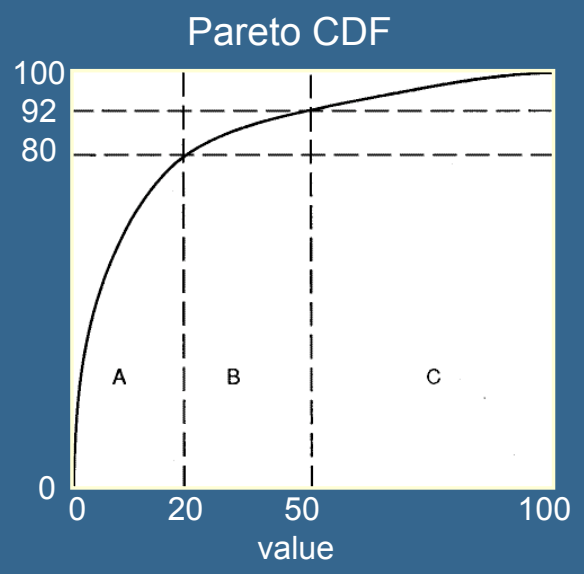
Introduction

- "Credibility crisis" in networking simulation analysis (Pawlikowski *et al.*, 2002)
  - effect of randomness
  - affects quality and repeatability of results
- Problems dealing with *heavy-tailed distributions*
  - describes Internet file sizes
- Problems dealing with *random number generators*

Heavy-Tailed Distributions

- Most common
  - Pareto
  - Lomax
    - Pareto of the 2nd kind
- Parameters
  - scale, *k*
  - shape, α
    - $\alpha \leq 2$, infinite variance
    - $\alpha \leq 1$, infinite mean



Heavy-Tailed Distributions
Usage in Network Simulation

- Network traffic is driven by transfers of files with a heavy-tailed size distribution
- Big question in network simulations is appropriate running time of simulation
  - typically, when sample mean approaches theoretical mean
- Workloads based on heavy-tailed distributions take a long time to converge

Heavy-Tailed Distributions
Problems in Network Simulation

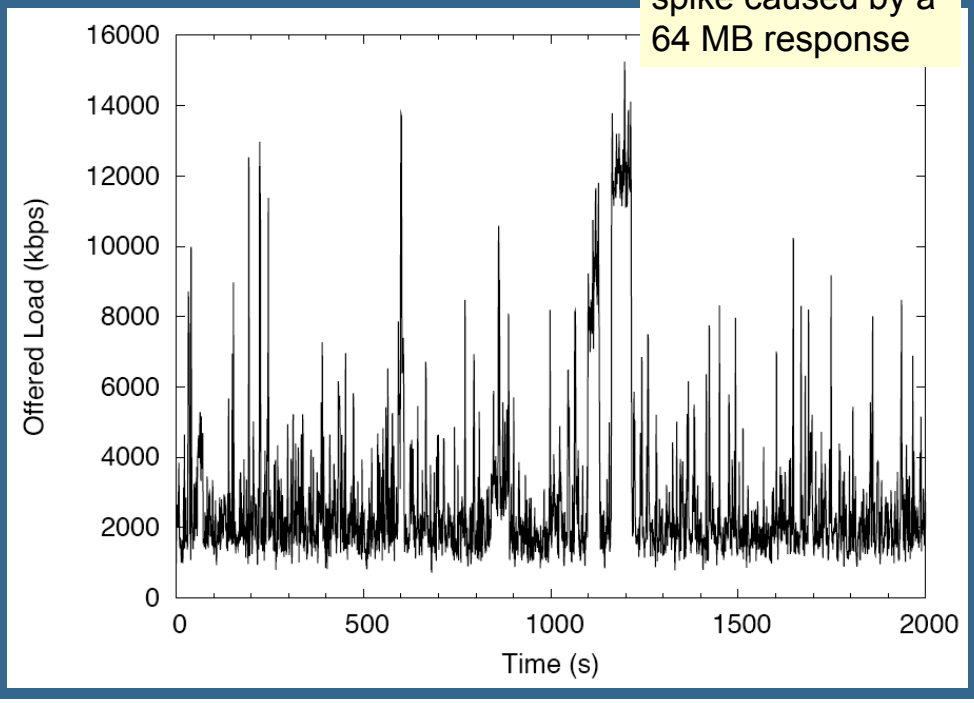
- For heavy-tailed distributions with $\alpha = 1.2$, takes 10^{10} samples for two-digit accuracy (Crovella and Lipsky, 1997)
- Swamping observation
  - one sample doubles the mean
  - with $\alpha = 1.2$, probability greater than 1 in 100
- When $\alpha < 1.5$, "simulation becomes infeasible" (Crovella and Lipsky, 1997)
- Practically, won't reach steady state, will always be transient

Problems in Network Simulation
Example

- PackMime-HTTP in ns-2
  - request sizes
    - Pareto, $\mu = 50$ bytes, $\alpha = 1.2$, k = 8.3
  - response sizes
    - Pareto, $\mu = 7000$ bytes, $\alpha = 1.2$, k = 1400
- 100,000 response size samples
- Took several hours to run
- Measure
  - offered load
  - cumulative mean of response sizes

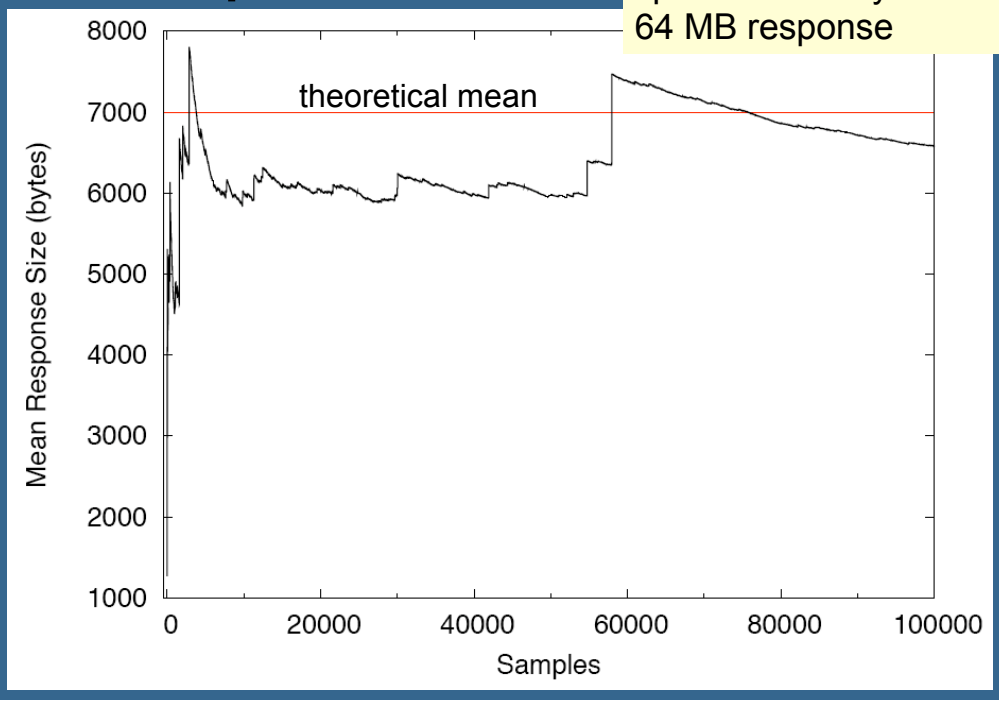
Heavy-Tailed Distributions

Offered Load



Heavy-Tailed Distributions

Mean Response Size



Heavy-Tailed Distributions
Problems in Network Simulation

- Running until steady-state is not feasible
- Approaches
  - bound the distribution
  - approximate Pareto
  - treat as transient

Approaches
Bound the Distribution

- Crovella and Lipsky, 1997
- Let Y be the maximum observation
- $E[Y] = knB(n, 1-1/\alpha)$
  - B is beta function
  - n is number of samples
- Maximum possible observation, p
  - *e.g.*, maximum file size possible
- Run simulation until $E[Y]$ approaches p

Bound the Distribution
Example

- k = 1400, α = 1.2
- Number of samples needed for E[Y] to approach maximum p

Maximum File Size (p)	Samples (n)
MP3 - 5 MB	2500
TV episode - 350 MB	400,000
CD image - 650 MB	850,000
DVD image - 4.7 GB	9,000,000

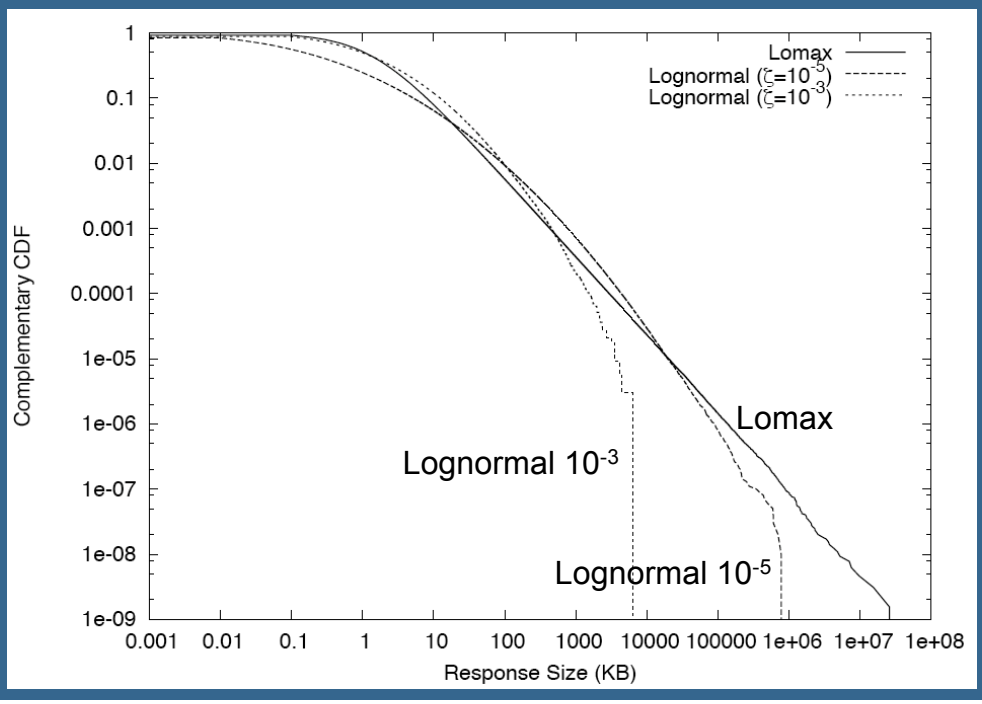
Bound the Distribution
Bounded Pareto

- Harchol-Balter *et al.*, 1999
- Use Bounded Pareto distribution to compute mean and variance of similar Pareto
- Run simulation until sample mean approaches mean of Bounded Pareto
- Technique has been used in previous studies

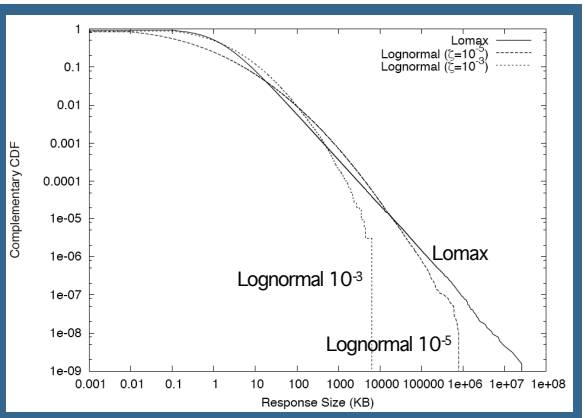
Approaches
Approximate Pareto

- Fishman and Adan, 2006
- Approximate Lomax (Pareto of 2nd kind) with Lognormal
  - variance is always defined
- Given *k* and α of Lomax, provide parameters for Lognormal, based on desired fit of the tail
  - ζ sets the point at which the tails diverge
  - smaller ζ, the better the fit
- Provide sample path length given desired accuracy of the mean
  - high 10^{-4}, moderate 10^{-3}, gross 10^{-2}

Approximate Pareto
CCDF Generated File Sizes



Approaches
Approximate Pareto



- Lognormal $\zeta = 10^{-3}$
  - 330,000 samples
- Lognormal $\zeta = 10^{-5}$
  - 100,000,000 samples
  - 50 minutes on 2.8 GHz Xeon
- Lomax
  - 643,783,352 samples
  - 10^{12} required for accuracy

Approaches
Treat as Transient

- Weigle *et al.*, 2005
- Run simulation long enough to capture a certain number of completed HTTP request-response pairs
  - 250,000 pairs
- Require that at least one response from tail is drawn
  - 10 MB response size
- Use same RNG seeds to generate traffic in each experiment
  - testing behavior of different protocols

Approaches
Treat as Transient

- Running time, or number of samples generated, may not be the most important factor in how well the tail of the distribution fits

- Large samples can occur at any time
  - be aware of the number of large samples present in simulations
  - run simulations long enough to observe a reasonable number of these large samples

Random Number Generation

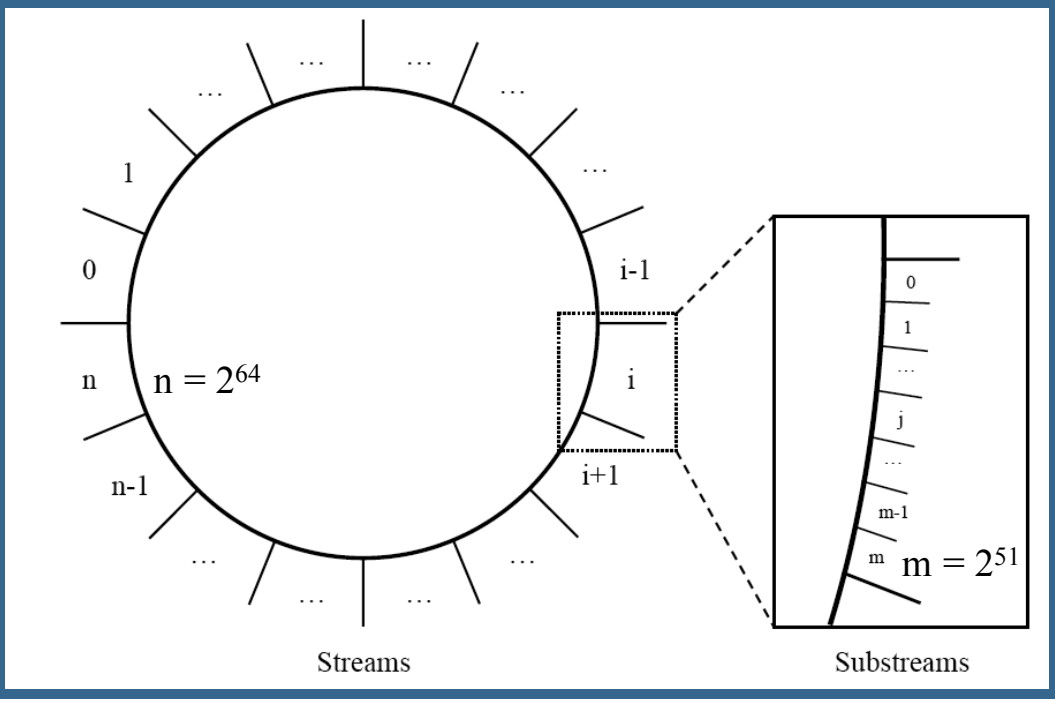
- Added the MRG32k3a combined multiple recursive generator (L'Ecuyer) to ns-2
  - default since ns-2.1b9, April 2002

- Divides the period into 2^{64} streams
  - each stream is guaranteed to be independent of every other stream

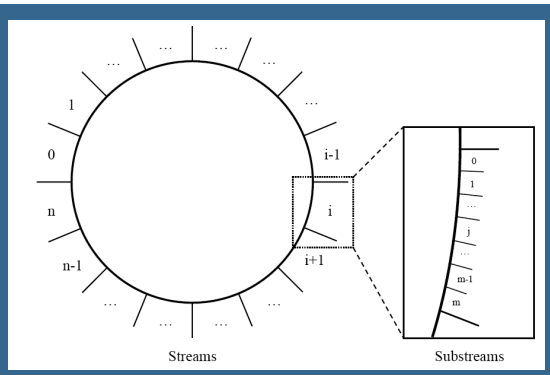
- Each stream consists of 2^{51} substreams
  - each substream is guaranteed to be independent of every other substream

- Each substream has a period of 2^{76}

RNG
Streams and Substreams



RNG
In ns-2



- Users set only a starting seed
- Independent seeds for additional RNGs automatically computed
  - `[new RNG]`
- Multiple replications
  - use a separate stream for each random variable
  - use a separate substream for each replication
    - `next-substream`

RNG
Effects of Improper RNG Usage

- Decreased reproducibility
  - if you use time of day as seed, it is very difficult for others to reproduce your simulation
- PackMime-HTTP as example
  - HTTP request size
  - HTTP response size
  - time between start of new connections
  - server delay time
  - round-trip time

RNG
Effects of Improper RNG Usage

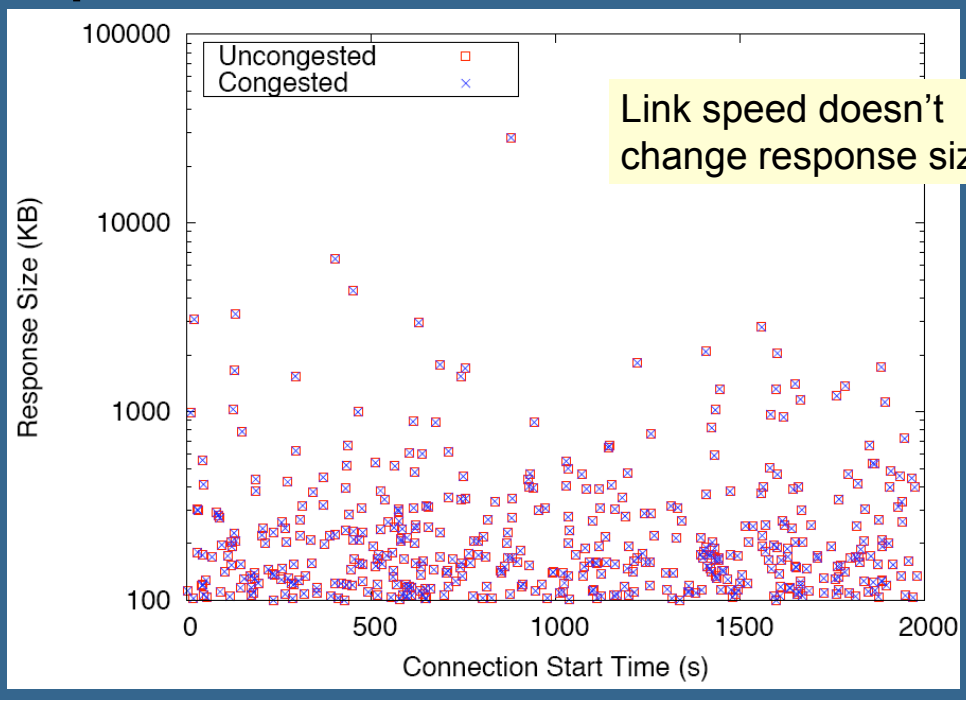
- When new connection starts,
  - request size, response size, time for next connection drawn
- When request received by server,
  - server delay time drawn
- Effects of change in network settings
  - could affect when requests reach the server
  - if using same RNG for all distributions, could cause different requests and responses to be drawn with the same starting seed

Effects of Improper RNG Usage
Example

- *A change in network settings should not change which request size and response sizes are drawn*

- Four simulations
  - uncongested network, all random variables use different, independent RNG (proper use of RNG)
  - congested network, proper use of RNG
  - uncongested network, all random variables use same RNG (improper use of RNG)
  - congested network, improper use of RNG

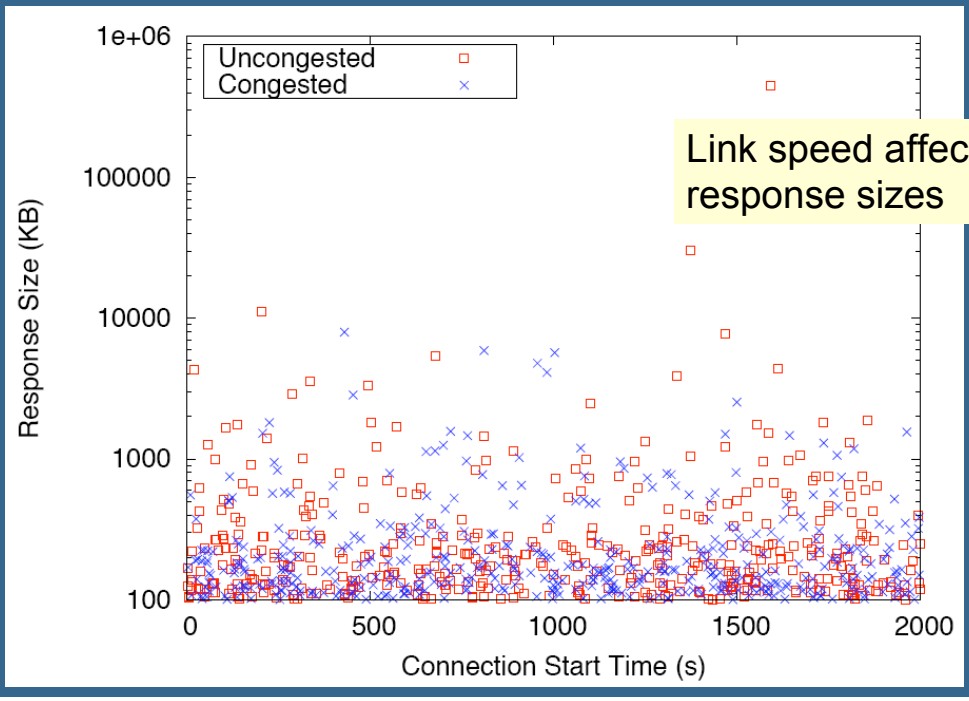
Example
Proper Use of RNGs



Link speed doesn't change response sizes

Example

Improper Use of RNGs



Link speed affects response sizes

RNG

Effects of Improper RNG Usage

- Congested case has no response larger than 10,000 KB
- Uncongested case has 3 such responses
- Results in a large impact on the offered load in the system
  - could invalidate results

Summary

- Heavy-tailed workloads are often used in network simulations
  - must be aware of issues in determining appropriate simulation running time
- Important to deal with RNGs properly in simulations
  - improper use could affect the validity of results
- Simulation scripts are available at http://www.cs.odu.edu/~mweigle/research/netsim/