Project Presentations

- Five slides
- Five minutes
- Five questions
- You're outta there!

Poll

- How many people know:
  - Lamport clocks
  - Timestamp vectors
  - Byzantine agreement
  - Epidemic/gossip dissemination algorithms
  - Consistency
  - Bayou

Internet Measurements

- This field went from casual sideline to serious science with Vern Paxson's thesis in 1997
- Now there is a massive literature in Internet measurements
- Two devoted conferences (PAM and IMC) in addition to standard networking conferences

Today's Lecture

- Provide a quick overview of the kinds of techniques used and questions addressed
- Tom Anderson (UW) will lead us in a design exercise
### Philosophical Question
- Why do we take Internet measurements?

### Measurement Techniques
- **Passive:**
  - Traces
  - Netflow data
  - Network telescopes
  - BGP looking glass sites
  - ……
- **Active:**
  - Ping
  - Traceroutes
  - ……

### Measurement Infrastructure
- NIMI
- Planetlab
- Telescopes (CIED)
- Traceroute servers
- ……

### Varieties of Measurement Studies
- Basic characterization from direct measurements
  - Raw statistics
  - Model fitting
  - Just because it is “direct” doesn’t mean it is easy!
    - Look at the care taken by Paxson in the two readings
- Deep inference
  - Estimating something that can’t be directly measured

### Examples of Direct Studies
- Packet sizes and protocol type
- Flow sizes
- Route stability
- DNS usage
- Stationarity
- ……

### A Few Results
- Most flows are small, but most bytes in large flows
- Most flows are slow, but most bytes are in fast flows
  - Rate/size highly correlated (not due to slow start)
- Losses are reasonably modeled as Poisson arrival of loss events followed by geometric loss train
- Internet routing does not yield good paths….

In 2003,
- Bytes: TCP 83%  UDP 16%
- Packets: TCP 75%  UDP 22%
- Flows: TCP 56%  UDP 33%
### Traffic Variances

- A Bellcore team discovered that ethernet traffic had strange behavior
- No matter what time scale they averaged it over, the variances were still large!
- How could that be?

### Self Similarity, LRD, and All That....

- Correlation: $r(t) = \langle x(s+t)x(s) \rangle - \langle x(s) \rangle^2$
- Short-range correlation: Sum $r(t)$ finite
- Long-range correlation (LRD): Sum $r(t)$ infinite
- Example of LRD: $r(t) \sim t^{-\gamma}$

### Aggregates and Variance

- Consider a sum of $M$ iid random variables:
  - Variance of sums $\sim 1/M$
- Consider process with short-range correlations:
  - On large-enough time scales, intervals are iid
  - Variance should decay as $1/M$
- Only with LRD can the variance decay more slowly
  - Often as a power law with $p<1$

### LRD Comes from Many Sources?

- Poisson arrivals, with long-tailed sizes is one mechanism
  - Most files small
  - Most bytes in large files
- Pareto distributions are very common!

### Zipf and Pareto

- Zipf: $F(\text{rank}) \sim \text{rank}^{-b}$
  - $F$ is frequency, size, etc.
  - $1 < b$
- Pareto: $P(\text{size}) \sim \text{size}^{-a}$
  - $1 < a < 2$
  - Log(size) has geometric distribution!
  - Pareto distributed interarrival times means logs are uncorrelated
- $a = 1+1/b$ and $b = 1/(a-1)$
- The tail of the distribution can’t be ignored!

### Examples of Zipf/Pareto

- Income distribution
- Asteroid sizes
- Letter frequencies
- File sizes
- Telnet packet interarrivals
- Web access frequencies (impact on caching)
- AS connectivity
Examples of Inference Tools

- Bandwidth estimation
- Critical path analysis
- Network tomography
- Flow rate causes
- …

Bandwidth Estimation (I)

- Send pair of packets back-to-back
- If not intermediate packets intervene, their spacing is a function of the bandwidth of the bottleneck link
- Send a series of packet-pairs, measure the minimal delays
- Doesn’t work well: often overestimate capacity!
- Can do better with many packets back-to-back

Bandwidth Estimation (II)

- Send variable sized packets, k hops (using TTL).
- Delay at link $i$: $D_i = A_i + P/C_i$
  - $A_i$ is size-independent delay
  - $P$ is packet size
  - $C_i$ is capacity of link
- Model delay of k hops: $\text{Sum (} i = 1 \text{ to } k ) \ D_i$

Possible Causes of Flow Rates

- Application: doesn’t generate data fast enough
- Opportunity: never leaves slow-start
- Receiver: limited by receive window
- Sender: limited by sending buffer
- Bandwidth: using full bottleneck bandwidth
- Congestion: flow is responding to packet loss
- Transport: none of the above…

Differentiating Causes

- Take trace of flow
- Estimate RTT
- Look at window epochs
- Identify where TCP is in cycle