Measurements

CSU CS557, Spring 2018
Instructor: Lorenzo De Carli
(Slides by Christos Papadopoulos, remixed by Lorenzo De Carli)
Outline

• End-to-End Packet Dynamics - Paxon99b
• Wireless measurements - Aguayo04a

• Note: both these studies are old, so the results have obviously changed. But the methodology is still valid
End-to-end Packet Dynamics

• How do you measure Internet performance?
  – Why do people want to know?
  – Are ISPs willing to tell you?

• What kinds of packet dynamics are observed in the network?

• Does there exist a *typical* Internet path?
Key Ideas

- Measure Internet traffic
  - active measurements
  - $n^2$ paths
  - lots of details out of TCP

- Evaluate dynamics
  - pathologies (out-of-order, duplication, corruption)
  - bandwidth
  - loss
  - delay
Methodology

• **Previous studies**
  – Focused on a small number of paths
  – Used unrealistic traffic (pings etc.)

• **Paxson’s study: quite revolutionary!**
  – Examined nearly 1000 paths in networks N1 and N2
  – Used TCP traffic
    • Routers designed to handle TCP as common case
    • Congestion-adaptive (both good and bad)
  – Was extraordinarily *careful*
    • Used statistically valid sampling to reduce bias
    • *Looked at the wire* to get most confidence
    • Adjusted for TCP implementation idiosyncrasies
Pathologies: Reordering

• Reordering: packets arrive at receiver in a different order than they were sent

• Evidence:
  – Significant (non-trivial) occurrence (10-30% connections)
  – Strongly-site dependent
  – Most egregious instances correlated with route flutter
    • Different packets sent along different routes

• Other curious effects
  – Router forwarding lulls
Impact of Reordering

• On TCP fast retransmit and recovery
  – Which assume packet loss upon receiving dupacks
  – But packets may actually have been reordered

• Can we avoid this by:
  – Waiting before sending ACK
    • Yes, about 20ms waits would have detected most reordering events
  – Reducing the dupack threshold
    • Possibly, to 2
  – But, these require server and client side change
    • Bottom line: current techniques are a good compromise
Other Pathologies

- **Packet replication**
  - Link layer retransmissions
  - Happens in these traces, but very infrequently

- **Packet corruption**
  - About 1 in 5000 ($2 \times 10^{-4}$)
  - Is TCP 16-bit checksum enough to protect against this?
    - One out of 300M packets may be accepted, so maybe not
  - Data packets much more likely to be corrupted
  - Problem seems real but needs further study
Bottleneck Bandwidth Estimation

• How do you compute the bottleneck path bandwidth?
  – Bottleneck BW: max possible rate
  – available bandwidth: reasonable share

• Packet pair
  – Send two packets, each size S, closely spaced
  – At bottleneck, the packets are separated by a time T
  – Bottleneck bandwidth $Q_b = S/T$

• Where to measure? Sender (RTT) or receiver (OTT)?
  – If inference done at sender, can be error-prone because of
    • Ack compression
    • Bandwidth asymmetry, which causes noise in reverse path
Packet Pair Problems and Fixes

- Clock granularity (fix: measure multiple packets)
- Route changes (fix: measure several, take mode)
- Out of order delivery (fix: filter out)
- Multi-channel links, route spraying (fix: allow multiple modes)
Fix? Packet-bunch Modes

- Compute estimates from *bunches* of packets each sent closely spaced to the next
- Get *modes* from the distribution of estimates
  - If two modes widely separated in trace-> route (bottleneck) change
  - If two modes for different bunch sizes-> multi-channel links
  - Bunches also eliminate clock granularity problems
Packet Loss

- Measure loss of ACKs rather than data to account for measurement drops
- Fairly high rates (3% or 5%)
  - much higher on some links, ex. US to Europe
- But many connections are loss-free (30-66%)
Is Loss Predictive?

• short-time-scale: packet $a$ to $b$
  – define *queued* and *unqueued* pkts
    • *queued*: back-to-back, $i$ queued behind $i-1$
    • else *unqueued* (sufficient spacing that no self-queueing)
  – queued pkts have much higher loss rates
Overall Loss Characteristics

- ACK loss is the correct determinant of network conditions
  - In measuring, must be careful to account for tcpdump losses
- Doubling of average loss in one year
- Loss rates don’t have predictive power
  - But the presence of loss is usually indicative of a high loss rate

- Existence of
  - Dual network states
  - Diurnal variations
  - Geographical diversity in loss patterns
  - No typical loss rate

- Avoiding unnecessary retransmissions
  - RTO implementation seems correct
  - SACK would help significantly
Loss Patterns

- **Data vs ack loss**
  - Data loss across connections well-modeled by exponential
  - Not so for acks

- **Bursts**
  - Loss are *not* independent
  - Burst sizes are heavy-tailed
Burst Loss

- conditional loss definition
  - \( P[\text{pkt } i \text{ lost} | \text{pkt } i-1 \text{ was lost}] \)

- why
  - drop-tail routers

- implications
  - losses are not i.i.d

### Table II

<table>
<thead>
<tr>
<th>Type of loss</th>
<th>( P_i^N )</th>
<th>( P_i^C )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( N_1 )</td>
<td>( N_2 )</td>
</tr>
<tr>
<td>Queued data pkt</td>
<td>2.8%</td>
<td>4.5%</td>
</tr>
<tr>
<td>Unqueued data pkt</td>
<td>3.3%</td>
<td>5.3%</td>
</tr>
<tr>
<td>Ack</td>
<td>3.2%</td>
<td>4.3%</td>
</tr>
</tbody>
</table>
Delays

- **Ack compression**
  - A flight of acks queued behind cross traffic
  - Happens quite infrequently
    - Although most connections experienced one
    - Durations are small and number of such events is small
  - Packet pair techniques can account for this by rejecting outliers

- **Data timing compression**
  - Much more infrequent than ACK compression
  - Possibly due to specific routers
Delays

- **Queueing time scales**
  - Measured by variations in one-way transit times
  - Show wide variability, so we cannot design for a particular regime

- **Available bandwidth**
  - Approximated by variations in delay experienced due to own loading
  - Again, shows wide variability
  - Most between 0.1 – 1 sec
Today's Infrastructure Measurement Examples

- PlanetLab
- Home router measurements
- ISP measurements
- Security company measurements
Questions?

• Do you think this study is valid today?
• What has happened since 1995?
• Dialup->broadband
• Better connectivity
• Higher backbone speeds
Wireless Measurements

Link-level Measurements from an 802.11b Mesh Network

Daniel Aguayo  John Bicket  Sanjit Biswas  Glenn Judd †  Robert Morris

M.I.T. Computer Science and Artificial Intelligence Laboratory
{aguayo, jbicket, biswas, rtm}@csail.mit.edu

† Carnegie Mellon University
glejj@cs.cmu.edu

(SIGCOMM 2004)
Wireless Communication

- Lots of literature has assumed a *threshold* model for wireless communication
  - nodes within a distance $d$ of a node can hear that node, others cannot
  - allows for a clean *neighbor abstraction* for routing protocols, for instance

- Questions:
  - Are real radios in a real environment like that?
  - If not, why not?
Methodology

• Rooftop network
  – Network of 38 real 802.11b radios
  – Single data set, from nodes individually sending packets as fast as they can

• Channel emulator
  – For validation of hypotheses derived from data
  – Can control path loss and multipath
Experimental Methodology

Roofnet:
• 38 nodes distributed over 6 km.
• Node consists of a PC, 802.11b card and omnidirectional antenna.
• For the experiment
  ➢ It was operated in “pseudo-IBSS mode”, with no Roofnet user traffic
  ➢ Each node sends 1500-byte 802.11 broadcast packets as fast as it can for 90 seconds at each of the bit rates
Experiment Methodology (cont..)

- **Channel Emulator:**
  - used to investigate Multi-path effects

- **Signal Strength Measurements:**
  - Prism 2.5 chip-set provides per-frame measurements:
    - RSSI (receive signal strength indication: total power including signal, interference and background noise)
    - Silence value (total power before frame is received)
Delivery Probabilities

Pairs for which at least one packer was received
Most links have intermediate loss (not 0 or 1)

[Fig. 4, Aguayo 04]
**Implications**

- Neighbor abstraction is flawed
- There is no sharp drop in loss probability between neighbors
- Hard for routing protocols to find paths without significant loss
- Other studies in real-world settings have reached similar conclusions
- Rest of the paper explores implications of intermediate delivery probabilities
Impact of Distance?

Reception patterns for three senders (one shown here)
Some correlation, but not consistent: obstacles etc.

[Fig. 5b, Aguayo 04]
Two links with about 50% loss rate
Bursty loss rate may be caused by long burst of interference
Considerable variation in loss burstiness for similar average loss
Impact of Time?

Most links don’t vary second to second
Most links with intermediate loss have independent loss

[Fig.11, Aguayo 04]
SNR as Predictor?

Not really, although high SNR implies high reception rate
Graphs for each of the bit rates, 1, 2, 5.5 and 11Mb/s
Each point is a sender/receiver pair, card spec is 3db
Fix: Rate Adjustment?
Lessons from Rate Adjustment

• Wait until high bit rate performs badly before you switch
• Higher rate provides better throughput than lower rate even when loss > 50%
• Performance at low rates not a good predictor for higher rates
• Thus: measure, do not predict for rate selection
Interference?

Not really
1Mb/s, 1500B packets

[Fig. 18, Aguayo 04]
Multi-path interference

Receiver may also hear reflected signals
Yes!

Attenuation vs. delay of reflected signal
Grey bar is region of intermediate loss (10% and 90%)