On the impact of variability on buffer dynamics in IP networks*


Extended version: TCP/IP traffic dynamics and network performance: A lesson in workload modeling, flow control, and trace-driven simulations, ACM CCR 2001
Objectives

❖ Main:
  ❖ Highlight by using a toy example the extent to which assumptions underlying the nature of network traffic can influence practical engineering decisions

❖ Secondary:
  ❖ Introduce some concepts and tools that one usually comes up to when analyzing network traffic
In more detail

- Toy example: a simple TCP/IP network

- Assumptions underlying the nature of network traffic: wrt. variability of network traffic

- Buffer dynamics of IP routers:
  - A substantial amount of the space, power and cost of a high-end router line card today is used by the buffer memory that stores packets during times of congestion.*
  - If these buffers fill up, they cause queueing delay and delay-variance; when they overflow they cause packet loss, and when they underflow they can degrade throughput.*

* G. Appenzeller, N. McKeown, J. Sommers, and P. Barford, Recent Results on Sizing Router Buffers, in Proc. of the NSDC 2004
Mechanisms that create variability*

- User behavior (large scales)
  - Application level variability, e.g., Web

- Network characteristics
  - Different delays, round-trip time, cross traffic

- Feedback control (small scales)
  - Reliability and adaptivity

Mechanisms that create variability

- Scaling
  - How does traffic behave at different agg. levels

- Large time scales: User dynamics
  - Users act mostly independent of each other
  - Users are unpredictable:
    - Variability in doc size, # of docs, time between docs

- Small time scales: Network dynamics
  - Network protocols effects: TCP flow control
  - Queue at network elements: delay
Approach

- Study traces from simulations (e.g., ns-2)
  - Complete control over all aspects of network workload model, network model, protocol
- Real network traces used as benchmark
  - Simulation setup and trace analysis
- Simulation traces used for trace-driven simulation
  - Study queuing dynamics
- Correlation of analysis results to simulation setup
  - Identify network features that cause divergence
Outline

- Simulation setup
  - Workload model
  - Network model
  - Protocol

- Impact of variability at the application layer
  - Mice vs. elephants [V. Jacobson]

- Impact of feedback
  - Open loop vs. closed loop
Workloads

- No variability:
  - Infinite sources
    - 50 clients requesting big files

- High variability:
  - Web sources
    - 350 clients downloading Web pages

- Simulation:
  - Client startup: random time 0-600 seconds
  - Duration: 4200 seconds
  - Analysis: 900-4200 seconds
High variability workload: Web

Parameters (similar to SURGE [BC98]):
- Number of clients, pages, objects, packets per object
- Time between Web pages, Web objects
A simple network topology

Server

Clients

- Used to limit capacity: 1.5 Mbits to 3 Mbits
- Used to vary delay: 640 ms or 40 ms
- Used to measure before bottleneck

40-100 Kbits/second
TCP: Reliable byte stream

- Data divided into segments
- Segments are ACKED by receiver (cumulative)
- Timer for every segment
- Segments retransmitted
  - Timer goes off
  - Four duplicate ACKs received
- Flow control
  - Sliding window protocol avoids losses at the receiver
  - Bandwidth limits impose congestion window (cwnd)
    - Slow start increases cwnd exponentially
    - Congestion avoidance increases cwnd linearly
    - Packet losses triggers cwnd changes
Elephants: Infinite sources

- Packet rate process and buffer occupancy process
  - Network round trip time 1.3 seconds
Elephants (cont.)

- Packet rate process and buffer occupancy process
  - Network round trip time 0.14 seconds
**Mice and elephants: Web sources**

- Significant portion of connections are short
Elephants vs. Mice

- No variability in workload and network
  - synchronization of packet rate process
  - synchronization of buffer occupancy process

- Mice stop synchronization
  - no apparent synchronization
  - higher packet arrival process
  - higher utilization
Effect of synchronization

- Percentage of connections with losses during $\Delta T$

### Infinite sources

![Graph showing the effect of synchronization on infinite sources](image)

### Web sources

![Graph showing the effect of synchronization on web sources](image)
Effect of synchronization (cont.)

- Fractions of connections with losses in slow-start

Infinite sources

Web sources
Why mice eliminate synchronization

- **Mice**
  - Too short for feedback
  - TCP states non-synchronized
  - Arrival highly bursty
  - Large fraction in slow-start

- **Elephant**
  - Within two cycles losses for almost all connections
  - TCP states synchronized
  - Small percentage in slow start

- **Consequence**
  - # of burst losses larger for Web than Infinite srcs
Open loop vs. close loop

- **Queuing system with finite buffer**
  - Change in link capacity can be modeled by change of service time distribution

- **A simple experiment**
  - ns-2 simulation with approx. finite buffer space (50 packets)
  - Trace driven queuing analysis of G/D/1 queue with varying service times

- **Evaluation**
  - Set of ns-2 simulations with different bottleneck speeds
    - Calculate packet loss
  - Compare packet losses from simulations to packet loss predicted from open loop queue system
Open loop vs. close loop (cont.)

Web sources

Either extremely conservative or overly aggressive
Open loop assumptions

- Queuing system with infinite buffer
  - Buffer occupancy probability $P[Q > x]$ can approximate finite buffer packet loss

- A simple experiment
  - ns-2 simulation (approx. inf. buffer space 1000 pkts)
  - Trace analysis to calculate buffer occupancy

- Evaluation
  - Set of ns-2 simulations with different finite buffers
  - Compare packet losses to buffer occupancy

- Result:
  - $P[Q > x]$ extremely conservative
Conclusion

- Infinite source models and queue analysis provide necessary simplifications for
  - Analysis
  - Simulations

- Challenge
  - Address variability at
    - User level
    - Network level
  - Judge the impact of feedback