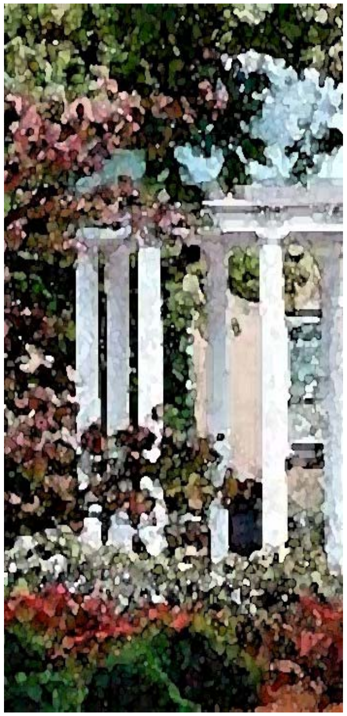

Generating Realistic TCP Workloads

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Joint work with
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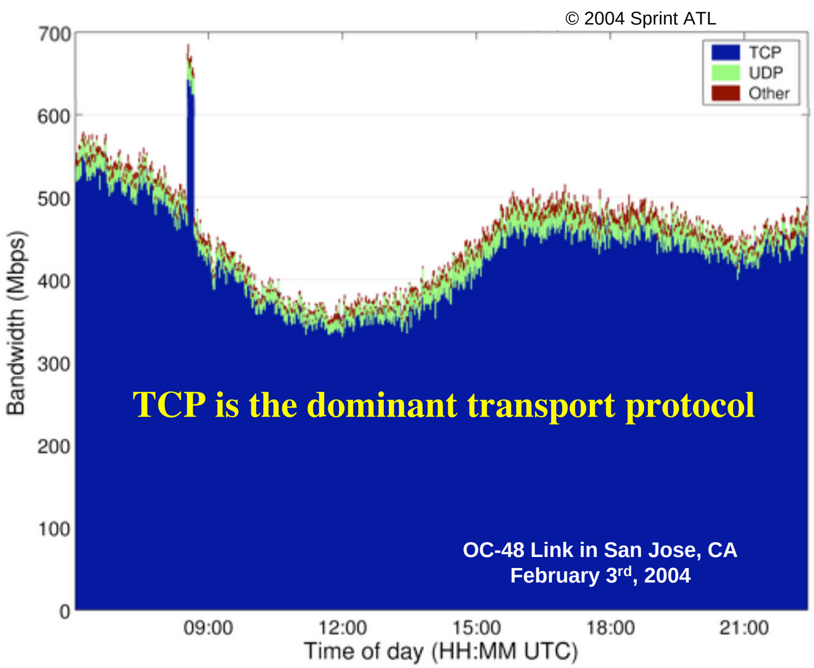
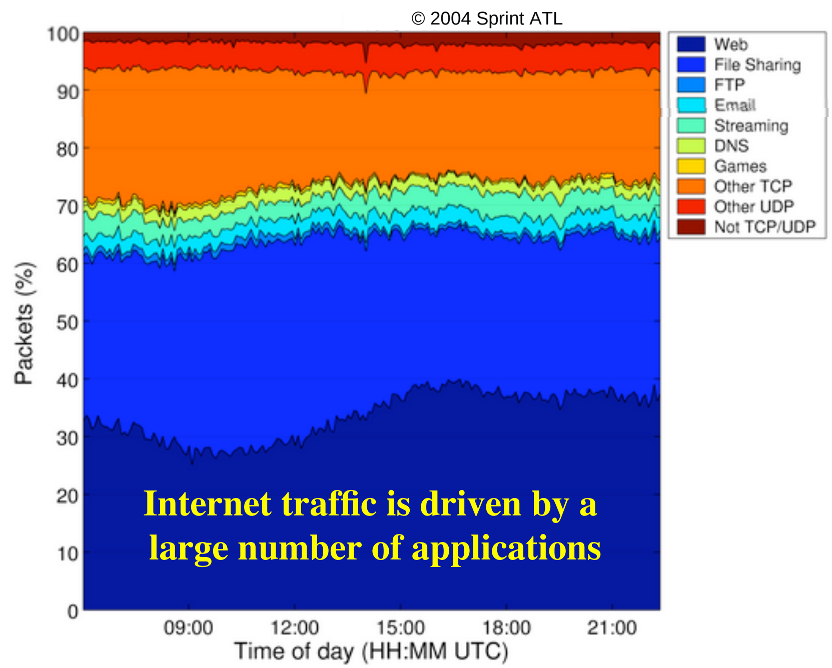
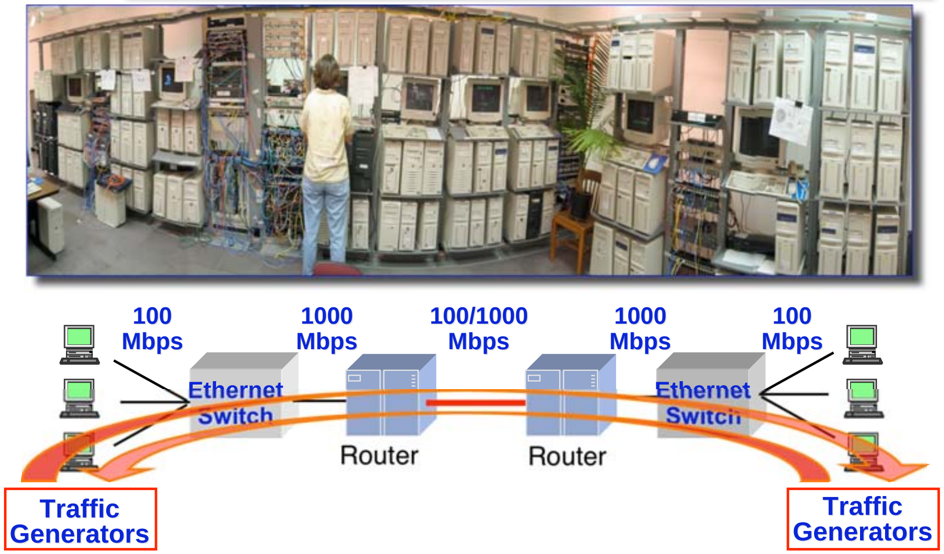
Experimental Networking Research and Performance Evaluation

- Evaluating network protocols and mechanisms requires careful experimentation
  - Network simulation (NS, Opnet, *etc*.)
  - Network testbeds
- A critical element of these experiments is the **traffic workload**
  - Are current workloads *realistic*?
- Let's look at some measurements
  - Sprint's tier-1 backbone network



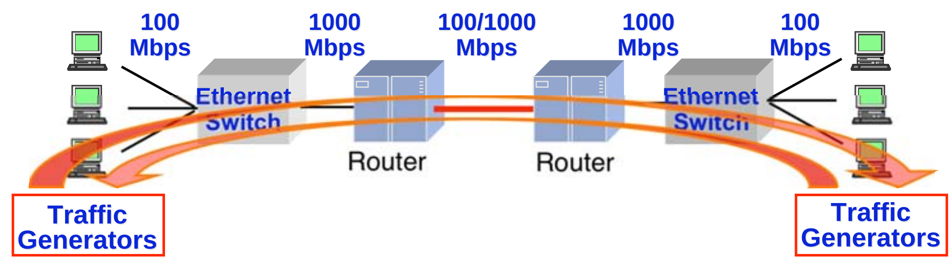


Internet Traffic Generation
Testbed example



Internet Traffic Generation
Testbed example

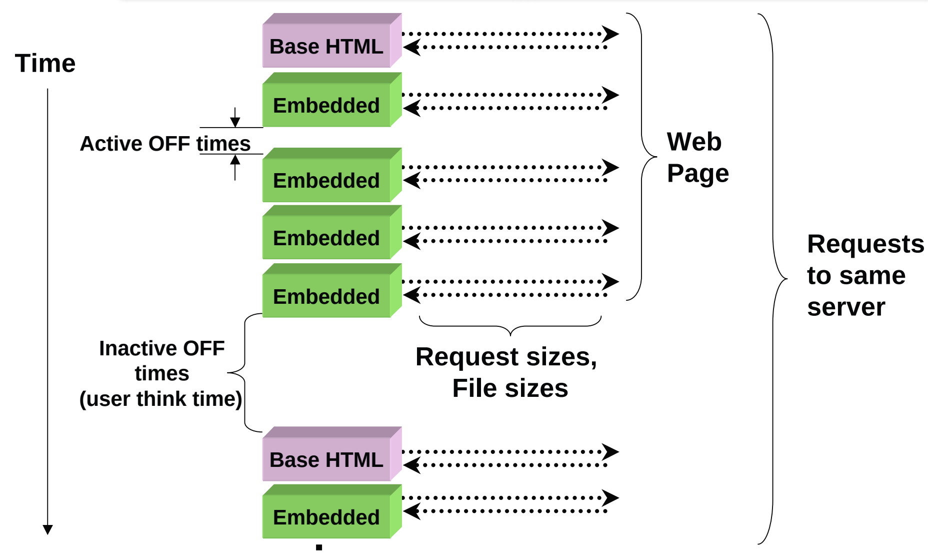
- Evaluate queuing mechanisms in the routers
- Evaluate transport protocols
- Evaluate intrusion/anomaly detection mechanisms
- Evaluate traffic monitoring techniques
- …



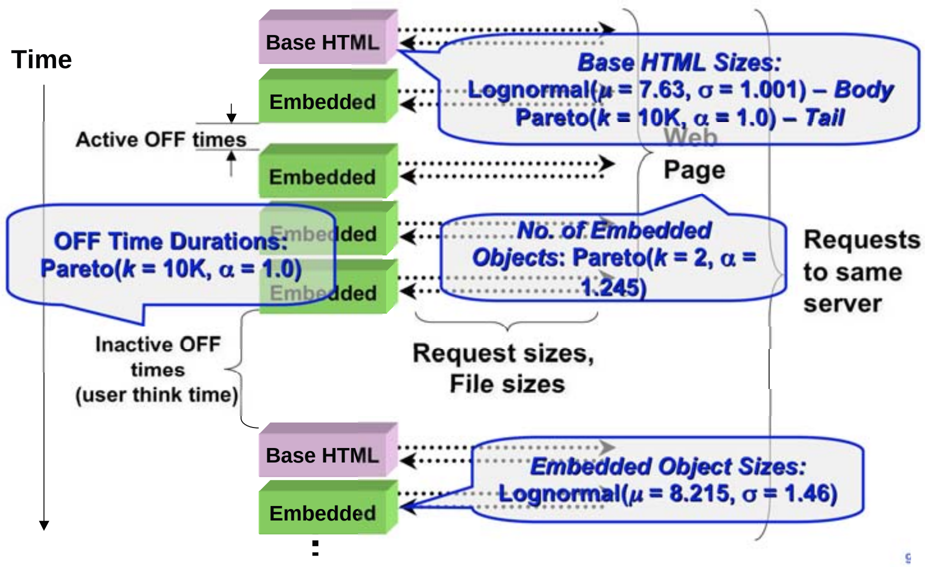
Traffic Generation
State-of-the-Art

- **Open-loop**
  - Large number of sophisticated models
    - » ***Packet-level modeling***
  - But TCP is a closed-loop protocol
    - » Open-loop traffic generation breaks reliability, flow control, and congestion control
- **Closed-loop**
  - The idea is to simulate the behavior of users/applications
    - » ***Source-level modeling of specific application***

Application-Specific Modeling
HTTP Model Example



SURGE HTTP Model
[Barford and Crovella, 1998]



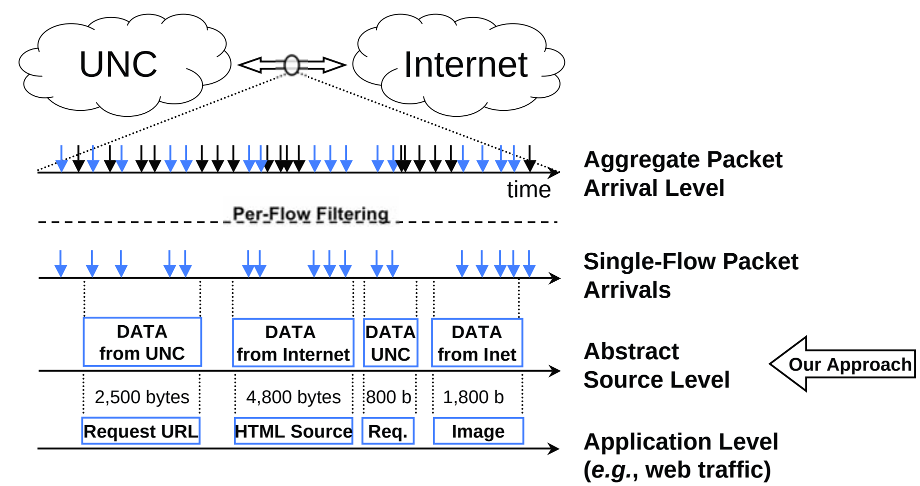
Application-Specific Models
Shortcomings

- Creating application models is a challenging, time-consuming task
  - Traffic mixes are driven by a large number of applications
- Set of dominant applications evolves quickly
  - Applications themselves also evolve
  - We cannot even identify a significant fraction of the traffic
- Modeling closed application protocols requires reverse-engineering
- Privacy considerations complicate data acquisition
  - *TCP header traces* are ok, *application data* is not

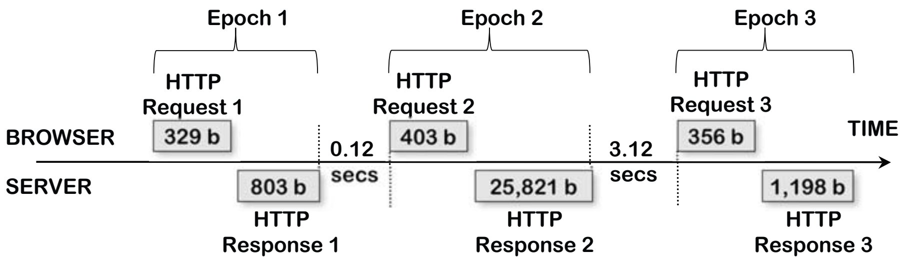
Our Approach

- **Abstract source-level modeling**
  - Application-neutral technique to describe the source-level behavior of any TCP connection
  - Efficient analysis applicable any arbitrary trace of TCP headers (no analysis of payloads)
  - We can also measure network-level parameters, such as round-trip times, receiver window sizes, *etc*.
- **Source-level trace replay**
  - Replaying abstract source-level behavior
- **Validation in network testbed**
  - We wrote a distributed, scalable traffic generator (tmix)
  - Comparison of original and synthetic traces

Different Views of Internet Traffic
Abstract Source-level Modeling



Client-Server Applications
Persistent HTTP Example

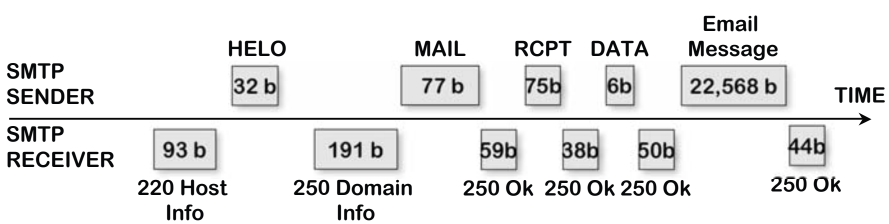


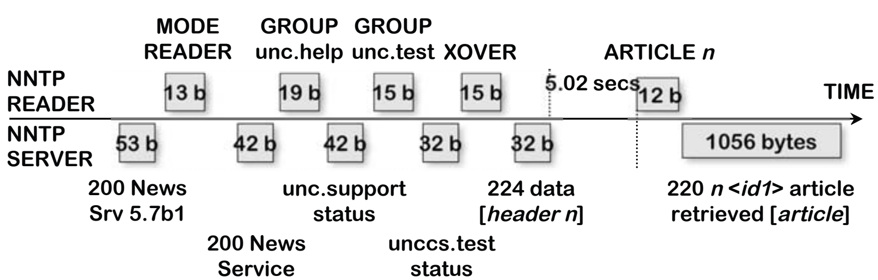
- We call a pair of application data units (ADUs) that carry a request/response exchange an *epoch*
- *Quiet times* are also part of the workload of TCP

Sequential A-b-t Model

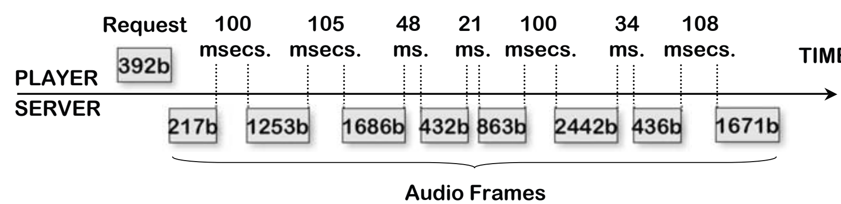
- Abstract source-level model for describing the workload of TCP connections
- Each connection is summarized using a ***connection vector*** of the form $C_i = (e_1, e_2, \ldots, e_n)$ with $n \geq 1$ epochs
  - Each epoch has the form $e_j = (a_j, ta_j, b_j, tb_j)$
- Connection vectors can be extracted from trace of TCP segment headers
  - Sequence number directionality, timing analysis, write size and packet size interactions
  - $O(n \log n) + O(n*W)$

Client-Server Applications
SMTP and NNTP Examples





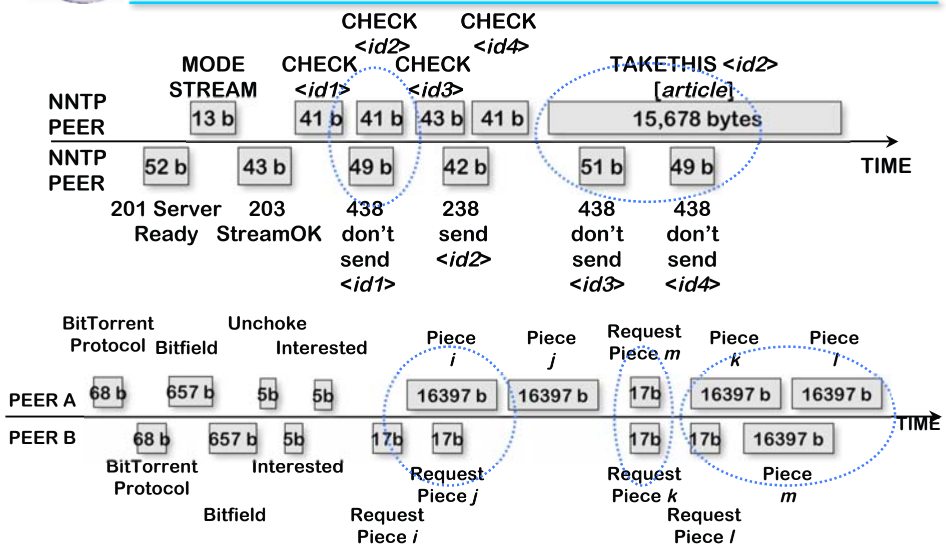
Beyond the Client-Server Model
Icecast – Internet Radio



- Server PUSH applications do not follow the traditional client-server model
- The sequential a-b-t model is still applicable
  - Make a_i and tb_i zero

Beyond the Client-Server Model

NNTP in Stream-Mode



Concurrent A-b-t Model

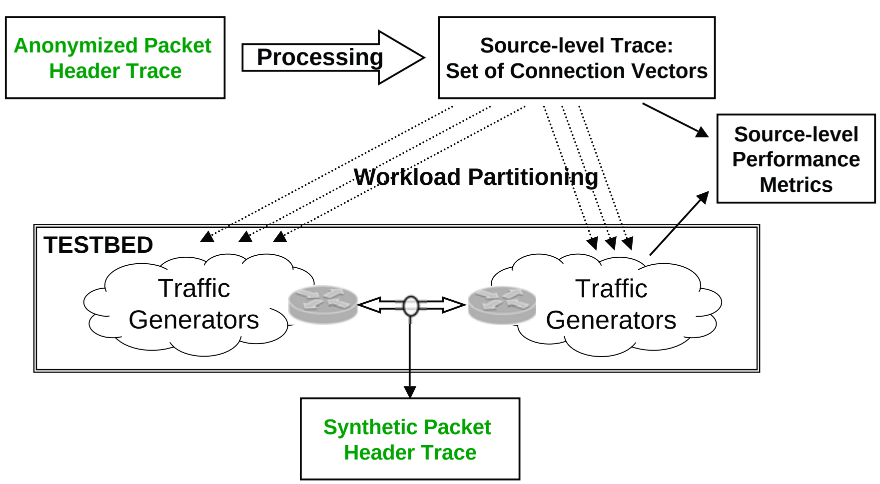
- Some connections are said to exhibit ***data exchange concurrency***
- Two reasons:
  - Increasing performance
  - Enabling natural concurrency
- Concurrent a-b-t model describes each side of the connection separately

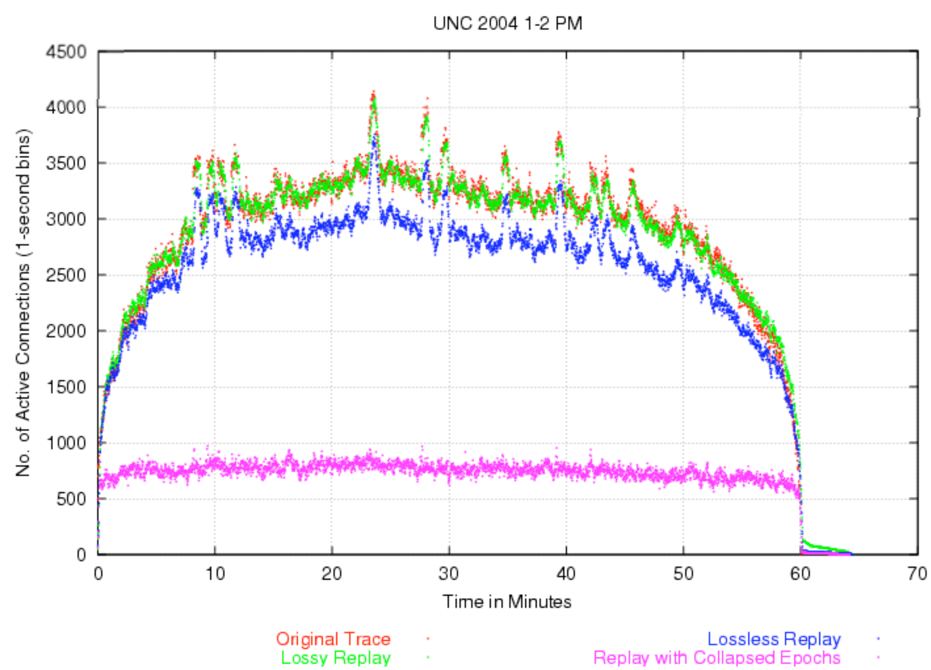
  $((a_1, ta_1), (a_2, ta_2), \ldots, (a_n, ta_n))$

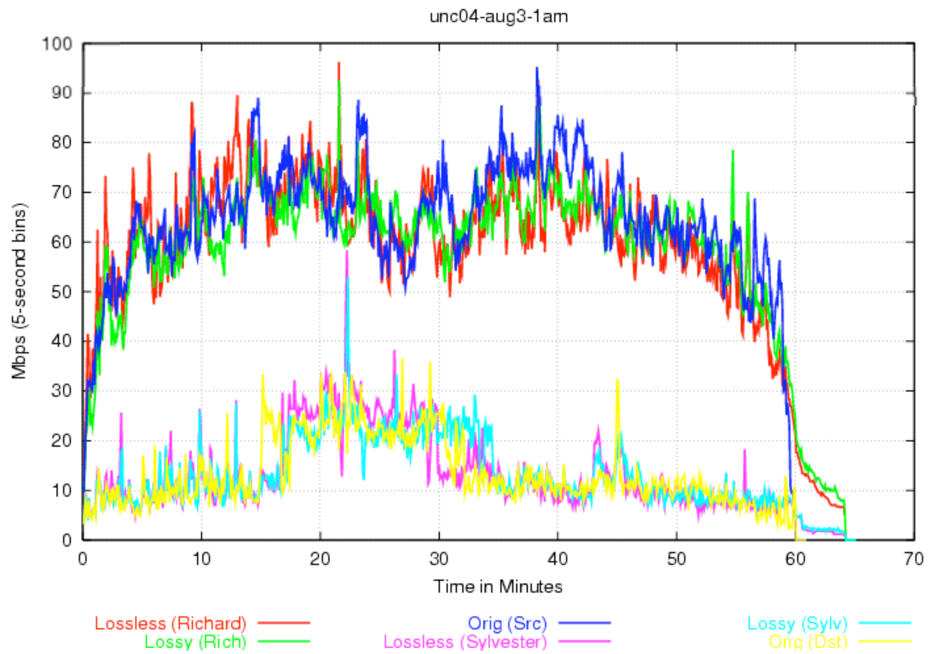
  $((b_1, tb_1), (b_2, tb_2), \ldots, (b_m, tb_m))$
- Concurrency can be detected with high probability
  - $p.seqno > q.ackno$ and $q.seqno > p.ackno$
  - $O(n*W)$

Source-Level Trace Replay

Traffic Generation in Lab Testbed







Conclusion

- New method for modeling traffic mixes
  - Empirically-derived connection vectors
  - Studied sequential vs. concurrent dichotomy
  - Fully automated, efficient analysis
- New traffic generation approach
  - Enables comparison of real and synthetic traffic
  - Implemented a distributed traffic generator
  - Techniques for scaling traffic load