Validation Experiences with the NS Simulator

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Workshop on Validation of Large Scale Network Simulation Models

The history of the NS simulator:

- Steve McCanne and I developed a network simulator in 1990 from Keshav's REAL simulator, for our own research on TCP, RED, CBQ, and RLM.

- A short note about the TCP validation tests was released in 1994.

- The NS-1 simulator was made publically available in 1995.

- The NS-2 simulator was released in 1997, and has been developed as joint work with USC/ISI and Xerox Parc.

Validation and verification:

• Validation: "ensuring that the assumptions used in developing the model are reasonable ..." [Jain 91].

• Verification: ensuring the correctness of the implementation of the model.

• The "validation tests" in NS are used for both validation and verification, in the above definitions.

NS and verification:

“While we have considerable confidence in ns, ns is not a polished and finished product, but the result of an on-going effort of research and development. In particular, bugs in the software are still being discovered and corrected. Users of ns are responsible for verifying for themselves that their simulations are not invalidated by bugs. We are working to help the user with this by significantly expanding and automating the validation tests and demos.”

NS and validation:

"Similarly, users are responsible for verifying for themselves that their simulations are not invalidated because the model implemented in the simulator is not the model that they were expecting. The ongoing ns Notes and Documentation should help in this process."

- NS Web Page.

Why We Don't Know How To Simulate The Internet:

- Do we want to model the current Internet, or do we want to model the Internet as it might be N years from now, when our proposed protocol might actually be deployed?

- Overly-specified models are not necessarily what we want.

– Paxson, V., and Floyd, S., "Why We Don't Know How To Simulate The Internet", Proceedings of the 1997 Winter Simulation Conference, December 1997.

Why We Don't Know How To Simulate The Internet, part 2:

- Even if we did want to model "the current Internet", it would not be easy to specify.

- Heterogeneity and rapid change of:
  - applications and traffic mixes
  - protocols
  - router mechanisms
  - topology and link characteristics

Details of choosing the model?

• Reno TCP, with its poor performance when multiple packets are dropped from a window of data, and with the myriad bugs documented in myriad real-world implementations?

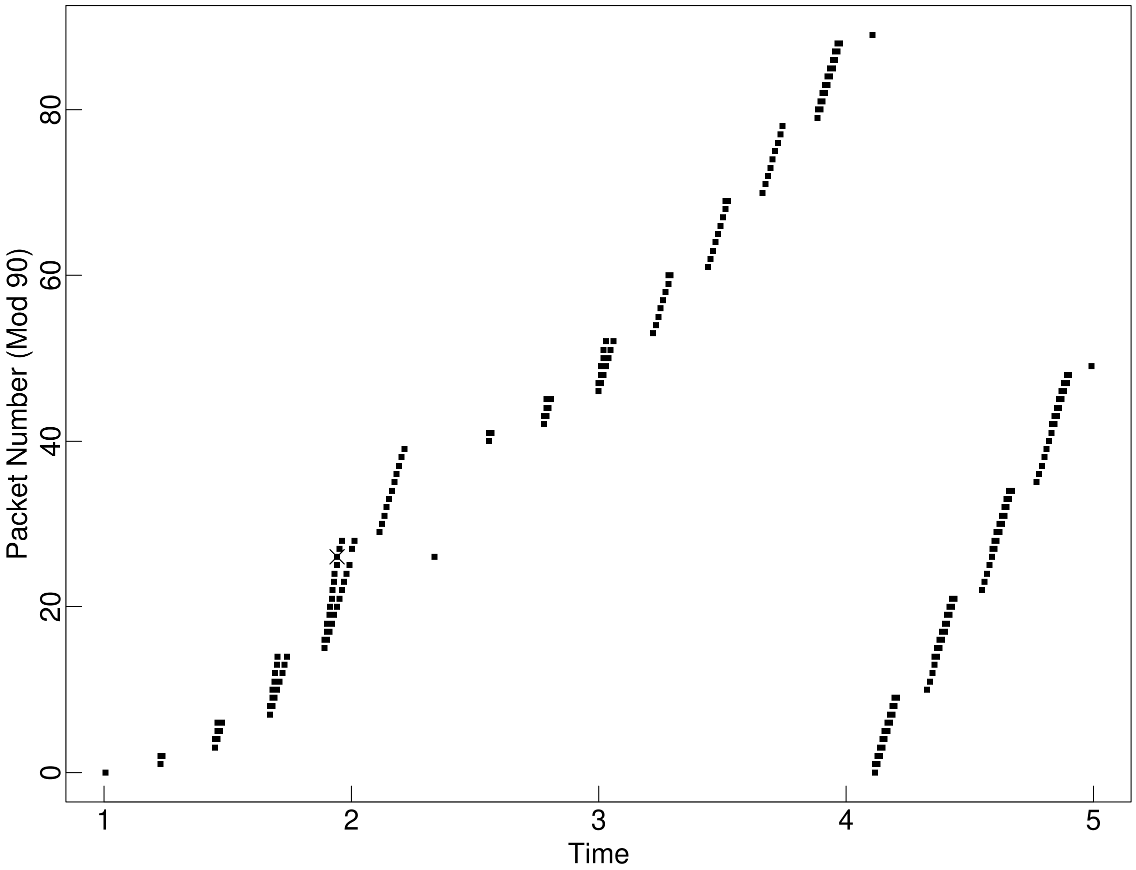
• Drop-tail queue management, with its phase effects and other sensitivities to small changes in the simulation scenario, or active queue management?

• 'One-way' TCP, with one-way data transfer and no modeling of connection set-up and tear-down, or 'two-way' TCP?

Some of the validation tests:

- Basic Simulator tests
- Ns Simulator Tests for Class-Based Queueing
- Simulation-based Comparisons of Tahoe, Reno, and SACK TCP
- Ns Simulator Tests for Random Early Detection (RED) Gateways
- Ns Simulator Tests for Two-Way TCP
- Ns Simulator Tests for TCP retransmit timers
- Ns Simulator Tests for larger TCP initial windows
- ECN Implementations in the NS Simulator

The Basic Simulator tests:



• The first test: Tahoe TCP's Slow Start, Congestion Avoidance, and Fast Retransmit.

The Basic Simulator tests:

• Tahoe TCP: Slow Start, Congestion Avoidance, Fast Retransmit
Including retransmit timers, delayed-ACK receivers, telnet sources, phase effects, different roundtrip times, multiple fast retransmits.

• Reno TCP: Fast Recovery
Including single and multiple packet drops.

• Reno TCP with Selective Acknowledgements
Including single and multiple packet drops.

• Random Drop and RED Queue Management.

– Described in: Floyd, S., “Simulator Tests”. July 1995, Revised May 1997.

Ns Simulator Tests for Class-Based Queueing:

• Tests showing hierarchical link-sharing.

• Tests comparing the three CBQ algorithms: Formal, Top-Level, and Ancestor-Only link-sharing.

• Tests of packet-by-packet and weighted round-robin scheduling.

• Tests showing effects of varying parameters.

– Described in: Floyd, S., “Ns Simulator Tests for Class-Based Queueing”. February 1996.

• Comparisons between simulation and experimental validation tests:

– Sally Floyd and Michael Speer, “Experimental Results for Class-Based Queueing”, November 1998.

Simulation-based Comparisons of Tahoe, Reno, and SACK TCP:

• Simulations with one, two, three, and four packet drops, with Tahoe, Reno, NewReno, and SACK TCP.

• Tests not illustrated in the paper include:
Tests for the “one-way” implementation of FACK;

Tests for the “two-way” implementations of Tahoe, Reno, NewReno, SACK, and FACK.

– Described in: Fall, K., and Floyd, S., “Simulation-based Comparisons of Tahoe, Reno, and SACK TCP”. Computer Communication Review, V. 26 N. 3, July 1996, pp. 5-21.

Ns Simulator Tests for Random Early Detection (RED) Gateways:

• Tests include RED with packet drop, RED with ECN, RED with poorly-set parameters.

• Tests of two-way traffic showing the queue measured in bytes and in packets.

• Tests comparing each flow's fraction of packet drops with that flow's fraction of the bandwidth.

– Floyd, S., Described in: "Ns Simulator Tests for Random Early Detection (RED) Gateways", October 1996.

Ns Simulator Tests for Two-Way TCP:

- Tests showing two-way data transfer, BSD-compatibility mode, delayed acks.

- The test suite includes additional tests that are not discussed in the paper.

  – Described in: Fall, K., Floyd, S., and Henderson, T., “NS Simulator Tests for Reno FullTCP”, July 1997.

Ns Simulator Tests for TCP retransmit timers:

- Tests showing the backing-off and later unbacking of the retransmit timers, the first or third packet of the connection dropped, with and without timestamps, the effect of different values for the TCP clock granularity, different multipliers for the mean deviation, different weights for the average roundtrip time.

- Tests showing the available statistics, including the number of retransmitted packets, and the number of retransmit timeouts.

  – Described in: tcl/test/test-suite-tcp.txt, September 1997.

Ns Simulator Tests for larger TCP initial windows:

- These tests verify the one-way TCP option specified in RFC 2414 on "Increasing TCP's Initial Window".

- The model for larger initial windows for the one-way TCP implementation:

  the sender sends a 40-byte data packet (modeling the SYN), the receiver sends an ACK, and the sender then sets its initial window to either two, three, or four segments, depending on the segment size. If the first packet (i.e., the SYN) is dropped, then the initial window is started at one segment.

  – Described in: tcl/test/test-suite-tcp-init-win.txt, April 1998

ECN Implementations in the NS Simulator:

- The CE (Congestion Experienced) bit in the IP header.

- The CWR (Congestion Window Reduction) and ECN-Echo bits in the TCP header.

- TCP's response to a CE bit with a congestion window of one packet.

- TCP's response to interspersed packet drops and CE bits.

  – Described in: Floyd, S., and Fall, K., ECN Implementations in the NS Simulator, December 1998.

Other validation tests in NS:

- HTTP, web caching and invalidation

- FACK TCP, TCP vegas, Reno and New-Reno TCP, rate-based pacing TCP

- Scalable Reliable Multicast (SRM)

- Routing: algorithmic routing, hierarchical routing, manual routing, centralized multicast, DM multicast, routing dynamics, session-level simulation

- Minimal validation tests for queue scheduling algorithms: FQ (Fair Queueing), SFQ (Stochastic Fair Queuing), DRR (Deficit Round Robin)

- Admission control algorithms

- LANs, with CSMA/CD MAC protocols

A Simulation and Emulation Infrastructure:

- Expose real-world devices to network dynamics constructed in the simulator.

- Expose simulation models to the traffic mixes of real-world networks.

- Extend real-world test networks with virtual portions.

- “On the Need for an Emulation and Simulation Infrastructure”, Kevin Fall.

A Validation Case Study:

- Using a simulator to replicate wide-area network traffic.

- "An Informal Validation Case Study: Using A Simulator to Isolate Correlation and Causality in Measured Network Traffic", - Polly Huang, Anja Feldmann, Anna C. Gilbert, Walter Willinger.