Performance Evaluation of TCP Tahoe, Reno, Reno with SACK, and NewReno Using OPNET Modeler

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Roadmap

- Introduction
- Background and related work
- Transmission Control Protocol (TCP) algorithms:
  - Tahoe
  - Reno
  - SACK
  - NewReno
- OPNET models and scenarios:
  - network topologies
- Simulation results:
  - wireless client and server
  - wired client and server
- Conclusions and references

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Introduction

- Transmission Control Protocol (TCP):
  - predominant Internet protocol
  - carries approximately 90% of the Internet traffic
  - connection oriented transport layer protocol that provides reliable packet delivery over unreliable links
  - independent on the underlying network layers
- TCP congestion control algorithms:
  - may not perform well in heterogeneous (wireless and wired) networks
  - originally proposed based on the assumption that congestion is the only cause for packet loss

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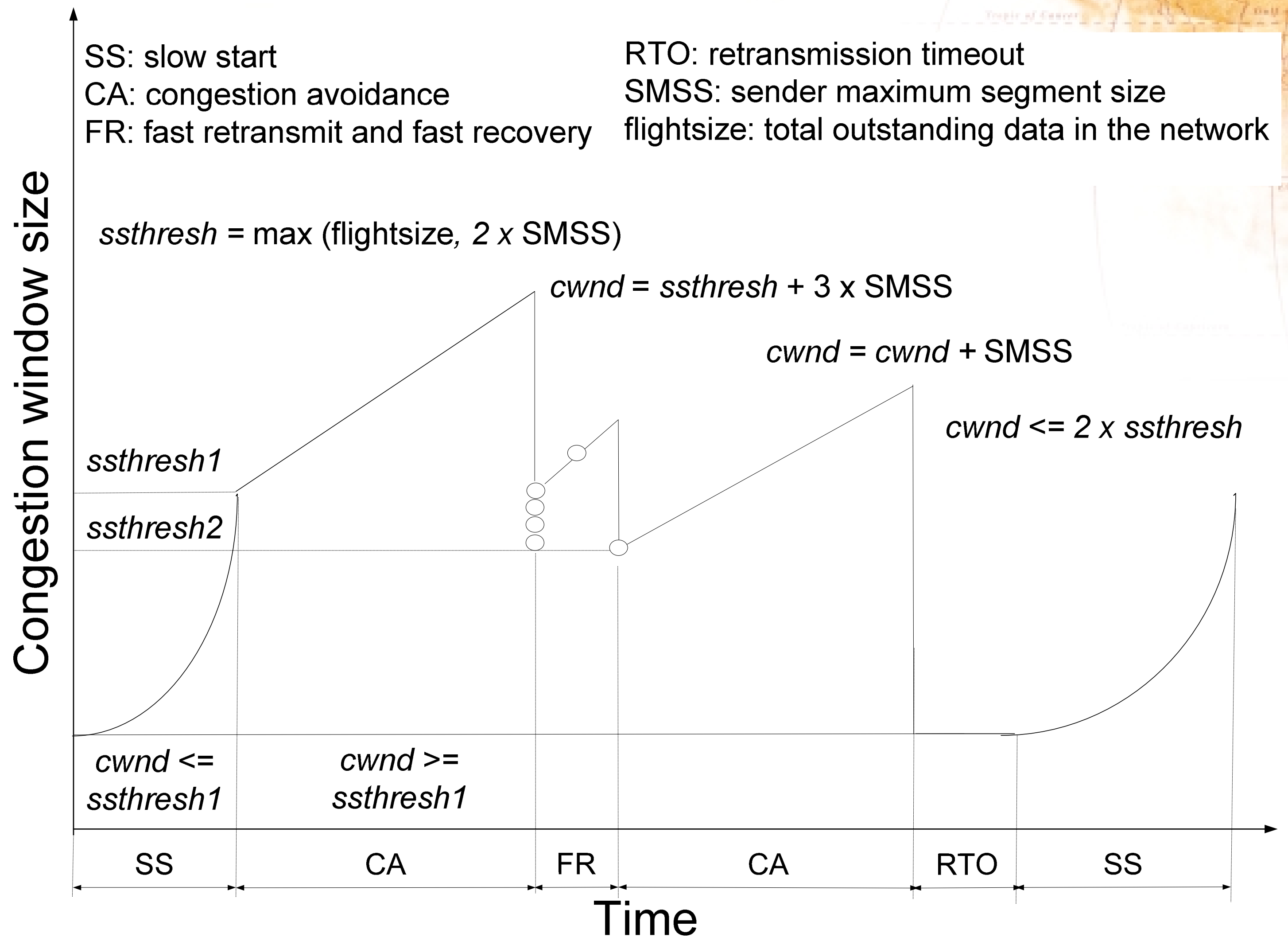
TCP congestion control mechanisms


SS: slow start
CA: congestion avoidance
FR: fast retransmit and fast recovery
RTO: retransmission timeout
SMSS: sender maximum segment size
flightsize: total outstanding data in the network
ssthresh = max (flightsize, *2 x* SMSS)
cwnd = *ssthresh* + 3 x SMSS
cwnd = *cwnd* + SMSS
cwnd <= *2 x ssthresh*
ssthresh1
ssthresh2
cwnd <= *ssthresh1*
cwnd >= *ssthresh1*
Congestion window size
SS
CA
FR
CA
RTO
SS
Time

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Related work

- TCP Reno with SACK:
  - shows lower bandwidth utilization in case of congested links
  - has lower goodput than TCP Reno and TCP NewReno *
- TCP Reno, Reno with SACK, and NewReno:
  - was compared using the ns-2 simulator **
- The behavior of the various TCP algorithms over wireless links with correlated packet losses indicated that:
  - TCP NewReno often performs worse than TCP Tahoe because of the inefficient fast recovery algorithm ***

* R. Paul and Lj. Trajkovic, "Selective-TCP for wired/wireless networks," *Proc. SPECTS 2006*, Calgary, AL, Canada, Aug. 2006, pp. 339–346.

** H. Lee, S. Lee, and Y. Choi, "The influence of the large bandwidth-delay product on TCP Reno, NewReno, and SACK," *Proc. Information Networking Conference*, Oita, Japan, Feb. 2001, pp. 327–334.

*** F. Anjum and L. Tassiulas, "Comparative study of various TCP versions over a wireless link with correlated losses," *IEEE/ACM Transactions on Networking*, vol. 11, no. 3, pp. 370–383, June 2003.

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Transmission Control Protocol

- TCP Tahoe:
  - original TCP algorithm
  - three transmission phases:
    - slow start
    - congestion avoidance
    - fast retransmit
- TCP Reno
- TCP Reno with Selective Acknowledgment (SACK)
- TCP NewReno

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TCP Reno

- Most widely adopted Internet TCP protocol
- TCP Reno transmission phases:
  - slow start
  - congestion avoidance
  - fast retransmit and fast recovery
- After duplicate acknowledgments (ACKs):
  - fast retransmit and fast recovery
  - fast recovery avoids slow start
- After timeout:
  - fast retransmit
  - slow start
- TCP Reno performs better than TCP Tahoe when a single packet is dropped within a round-trip time

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TCP Reno with Selective Acknowledgment (SACK)

- SACK algorithm allows a TCP receiver to acknowledge out-of-order segments selectively rather than cumulatively by acknowledging the last correctly received in order segment
- TCP Reno with SACK helps improve performance in case of multiple packet losses
- Multiple blocks can be transmitted in a single segment
- TCP Reno with SACK:
    - initiate fast recovery upon 3 duplicate ACKs
    - sender keeps records of SACKs and understands if segments are lost
    - sender retransmits the subsequent segment from the list of the lost segments

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TCP NewReno

- Modification of TCP Reno
- Improved retransmission process during the fast recovery phase
- Can recover multiple packet losses within a window of data
- Partial ACK:
  - occurs if multiple packets are lost
  - does not acknowledge all packets that are outstanding at the beginning of a fast recovery (this causes sender to leave fast recovery)
  - sender must wait until timeout occurs

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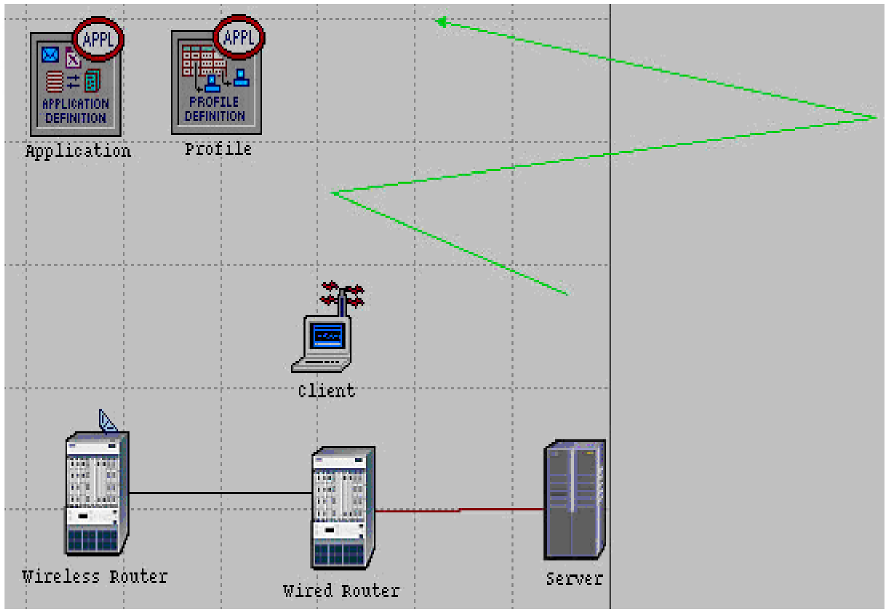
Wireless topology scenario



- OPNET modeler v. 11.0.A
- A file transfer protocol (FTP) server connected with wired router by a 10 Mbps link
- A wireless router (base station for a mobile client) connected to a wired router by a 1.5 Mbps link
- File size: 50 MB
- Packet losses occur due to signal attenuation

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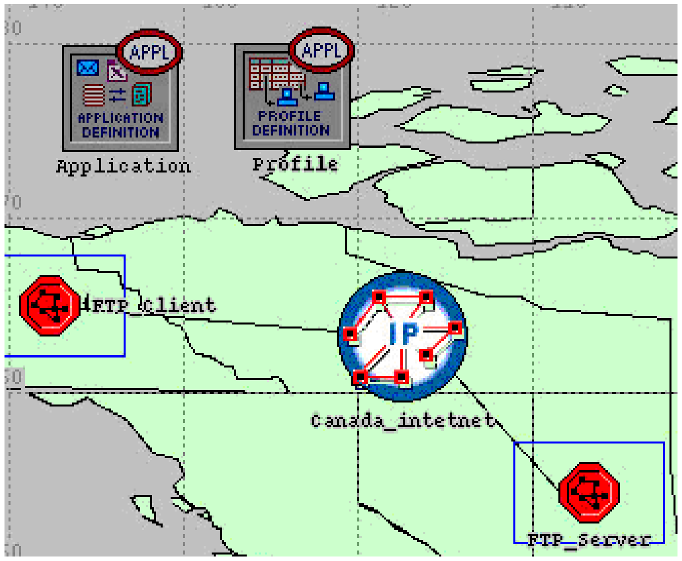
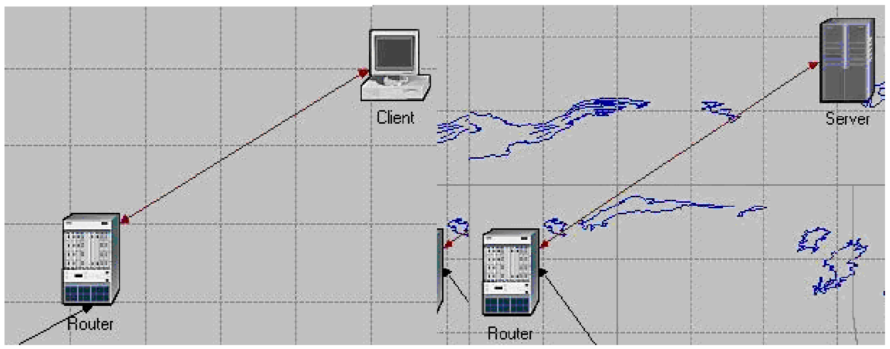
Wired topology scenario





- OPNET modeler v. 11.0.A
- Network consists of an Ethernet server and a client connected to the corresponding wired routers via 10 Mbps wired links
- Two routers are connected to the Internet cloud via 1.5 Mbps wired link
- FTP application is used to transfer 10 MB file from the server to the client

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OPNET model: wireless client and server

TCP parameters	Value
Slow start initial count (MSS)	1
Receive buffer size (bytes)	65,535
Maximum ACK segment	2
Initial RTO (sec)	1.0
Minimum RTO (sec)	0.5
Maximum RTO (sec)	64
RTT gain	0.125
Deviation gain	0.25
RTT deviation coefficient	4.0
Duplicate ACK threshold	3

- TCP versions:
  - Tahoe
  - Reno
  - SACK
  - NewReno
- Performance parameters:
  - congestion window size
  - file download response time
  - throughput
  - goodput
- TCP parameters

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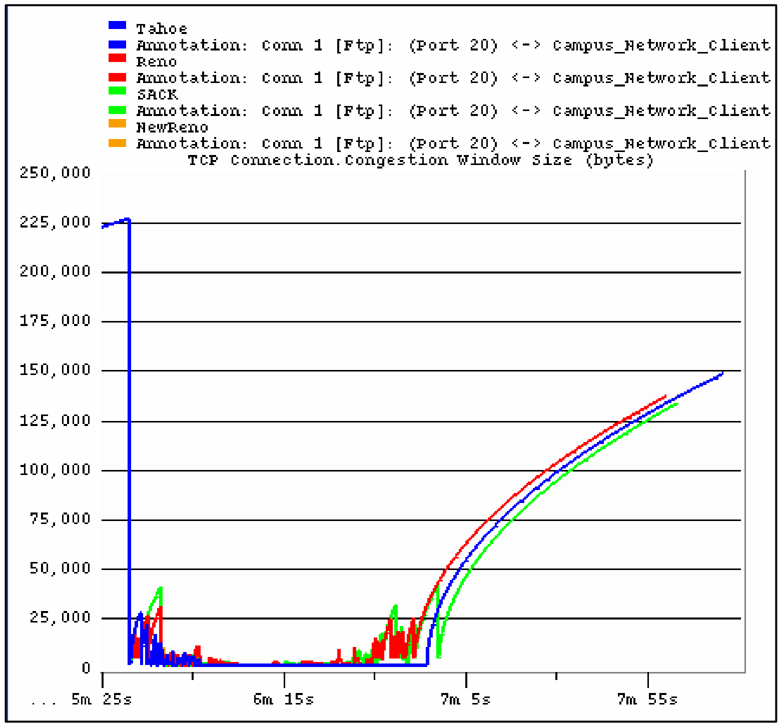
Wireless network scenario: congestion window size and file download response time



TCP variants	Download response time (s)
Tahoe	491
Reno	480
Reno with SACK	483
NewReno	496

- TCP Reno outperforms the remaining three algorithms
- TCP Reno with SACK has larger congestion window size than TCP Tahoe and TCP NewReno
- TCP Tahoe and TCP NewReno have comparable congestion window size
- TCP Reno has shorter file download response time followed by TCP Reno with SACK while TCP NewReno has the longest file download response time

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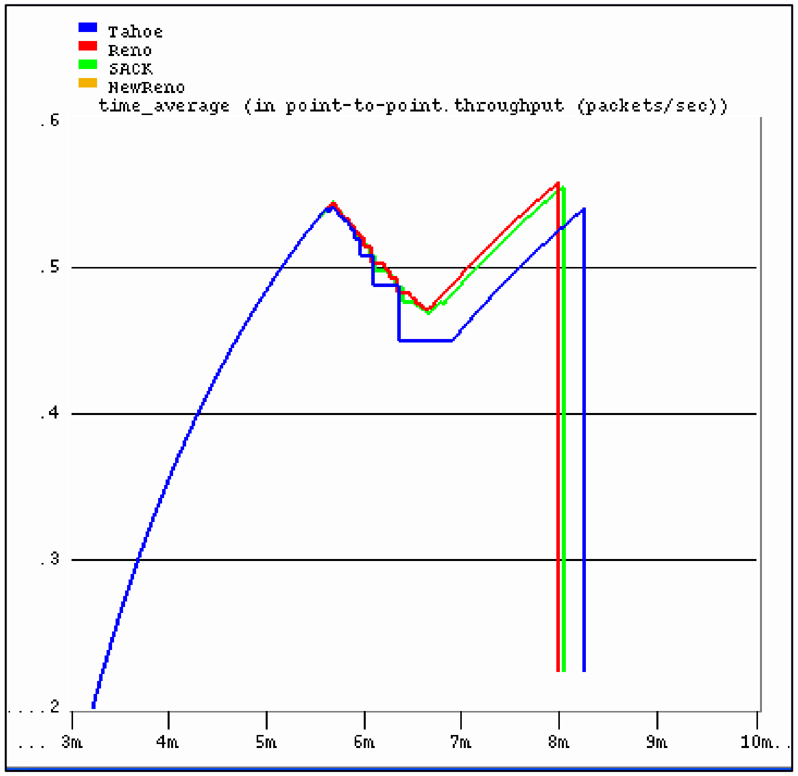
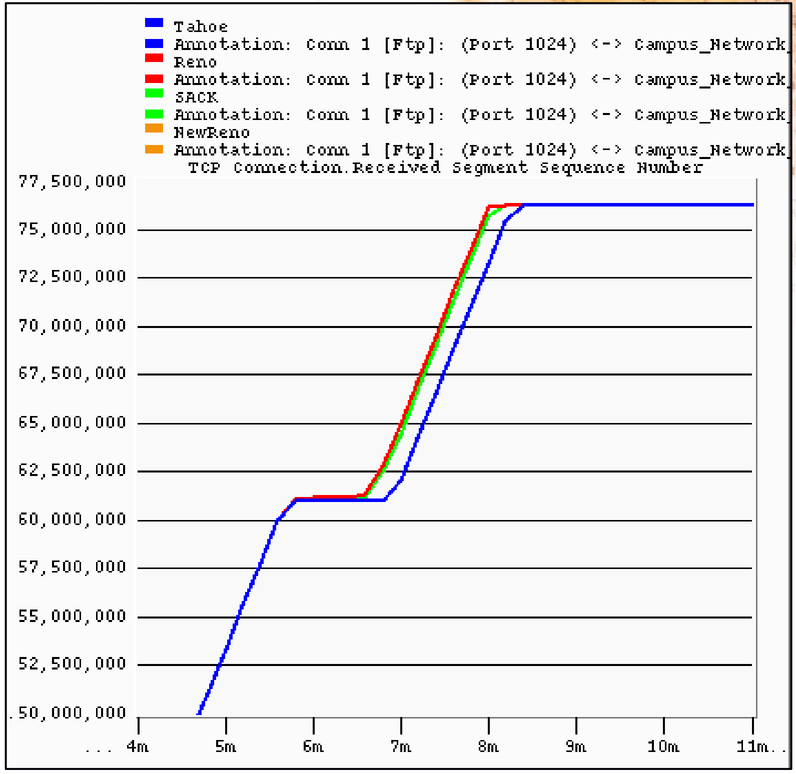
Wireless network scenario: throughput and goodput





- TCP Reno has the highest throughput and goodput compared to the remaining three algorithms
- TCP Reno with SACK has higher throughput and goodput than TCP NewReno and Tahoe

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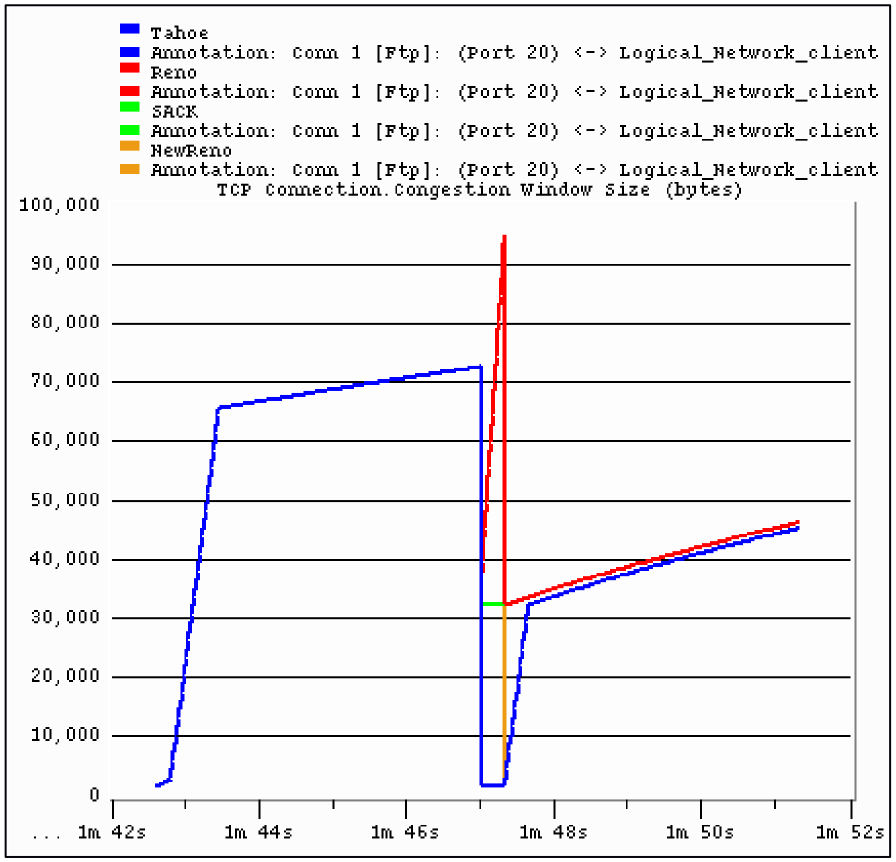
Single packet loss scenario: congestion window size



- Evolution of the congestion window size in a simulated client server network
- Single packet loss:
  - TCP Tahoe performs the slow start phase
  - other algorithm perform individual fast recovery and fast retransmit
- The four algorithms have the same file download response time

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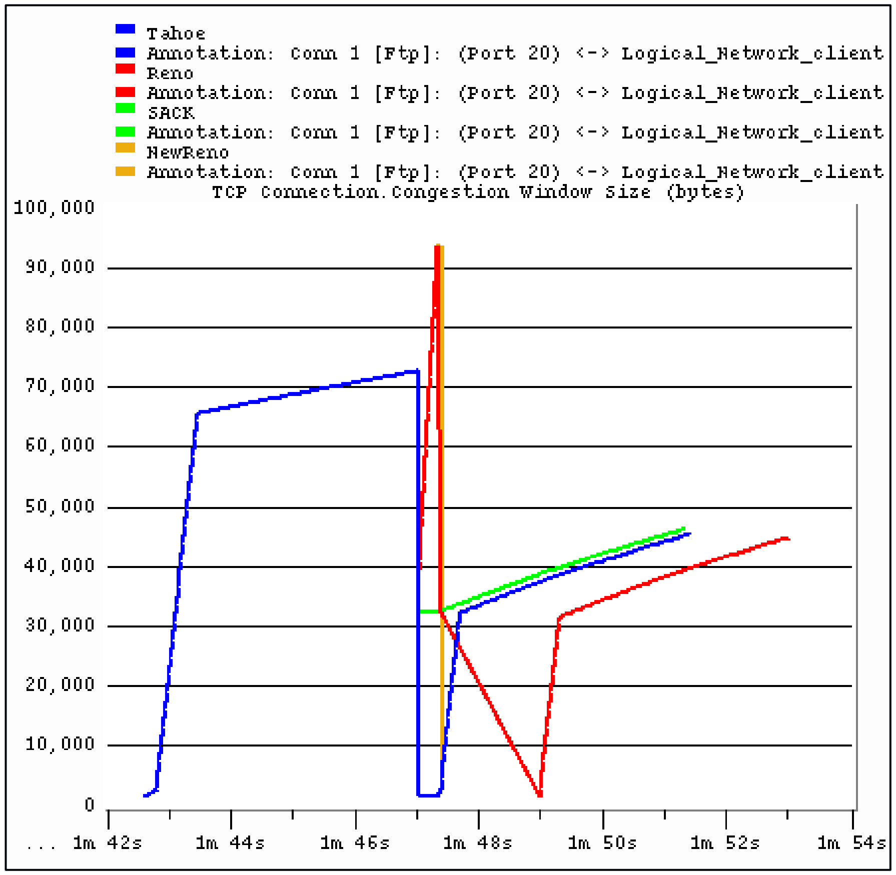
Two packet losses scenario: congestion window size



- Evolution of the congestion window size in case of two packet losses in a window of data
- TCP Reno with SACK has a larger congestion window size and shorter file download response time compared to the remaining three algorithms
- TCP NewReno and TCP Tahoe have similar congestion window size
- TCP Reno has the worst performance

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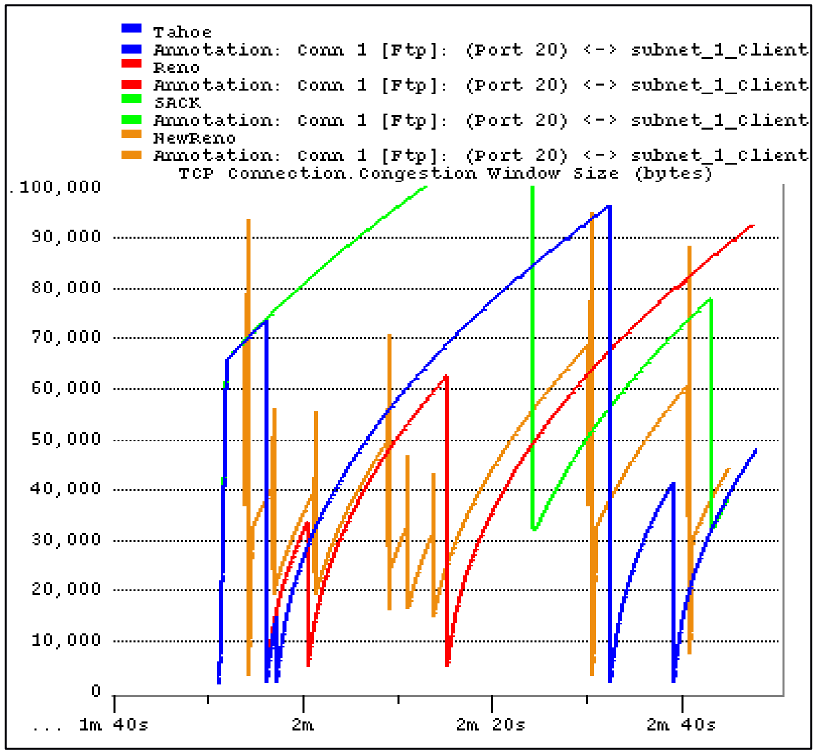
0.05% packet loss and 0.001 sec packet latency scenario



TCP variants	Download response time (s)
Tahoe	168
Reno	167
Reno with SACK	164
NewReno	165

- Evolution of the congestion window size
- File download response time:
  - TCP Reno has larger file download response time than TCP Reno with SACK and NewReno
  - TCP Reno with SACK and NewReno have approximately the same file download response time
  - TCP Tahoe performs the worst compared to the remaining three algorithms

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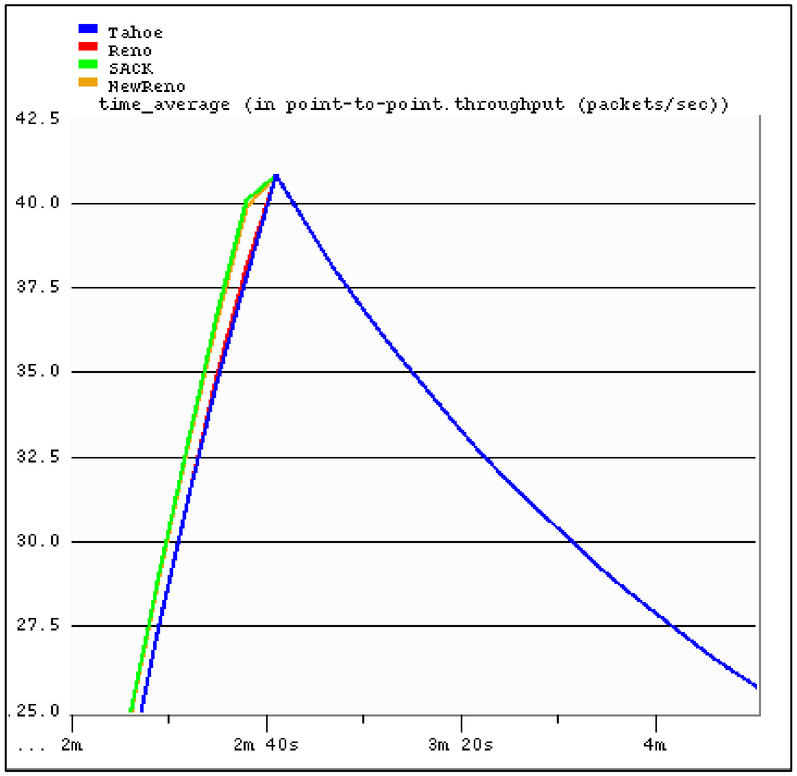
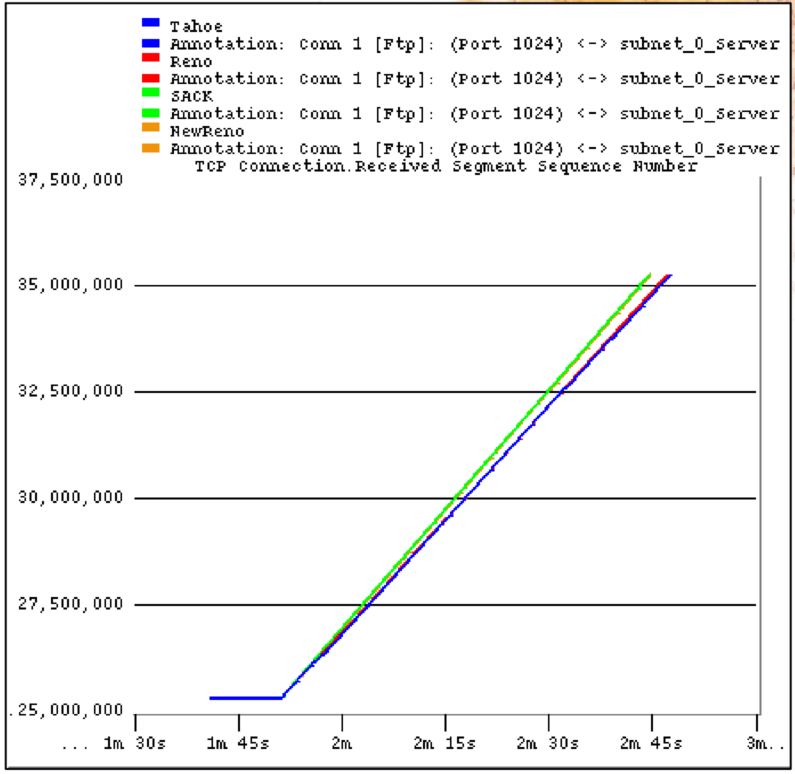
Wired network scenario: throughput and goodput





- TCP Reno with SACK shows higher throughput and goodput than the remaining three algorithms

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Conclusions

- We simulated and compared performance of various TCP algorithms in wireless and wired networks
- Simulation results indicated that in wireless networks with signal attenuation, fading, and multipath, TCP Reno outperforms other congestion control algorithms in terms of congestion window size and file download response time
- Throughput and goodput in the case of TCP Reno is also higher than in the remaining three algorithms
- In wired networks, TCP Reno shows significant performance degradation in case of multiple packet losses
- The overall performance of TCP Reno with SACK and TCP NewReno is comparable in terms of file download response time even though TCP Reno with SACK does not exhibit sharp decrease in congestion window as TCP NewReno when a packet loss occurs
- TCP Reno with SACK shows higher throughput and goodput than the remaining three algorithms

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