High-Performance Transport Protocols for Data-Intensive World-Wide Grids

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Outline

- Overview of DataTAG project
- Problems with TCP in data-intensive Grids
  - Problem statement
  - Analysis and characterization
- Solutions:
  - Scalable TCP
  - GridDT
- Future Work

Overview of
DataTAG Project

Member Organizations

CERN

INFN
ISTITUTO NAZIONALE DI FISICA NUCLEARE

INRIA

PPARC

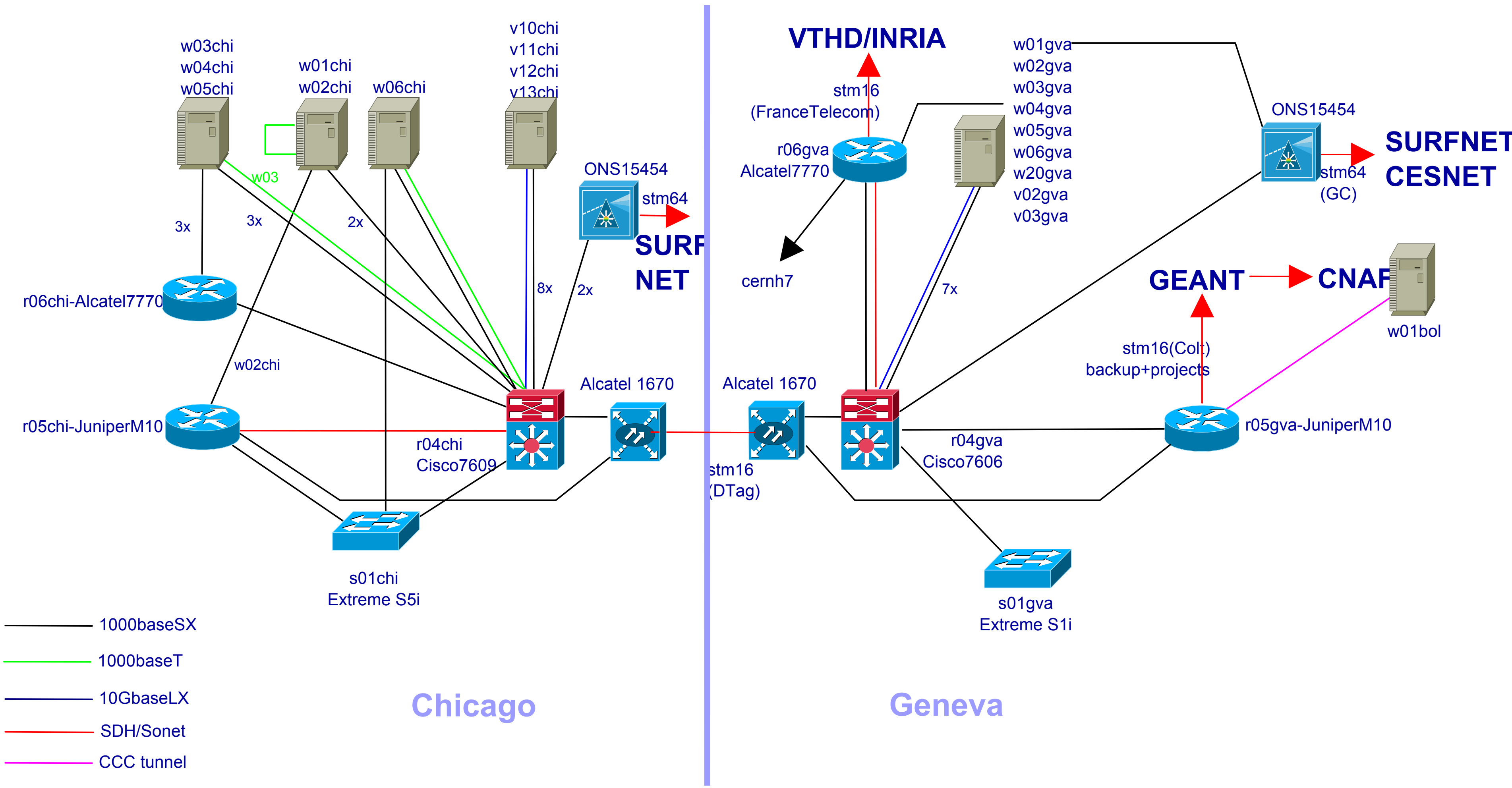
UNIVERSITEIT VAN AMSTERDAM

http://www.datatag.org/

Project Objectives

- Build a testbed to experiment with massive file transfers (TBytes) across the Atlantic
- Provide high-performance protocols for gigabit networks underlying data-intensive Grids
- Guarantee interoperability between major HEP Grid projects in Europe and the USA

DataTAG Testbed



Edoardo Martelli

Records Beaten Using DataTAG Testbed

- Internet2 IPv4 land speed record:
  - February 27, 2003
  - 10,037 km
  - 2.38 Gbit/s for 3,700 s
  - MTU: 9,000 Bytes
- Internet2 IPv6 land speed record:
  - May 6, 2003
  - 7,067 km
  - 983 Mbit/s for 3,600 s
  - MTU: 9,000 Bytes
- http://lsr.internet2.edu/

Network Research Activities

- Enhance performance of network protocols for massive file transfers:
  - Data-transport layer: TCP, UDP, SCTP
- QoS:
  - LBE (Scavenger)
  - Equivalent DiffServ (EDS)
- Bandwidth reservation:
  - AAA-based bandwidth on demand
  - Lightpaths managed as Grid resources
- Monitoring

Rest of this talk

Problems with TCP in Data-Intensive Grids

Problem Statement

- *End-user's perspective:*
  - Using TCP as the data-transport protocol for Grids leads to a poor bandwidth utilization in fast WANs
- *Network protocol designer's perspective:*
  - TCP is inefficient in high bandwidth*delay networks because:
    - few TCP implementations have been tuned for gigabit WANs
    - TCP was not designed with gigabit WANs in mind

Design Problems (1/2)

- TCP's congestion control algorithm (AIMD) is not suited to gigabit networks
- Due to TCP's limited feedback mechanisms, line errors are interpreted as congestion:
  - Bandwidth utilization is reduced when it shouldn't
- RFC 2581 (which gives the formula for increasing *cwnd*) "forgot" delayed ACKs:
  - Loss recovery time twice as long as it should be

Design Problems (2/2)

- TCP requires that ACKs be sent at most every second segment:
  - Causes ACK bursts
  - Bursts are difficult to handle by kernel and NIC

AIMD (1/2)

- Van Jacobson, SIGCOMM 1988
- Congestion avoidance algorithm:
  - For each ACK in an RTT without loss, increase:

$$cwnd_{i+1} = cwnd_i + \frac{1}{cwnd_i}$$

  - For each window experiencing loss, decrease:

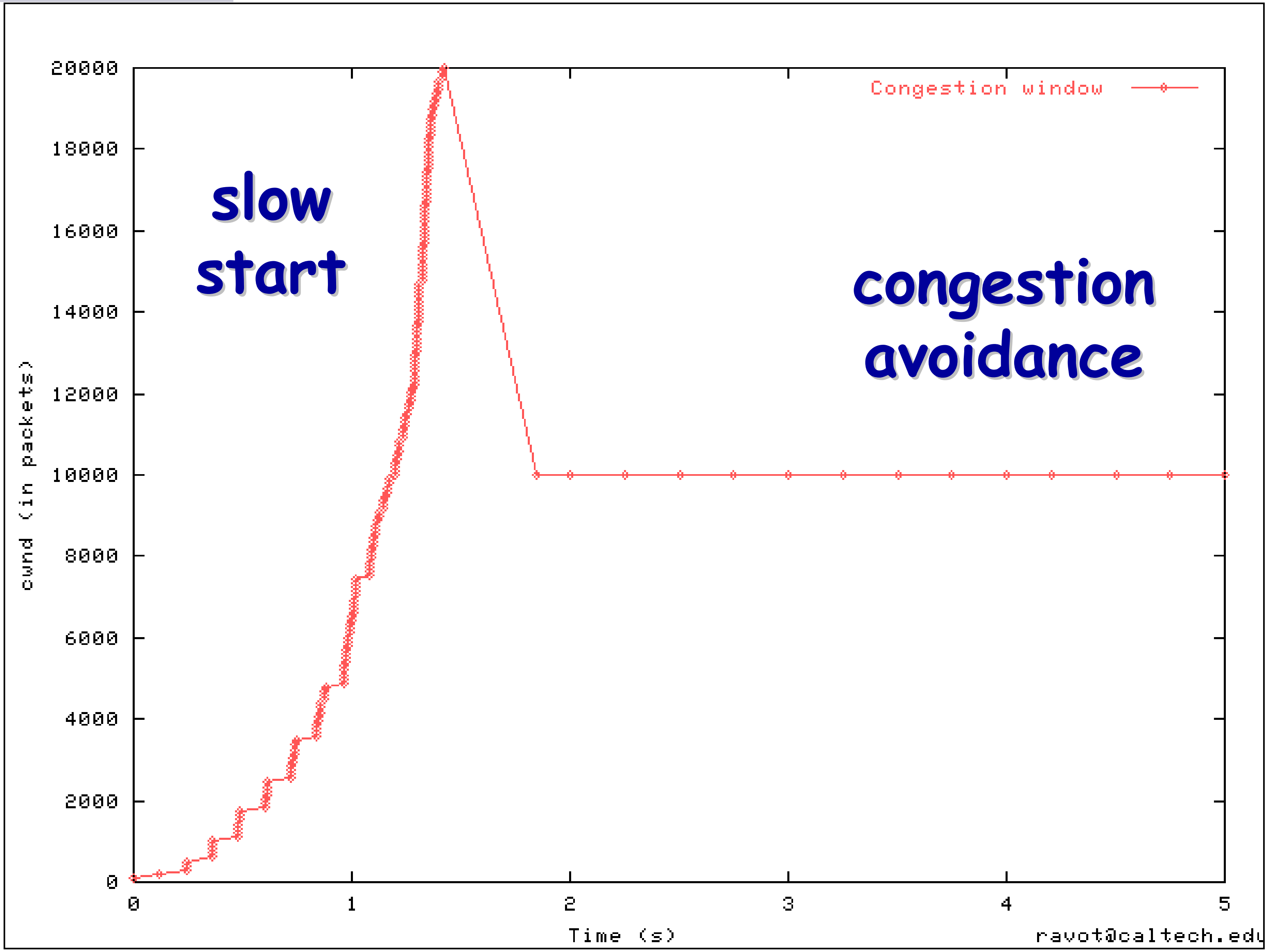
$$cwnd_{i+1} = \frac{1}{2} \times cwnd_i$$

- Slow-start algorithm:
  - Increase by one MSS per ACK until *ssthresh*

AIMD (2/2)

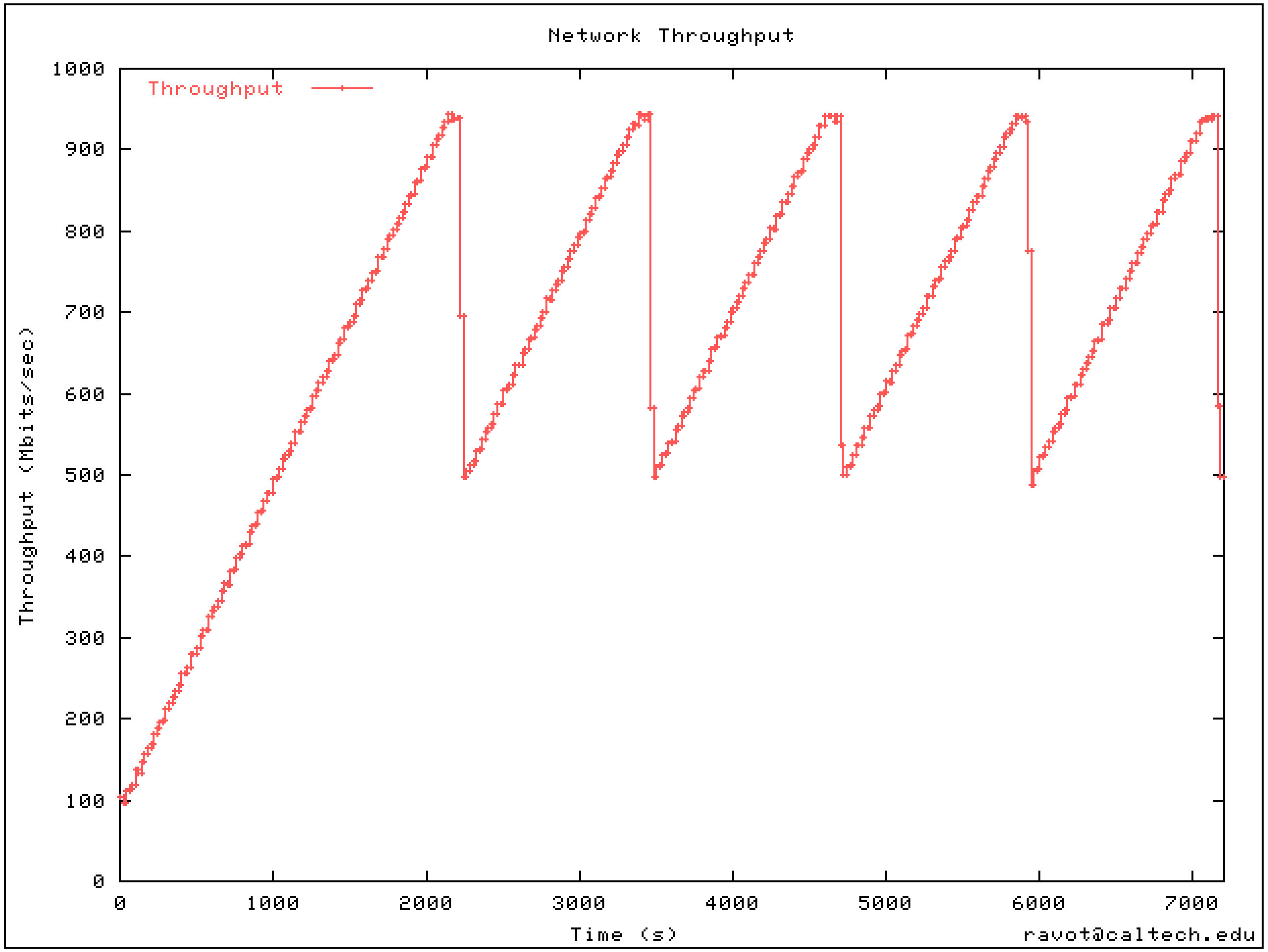
- Additive Increase:
  - A TCP connection increases slowly its bandwidth utilization in the absence of loss:
    - forever, unless we run out of send/receive buffers or detect a packet loss
    - TCP is greedy: no attempt to reach a stationary state
- Multiplicative Decrease:
  - A TCP connection reduces its bandwidth utilization drastically whenever a packet loss is detected:
    - assumption: line errors are negligible, hence packet loss means congestion

Congestion Window (*cwnd*)



Disastrous Effect of Packet Loss on TCP in Fast WANs (1/2)

AIMD C=1 Gbit/s MSS=1,460 Bytes



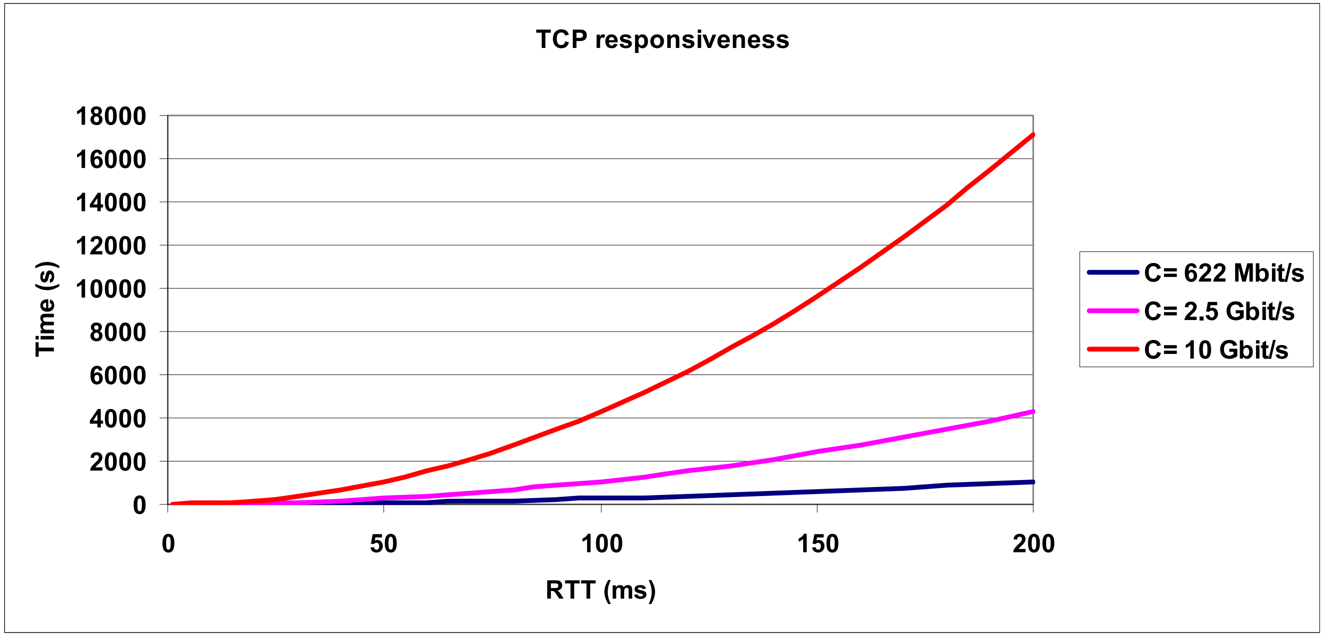
Disastrous Effect of Packet Loss on TCP in Fast WANs (2/2)

- Long time to recover from a single loss:
  - TCP should react to congestion rather than packet loss:
    - line errors and transient faults in equipment are no longer negligible in fast WANs
  - TCP should recover quicker from a loss
- TCP is particularly sensitive to packet loss in fast WANs (i.e., when both *cwnd* and RTT are large)

Characterization of the Problem (1/2)

The *responsiveness* ρ measures how quickly we go back to using the network link at full capacity after experiencing a loss (i.e., loss recovery time if loss occurs when bandwidth utilization = network link capacity)

$$\rho = \frac{C \cdot RTT^2}{2 \cdot inc}$$



Characterization of the Problem (2/2)

inc size = MSS = 1,460 Bytes

Capacity	RTT	# inc	Responsiveness
9.6 kbit/s (typ. WAN in 1988)	max: 40 ms	1	0.6 ms
10 Mbit/s (typ. LAN in 1988)	max: 20 ms	8	~150 ms
100 Mbit/s (typ. LAN in 2003)	max: 5 ms	20	~100 ms
622 Mbit/s	120 ms	~2,900	~6 min
2.5 Gbit/s	120 ms	~11,600	~23 min
10 Gbit/s	120 ms	~46,200	~1h 30min

DataTAG

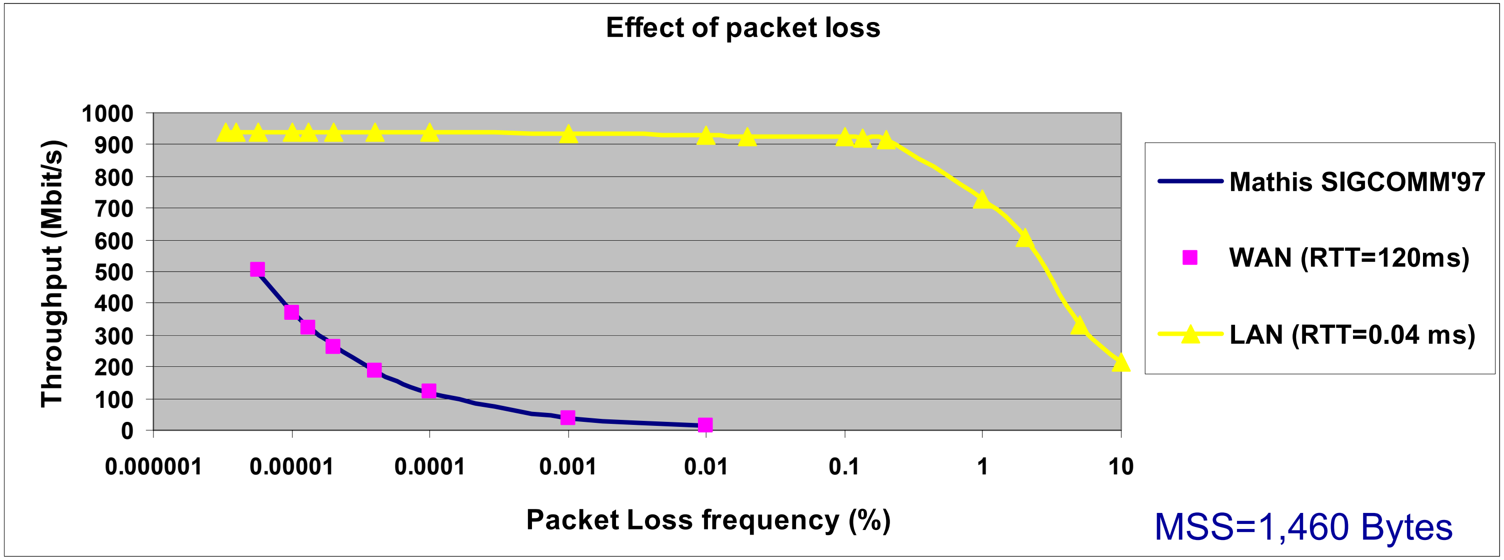
Congestion vs. Line Errors

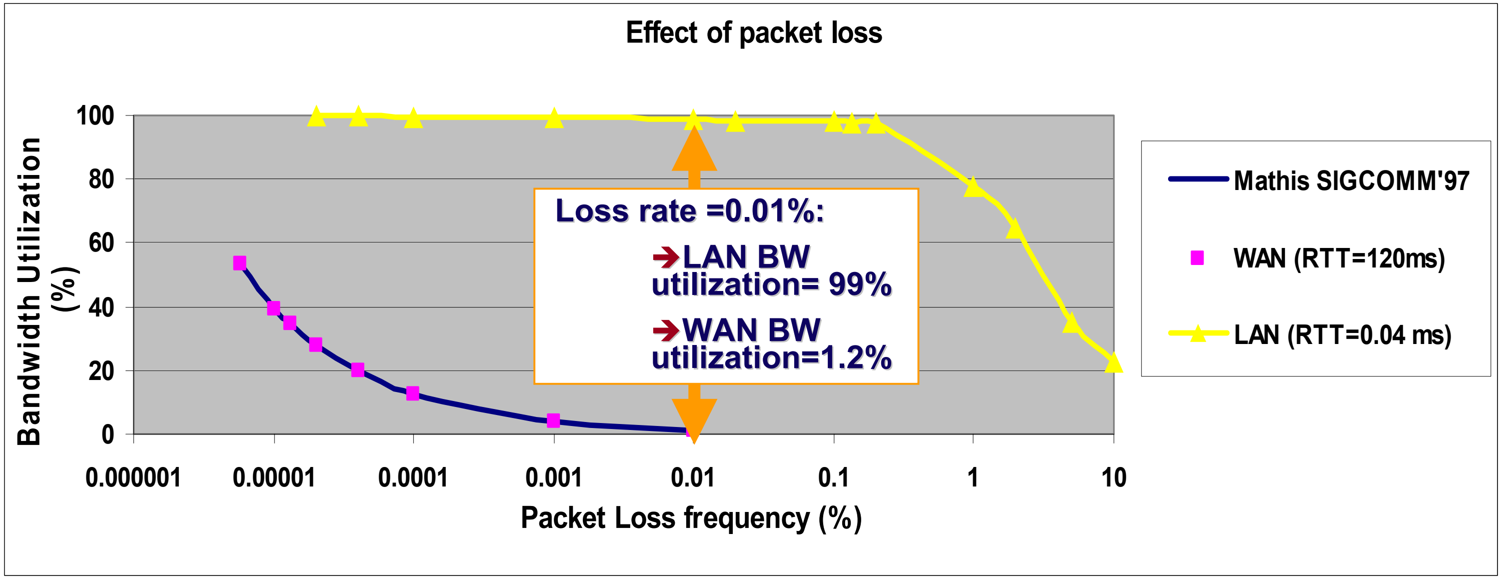
RTT=120 ms, MTU=1,500 Bytes, AIMD

Throughput	Required Bit Loss Rate	Required Packet Loss Rate
10 Mbit/s	**$2\ 10^{-8}$**	**$2\ 10^{-4}$**
100 Mbit/s	**$2\ 10^{-10}$**	**$2\ 10^{-6}$**
2.5 Gbit/s	**$3\ 10^{-13}$**	**$3\ 10^{-9}$**
10 Gbit/s	**$2\ 10^{-14}$**	**$2\ 10^{-10}$**

At gigabit speed, the loss rate required for packet loss to be ascribed only to congestion is unrealistic with AIMD

Single TCP Stream Performance under Periodic Losses





Solutions

What Can We Do?

- To achieve higher throughputs over high bandwidth*delay networks, we can:
  - Fix AIMD
  - Change congestion avoidance algorithm:
    - Kelly: Scalable TCP
    - Ravot: GridDT
  - Use larger MTUs
  - Change the initial setting of *ssthresh*
  - Avoid losses in end hosts

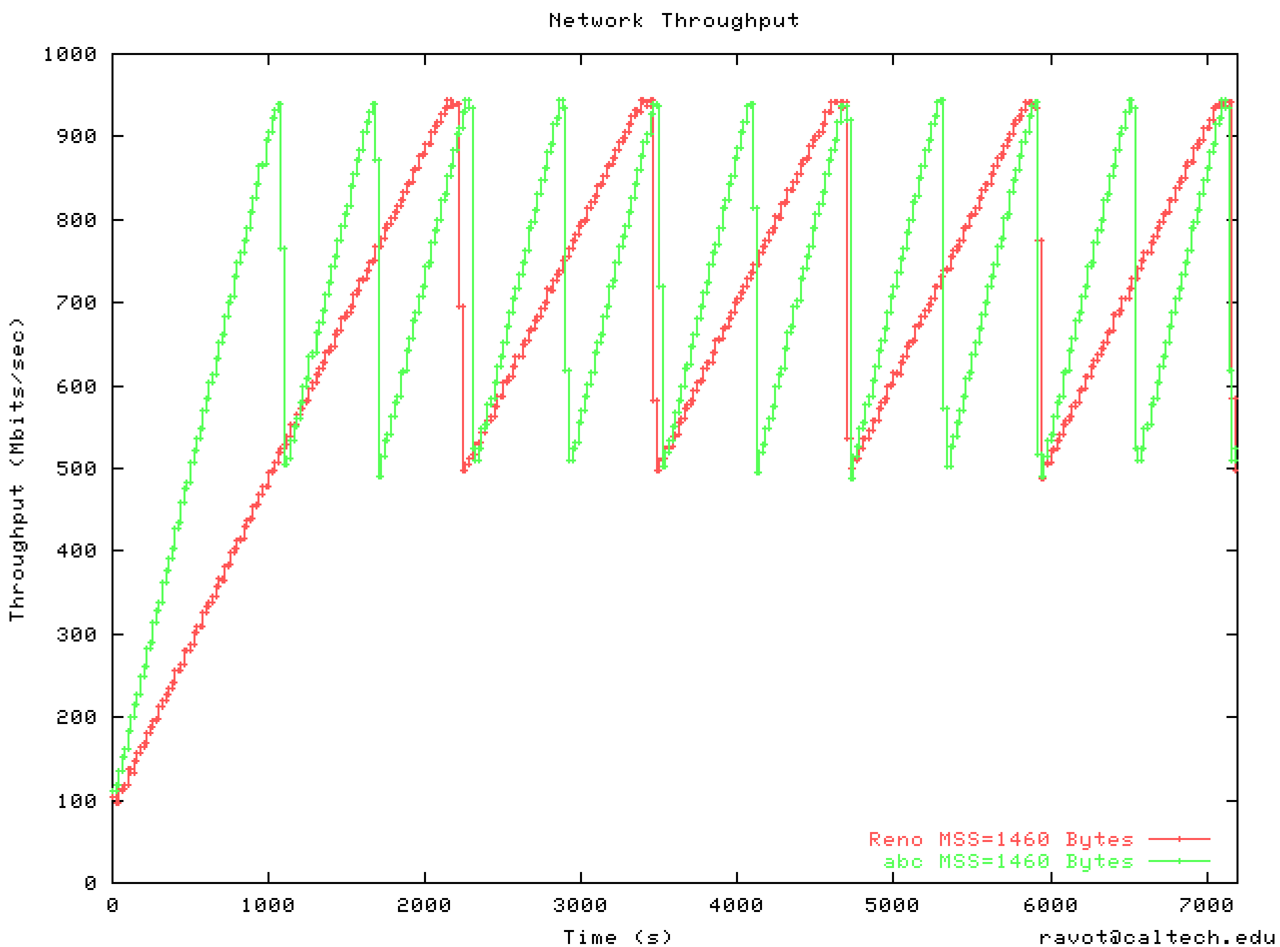
Delayed ACKs with AIMD

- RFC 2581 (spec. defining TCP congestion control AIMD algorithm) erred:

$$cwnd_{i+1} = cwnd_i + \frac{SMSS \times SMSS}{cwnd_i}$$

- Implicit assumption: one ACK per packet
- In reality: one ACK every second packet with delayed ACKs
- Responsiveness multiplied by two:
  - Makes a bad situation worse in fast WANs
- Problem fixed by ABC in RFC 3465 (Feb 2003)
  - Not implemented in Linux 2.4.21

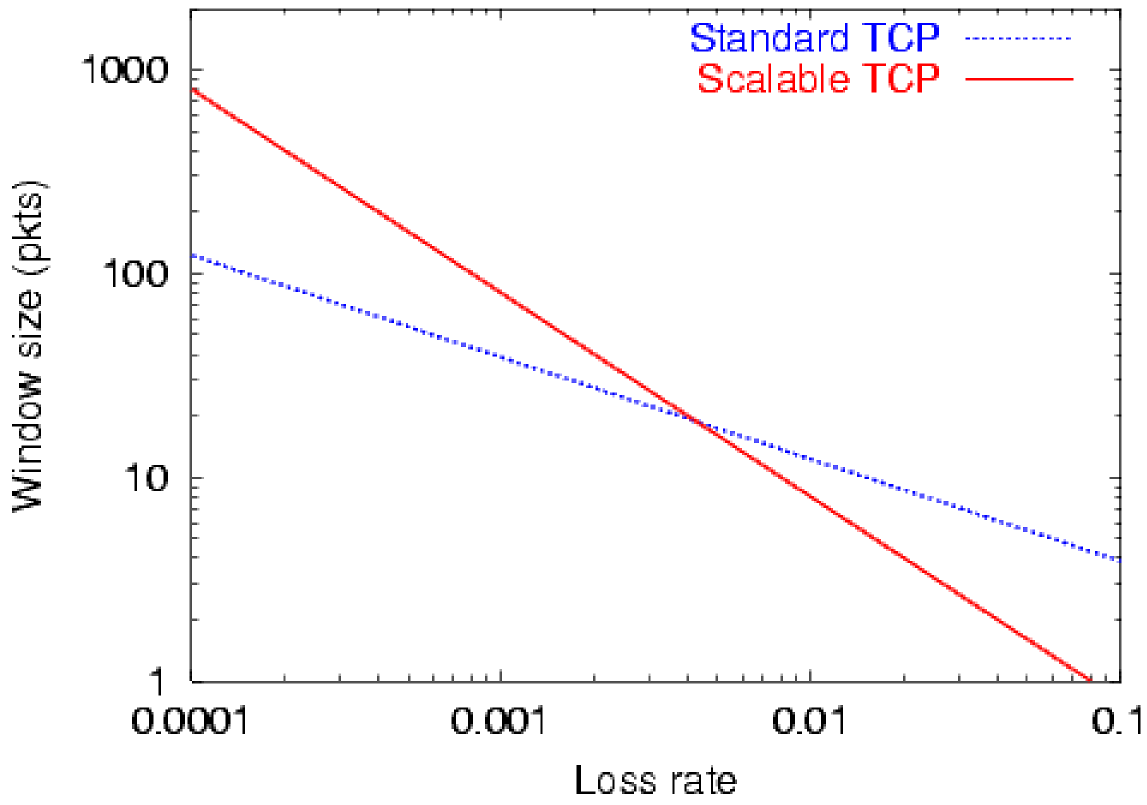
Delayed ACKs with AIMD and ABC



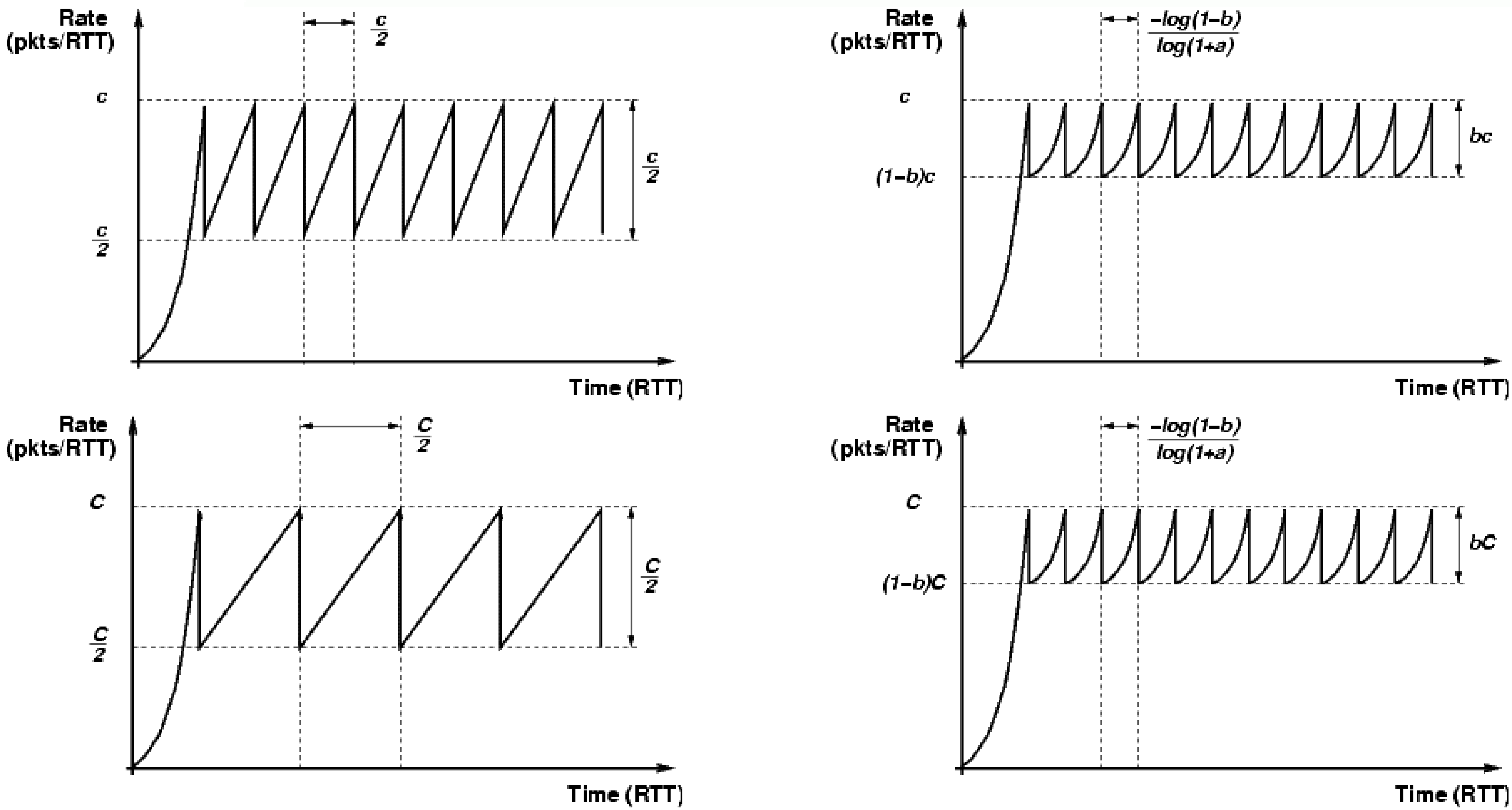
Scalable TCP: Algorithm

- For cwnd>lwnd, replace AIMD with new algorithm:
  - for each ACK in an RTT without loss:
    - $cwnd_{i+1} = cwnd_i + a$
  - for each window experiencing loss:
    - $cwnd_{i+1} = cwnd_i - (b \times cwnd_i)$
- Kelly’s proposal during internship at CERN: (lwnd,a,b) = (16, 0.01, 0.125)
  - Trade-off between fairness, stability, variance and convergence

Scalable TCP: *lwnd*



Scalable TCP: Responsiveness Independent of Capacity



Scalable TCP: Improved Responsiveness

- Responsiveness for RTT=200 ms and MSS=1,460 Bytes:
  - Scalable TCP: ~3 s
  - AIMD:
    - ~3 min at 100 Mbit/s
    - ~1h 10min at 2.5 Gbit/s
    - ~4h 45min at 10 Gbit/s
- Patch against Linux kernel 2.4.19:
  - http://www-lce.eng.cam.ac.uk/˜ctk21/scalable/

Scalable TCP vs. AIMD: Benchmarking

Number of flows	2.4.19 TCP	2.4.19 TCP + new dev driver	Scalable TCP
1	**7**	**16**	**44**
2	**14**	**39**	**93**
4	**27**	**60**	**135**
8	**47**	**86**	**140**
16	**66**	**106**	**142**

Bulk throughput tests with C=2.5 Gbit/s. Flows transfer 2 GBytes and start again for 20 min.

GridDT: Algorithm

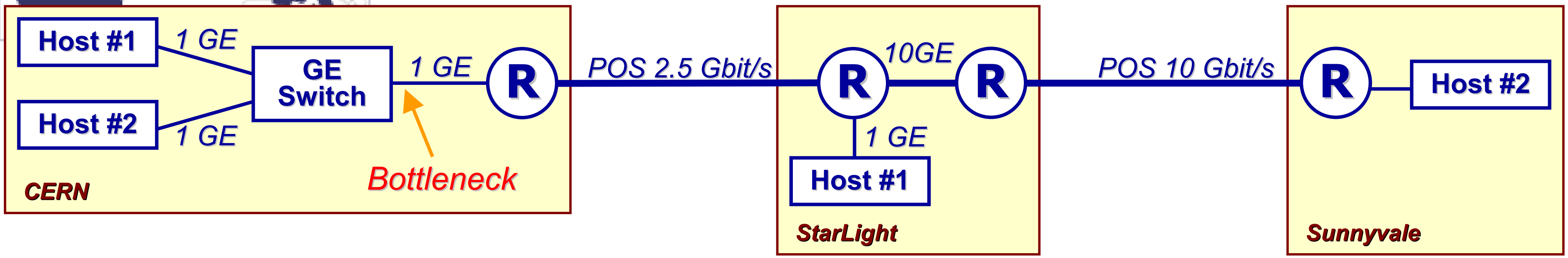
- Congestion avoidance algorithm:
  - For each ACK in an RTT without loss, increase:

$$cwnd_{i+1} = cwnd_i + \frac{A}{cwnd_i}$$

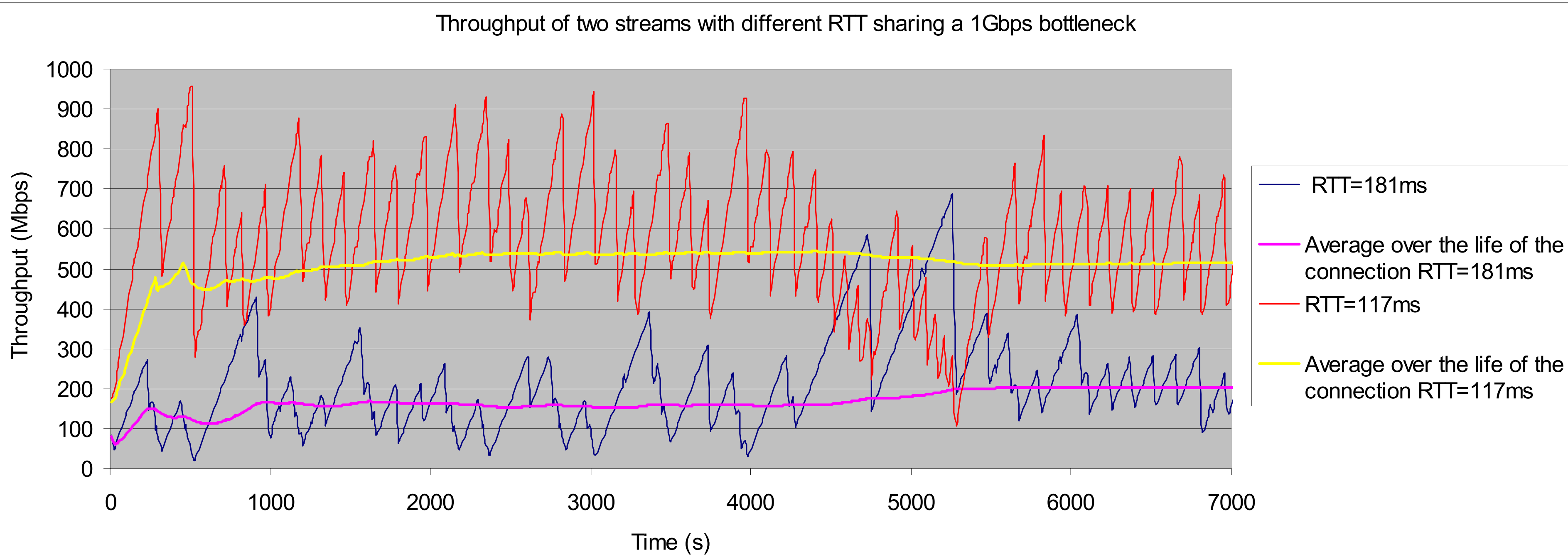
- By modifying A dynamically according to RTT, GridDT guarantees fairness among TCP connections:

$$\frac{A1}{A2} = \left(\frac{RTT_{A1}}{RTT_{A2}} \right)^2$$

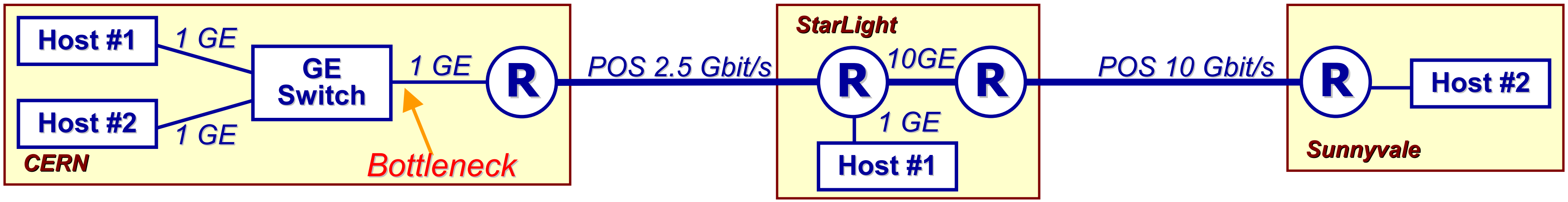
AIMD: RTT Bias



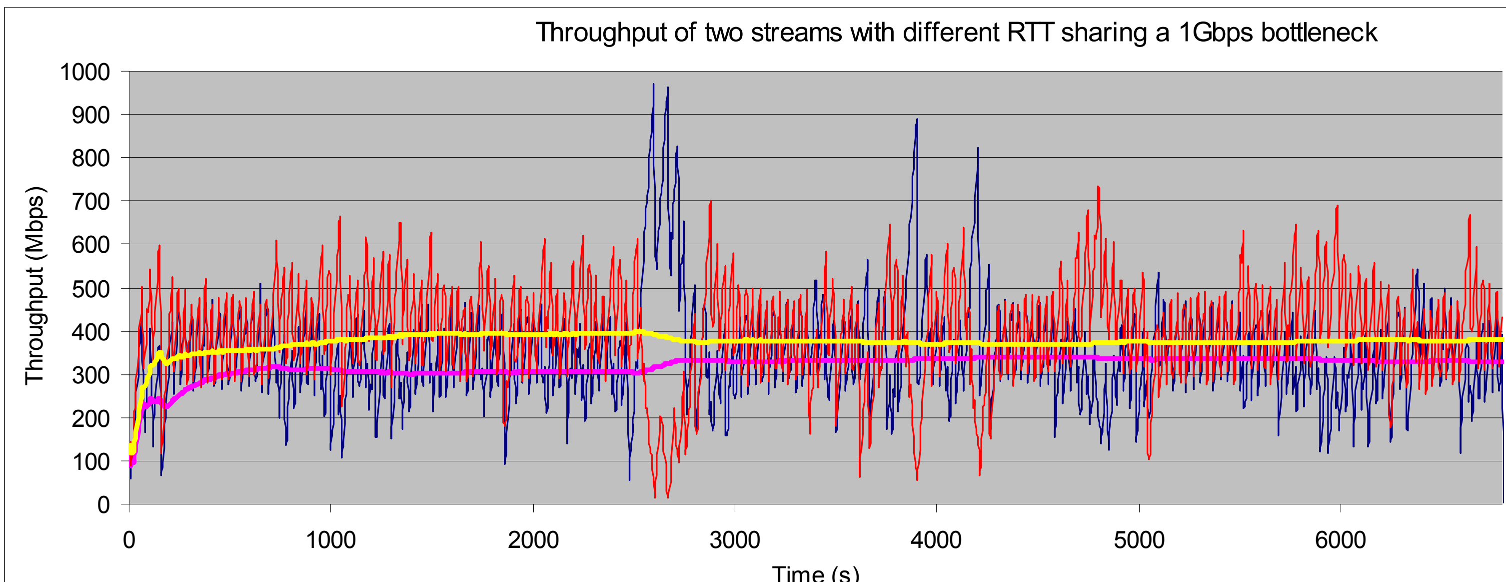
- Two TCP streams share a 1 Gbit/s bottleneck
- CERN-Sunnyvale: RTT=181ms. Avg. throughput over a period of 7,000s = 202 Mbit/s
- CERN-StarLight: RTT=117ms. Avg. throughput over a period of 7,000s = 514 Mbit/s
- MTU = 9,000 Bytes. Link utilization = 72%



GridDT Fairer than AIMD



- CERN-Sunnyvale: RTT = 181 ms. Additive inc. A1 = 7. Avg. throughput = 330 Mbit/s
- CERN-StarLight: RTT = 117 ms. Additive inc. A2 = 3. Avg. throughput = 388 Mbit/s
- MTU = 9,000 Bytes. Link utilization 72%



$$\left(\frac{RTT_{A1}}{RTT_{A2}}\right)^2 = \left(\frac{181}{117}\right)^2 = 2.39$$

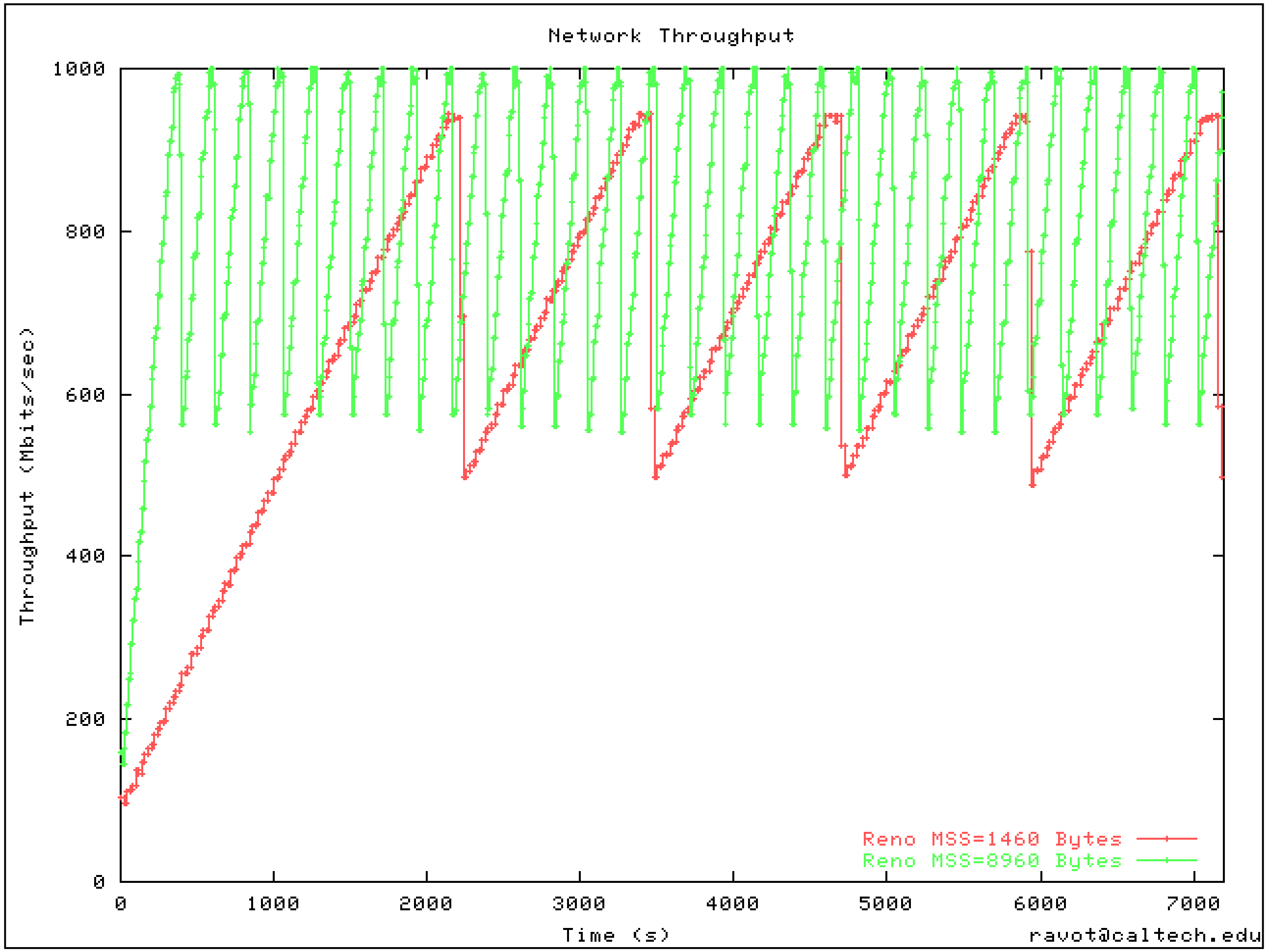
$$\frac{A1}{A2} = \frac{7}{3} = 2.33$$

Larger MTUs (1/2)

- Advocated by Mathis
- Experimental environment:
  - Linux 2.4.21
  - SysKonnect device driver 6.12
  - Traffic generated by iperf:
    - average throughput over the last 5 seconds
  - Single TCP stream
  - RTT = 119 ms
  - Duration of each test: 2 hours
  - Transfers from Chicago to Geneva
- MTUs:
  - POS MTU: 9180 Bytes
  - MTU on the NIC: 9000 Bytes

Larger MTUs (2/2)

TCP max: 990 Mbit/s (MTU=9000)
TCP max: 940 Mbit/s (MTU=1500)



Related Work

- Floyd: High-Speed TCP
- Low: Fast TCP
- Katabi: XCP
- Web100 and Net100 projects
- PFLDnet 2003 workshop:
  - http://www.datatag.org/pfldnet2003/

Research Directions

- Compare performance of TCP variants
- Investigate proposal by Shorten, Leith, Foy and Kildu
- More stringent definition of congestion:
  - Lose more than 1 packet per RTT
- ACK more than two packets in one go:
  - Decrease ACK bursts
- SCTP vs. TCP