Transport protocols for datagram satellite networks

Tom Henderson
Randy Katz

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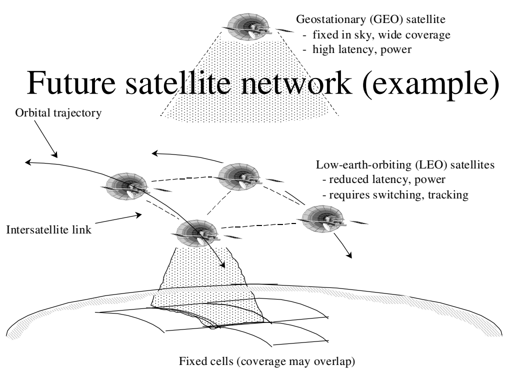
Dept. of Electrical Engineering and Computer Science
University of California at Berkeley

Outline

- How well can TCP perform over current and future satellite networks?
  - large file transfers
  - short http transfers
- What techniques can be used to improve TCP's performance?
  - how much do satellite gateways help?

Future satellite network (example)



Future satellite networks (cont.)

- Asymmetry: downlink has more capacity
  - e.g., Hughes Spaceway: 92 Mb/s down, 16-1544 kb/s up
- Latency: problematic for GEOs, reduced for LEOs
  - 270ms single satellite hop for GEO
  - 20ms single satellite hop for LEO
- Low BERs (10^{-10}) achievable

What causes TCP performance problems over satellites?

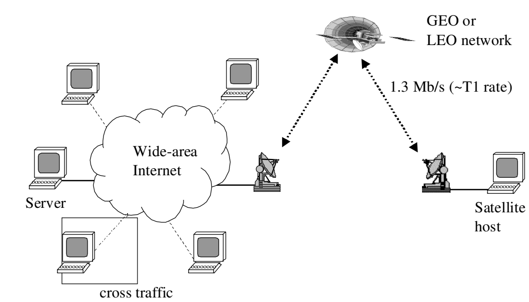
- Recent TCP additions (SACK, large windows) improve satellite performance, but...
  - Chronic latency problems
    - congestion avoidance algorithm highly unfair
    - application/kernel buffer sizes typically too small to support high speed communications
    - slow start algorithm is often too slow
  - TCP handles connection asymmetry poorly

Standard TCP performance

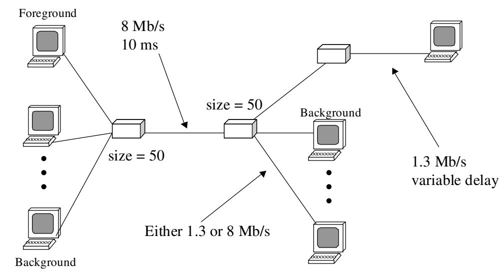
Q. So how well can TCP perform over satellite links (especially GEO links) ?

A. It depends...
- TCP with Selective Acknowledgments (SACK) and large windows can perform adequately for large file transfers under light congestion
- Otherwise, performance can be poor

Assumed network topology

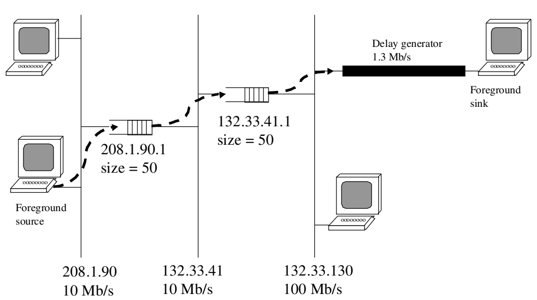


Simulation configuration



UCB/LBL network simulator (ns)

Experimental validation



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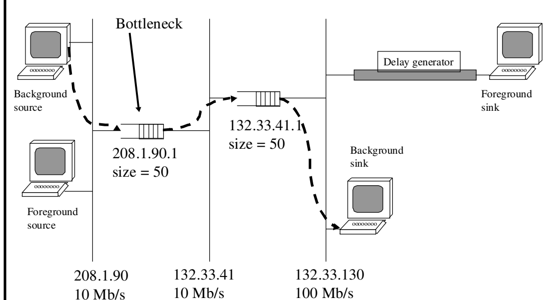
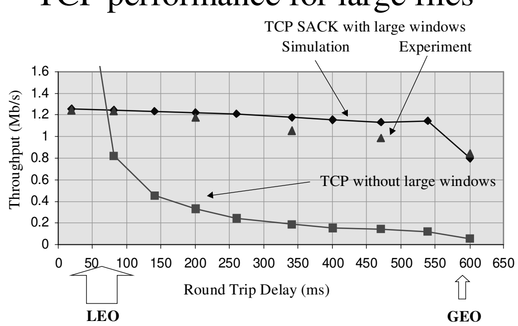
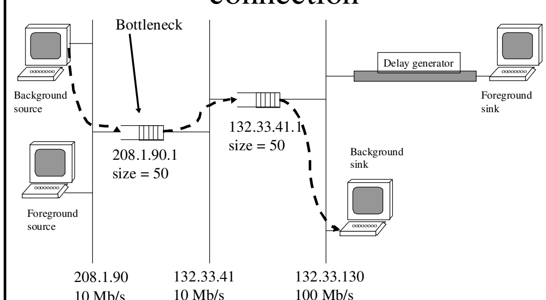


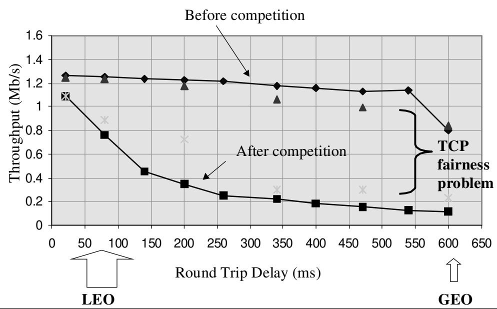
TCP performance for large files



Persistent background TCP connection



Performance with single persistent background flow



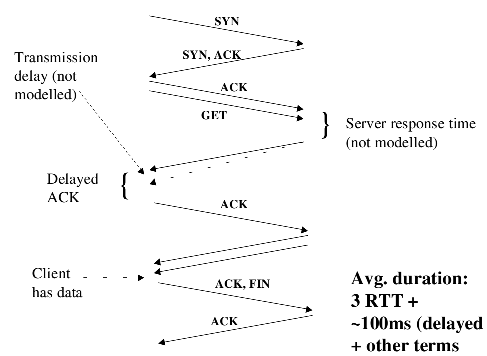
Web transfers

- HTTP traces analyzed
  - Bruce Mah's 1995 traces (Berkeley subnet)
  - Steve Gribble's 1996 traces (Home-IP)
- Four TCP combinations examined:
  - standard
  - T/TCP (TCP for Transactions)
  - standard with 4K slow start (4 segments)
  - T/TCP with 4K slow start

Analysis

- Analysis considered RTT effects on user-perceived latency
- Used pdfs derived from traces to estimate the minimum, mean, and median latencies
- Assumed no packet errors, fixed RTT, and no server delays or transmission delays

Example: 3 segment reply



Avg. duration:
3 RTT +
~100ms (delayed ACK)
+ other terms

GEO latency effects of TCP

	Home-IP traces		
	minimum	median	mean
TCP	1.2	2.5	2.4
T/TCP	0.6	1.9	1.8
TCP with 4K	1.2	1.2	1.7
T/TCP with 4K	0.6	0.6	1.1

All times in seconds, and do not include server latency and transmission delay

	Subnet traces		
	minimum	median	mean
TCP	1.2	1.9	2.0
T/TCP	0.6	1.3	1.4
TCP with 4K	1.2	1.2	1.5
T/TCP with 4K	0.6	0.6	0.9

LEO latency effects of TCP

	Home-IP traces		
	minimum	median	mean
TCP	0.16	0.42	0.42
T/TCP	0.08	0.34	0.34
TCP with 4K	0.16	0.16	0.22
T/TCP with 4K	0.08	0.08	0.14

LEO RTT = 80 ms

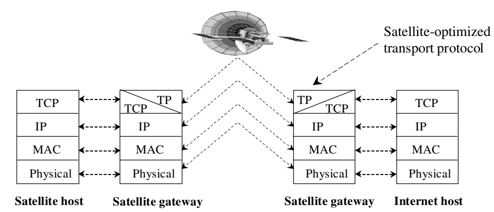
	Subnet traces		
	minimum	median	mean
TCP	0.16	0.34	0.35
T/TCP	0.08	0.26	0.27
TCP with 4K	0.16	0.16	0.20
T/TCP with 4K	0.08	0.08	0.12

Alternatives for improving performance

1) Move to LEO satellite networks
   – solves latency but not asymmetry problems
   – LEO constellations are long term solutions
2) Modify the end-system protocol
   – TCP standard is difficult to change
   – unilateral changes offer only modest improvement
3) Split the transport connection
   – shields users from latency and asymmetry

Splitting transport connections

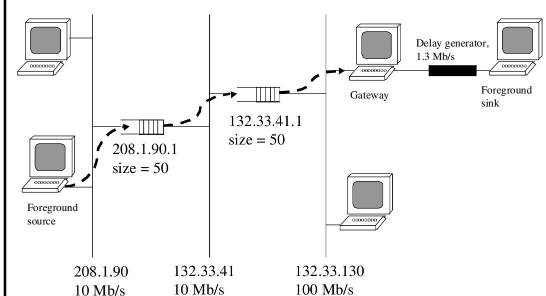
- Split connections isolate special network segment from rest of network



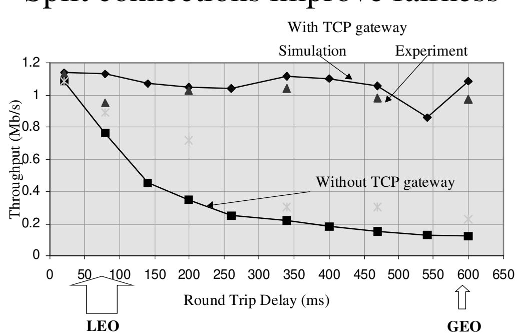
Splitting transport connections

- Drawbacks to split connections:
  – requires gateway implementations
  – breaks TCP semantics
  – IPSEC blocks TCP header snooping

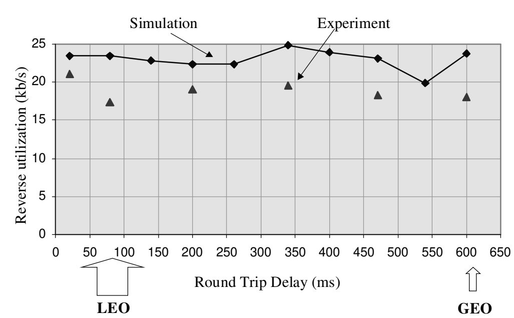
Experimental validation



Split connections improve fairness



TCP reverse channel utilization



Satellite Transport Protocol (STP)

- An ATM link layer protocol (SSCOP) has desirable satellite features

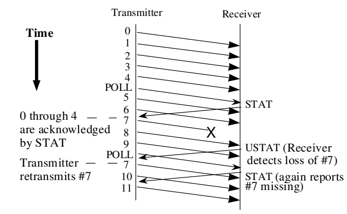
TCP (transport layer)
- "fast retransmit"

SSCOP (link layer)
- error recovery mechanism

Further modifications
- congestion control mechanism
- connection control

Satellite Transport Protocol (STP)

Basic SSCOP operation

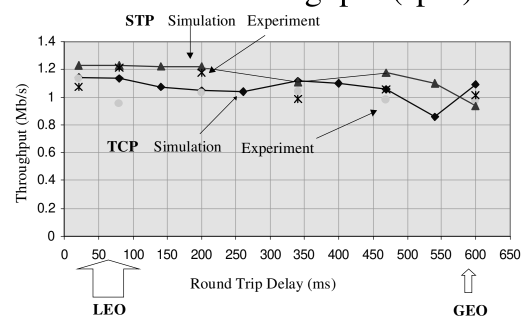


Full, periodic state exchange is the basic design philosophy

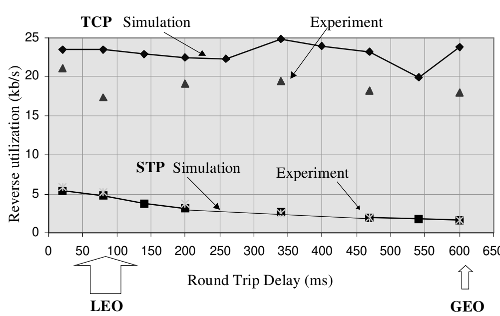
Our modifications

- SSCOP requires in-sequence delivery
  - Future satellite connections may traverse multiple hops
- Congestion control never completed
  - SSCOP is used as a signaling link layer
  - Want rate control and standard congestion control
- Want to enable data transfer during connection setup (like T/TCP)

STP forward throughput (split)



STP reverse channel utilization



STP performance over actual networks

- DirecPC satellite network (400 ms hop in forward direction, 56 kb/s link in return)
  - STP
    - fwd (kb/s)- 407 kb/s
    - rev (kb/s)- 2.0 kb/s
  - TCP-Sack
    - fwd (kb/s)- 253 kb/s
    - rev (kb/s)- 4.7 kb/s
- Richochet packet radio network
  - STP
    - fwd (kb/s)- 33.4 kb/s
    - rev (kb/s)- 0.2 kb/s
  - TCP-Sack
    - fwd (kb/s)- 27.6 kb/s
    - rev (kb/s)- 0.9 kb/s

STP status

- *ns* implementation and simulation scripts already available on web
- UNIX kernel implementation will be released this spring
- Formal STP specification to be completed

Related activities

- IETF informational RFC under preparation
  - describes what options to use
- DoD recently approved "TCP for space communications"
  - bilateral protocol extensions
- "4K slow start" being studied by NASA
  - under consideration by TCP implementors group at IETF

Transport conclusions

- TCP over satellite can work well for large file transfers over lightly utilized paths
- Otherwise, split-connection approaches can reduce the effects of latency
- More efficient transport protocols (STP) are better suited for asymmetric satellite environment

Future directions

- Unicast routing and addressing for hybrid LEO/GEO satellite networks
- Multicast routing and IGMP scaling