An Application-Level Solution to TCP's Satellite Inefficiencies

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Why Does TCP Have Problems?

- TCP was designed to be a general-purpose, reliable stream protocol
  - Works well in many different types of network environments
  - Used for many widely-used types of applications
    - file transfer (FTP)
    - remote login (TELNET,rlogin)
    - email (SMTP)
    - news (NNTP)
    - WWW (HTTP)

Does TCP Work Correctly Over Satellite Links?

- **YES!**
  - No errors introduced
  - No file corruption
  - No “tragic flaws”

Why Does TCP Have Problems?

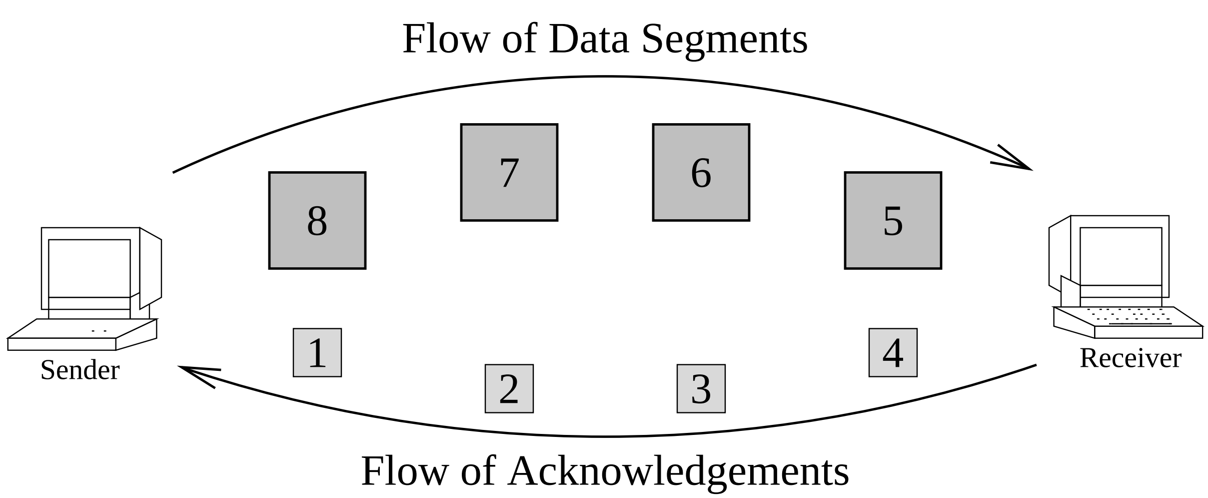
- Although TCP works "correctly", it is unable to use the entire bandwidth of the satellite link in this environment
  - Satellite links introduce a large delay
    - $\approx$ 560 milliseconds over the NASA ACTS satellite
    - Limits TCP's maximum throughput
  - Satellite link error characteristics
    - TCP assumes that when data is lost, it's because intervening routers are overloaded
      - Called router congestion
      - TCP responds by slowing down

Receiving Window Implications

- In a *sliding window* protocol like TCP, there can only be a fixed amount of data on the link at any one time
  - Called the "receiver's window" in TCP
  - In standard TCP, the maximum size of the receiver's window is 64 KBytes
- Assuming a TCP connection with a receive window that holds N packets (segments)
  - Segment S is sent as soon as the ACK for segment $(S-N)$ is received
  - This means that there can only be N segments outstanding at once
    - In the expected case, $\frac{N}{2}$ are in the form of data segments traveling toward the receiver, $\frac{N}{2}$ are returning as acknowledgments (ACKs)

TCP Receive Window Example

- As a simple example, consider this TCP connection
  - 8 Kbyte receive window
  - 1 Kbyte data packets (segments)
  - 10ms round trip time



RTT vs. Maximum Throughput

- Maximum throughput is limited by the *Round Trip Time* (RTT)
  - One "window" of data can be transmitted per RTT

$$throughput_{max} = \frac{receive\ buffer\ size}{round\ trip\ time}$$

- In the previous figure (with an RTT of 10ms), this yields

$$tput_{max} = \frac{8KBytes}{10ms} \approx 800,000 \frac{bytes}{second}$$

- Using the NASA ACTS Satellite, this yields:

$$tput_{max} = \frac{24KBytes}{560ms} \approx 44,000 \frac{bytes}{second}$$

"Obvious" Solutions to the RTT problem

- RTT limits TCP's maximum throughput
- There are (at least) 3 obvious solutions to this problem
  - Reduce the RTT
    - Move the satellites lower!
  - Increase the window size
    - Recently-proposed version of TCP (RFC 1323) allows window sizes of up to 2^{30} bytes ($\approx$ 1 GByte)
  - Use multiple TCP connections
    - That's the approach taken for the research in this presentation

XFTP

- We built a prototype multi-connection FTP client and server
  - Called XFTP
  - Prototype runs under various flavors of Unix
  - Uses an extension to the FTP application protocol to request multiple connections
  - User can control the "multiplicity" of the transfer
  - Source code is available
    - See the URL at the end of the talk

How FTP Transfers Files

- The standard FTP client application starts the TCP connection
  - FTP client opens *Passive* (listening) TCP connection on random local port
  - FTP client uses `PORT` command to tell the FTP server which port to use
  - FTP server makes an active TCP connection to that port on the client
  - The file is sent across that connection
  - TCP connection is closed when entire file has been sent

Changes to the FTP Application Protocol

- We added a command `MULT` to the FTP protocol
  - Sent from the client to the server
  - If supported, the server will respond with the maximum number of parallel TCP connections that it supports
- We use a modified version of the PORT command
  - Allows the client application to specify a list of ports to connect to
  - Uses modified version of the FTP PORT command
    - Called MPRT
    - Better solution is extended EPRT command (see IETF Draft)

Changes to the FTP user interface

- There needs to be a way for the user to request multiple-connection transfers
  - Details depend on user interface
- Our prototype adds a new user-level command `MULT`
  - With no arguments, requests that the client and server applications negotiate a default number of connections (currently 4)
  - With an argument, requests that number of connections
    - Actual number of connections used will depend on configuration limits imposed by both the client and the server application

Dividing a File across Multiple Connections

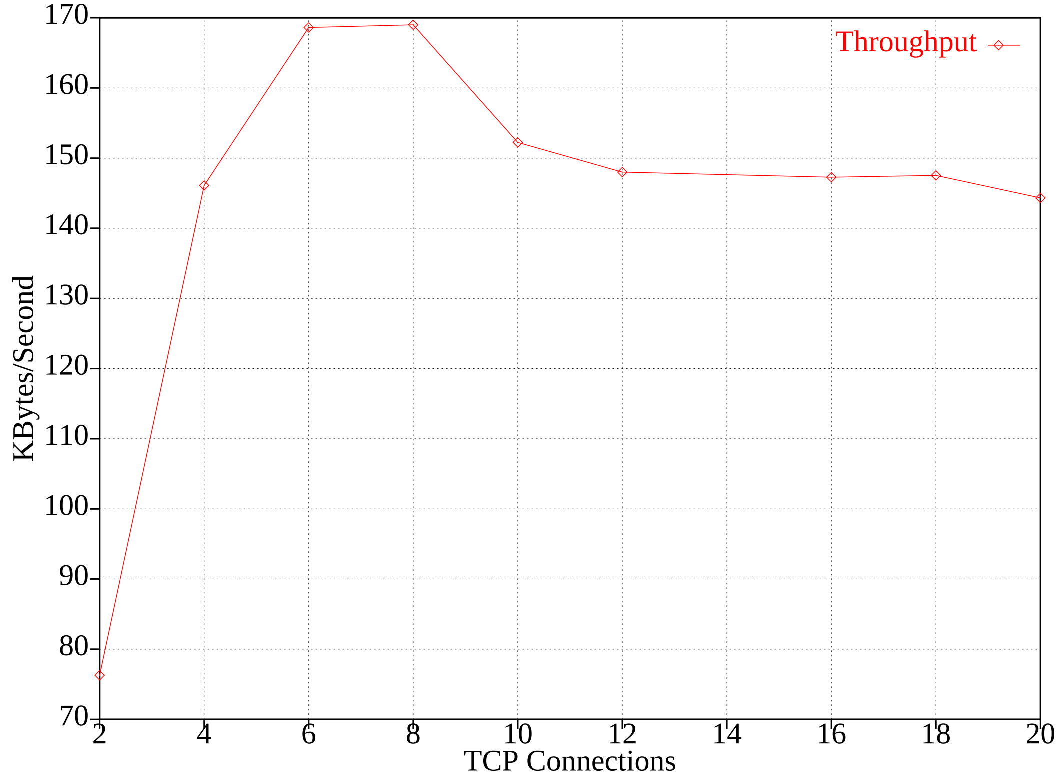
- This idea can be thought of as "*file striping*"
- Divides a files across multiple connections
- Naive design can result in poor performance
  - Not all of the TCP connections will progress at the same rate
    - Don't all start at the same time
    - All see different loss and congestion
  - Static division yields poor performance
- XFTP divides a file into 8k records
  - Number of records assumed to be much greater than the number of connections
  - Each record includes offset value
    - Allows reassembly
  - Records sent over next free connection

Initial Experiments

- We tested the original XFTP client/server using the NASA ACTS satellite
- Maximum theoretical throughput
  - T1 channel - 1.536 Mbits/second
  - 192,000 bytes/second
  - TCP/IP packet overhead
    - 20 bytes of IP header
    - 20 bytes of TCP header
    - 512 bytes of TCP data
    - $\approx$ 7% overhead
  - Best possible throughput should be about 178,000 bytes/second

Initial Results

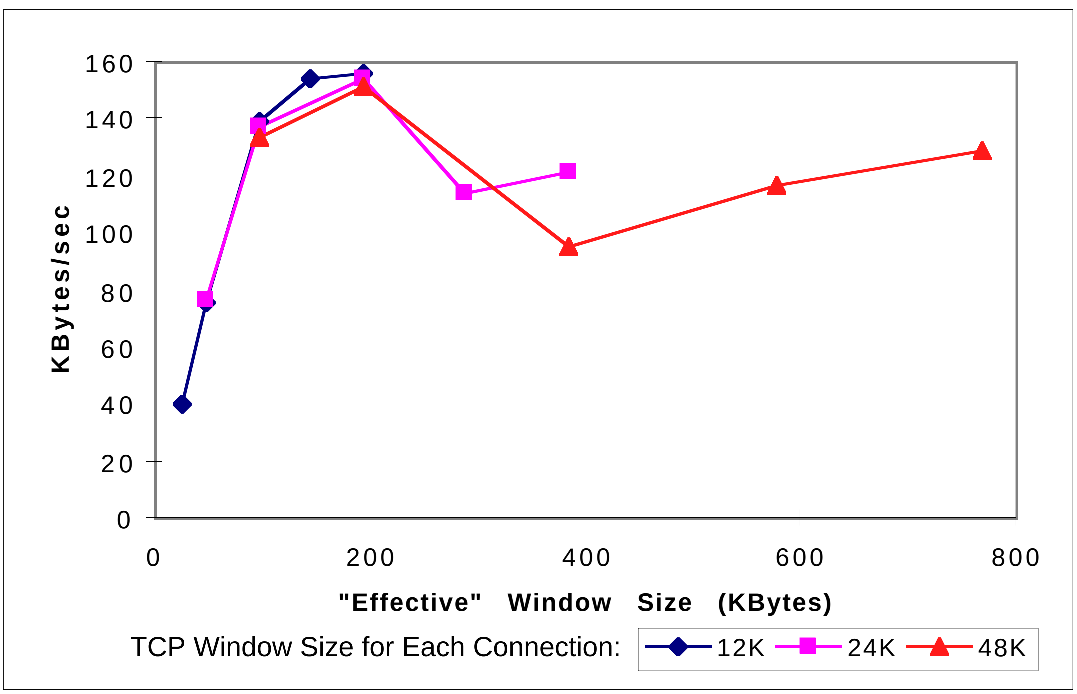
- In our initial experiments, we saw $\approx 170,000$ bytes/second (5 MByte files)
  - 96% efficiency



- Unfortunately, throughput was sensitive to the number of connections
  - Best results for 6 to 8 connections

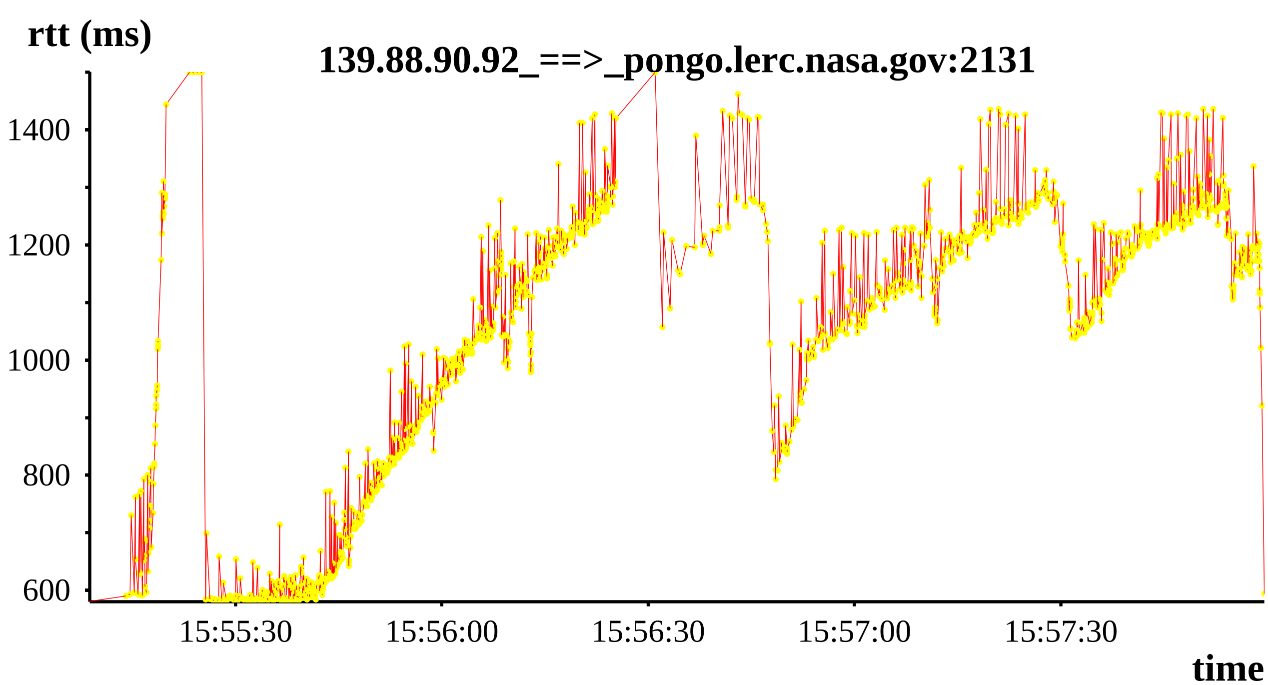
Overhead of Managing Multiple Connections

- Could multiple connections overhead be hurting application throughput?
- Ran experiment which varied the number of connections and the receive window size
  - Plotted the "effective" window size vs. throughput



What's the Problem?

- The reason that too many connections hurts performance is the interaction of TCP's congestion control and *Slow Start* algorithms and router queuing
  - Large router queues allow RTT's to grow
  - When router queues overflow, many segments from many connections are discarded
  - Loss causes connections to slow down

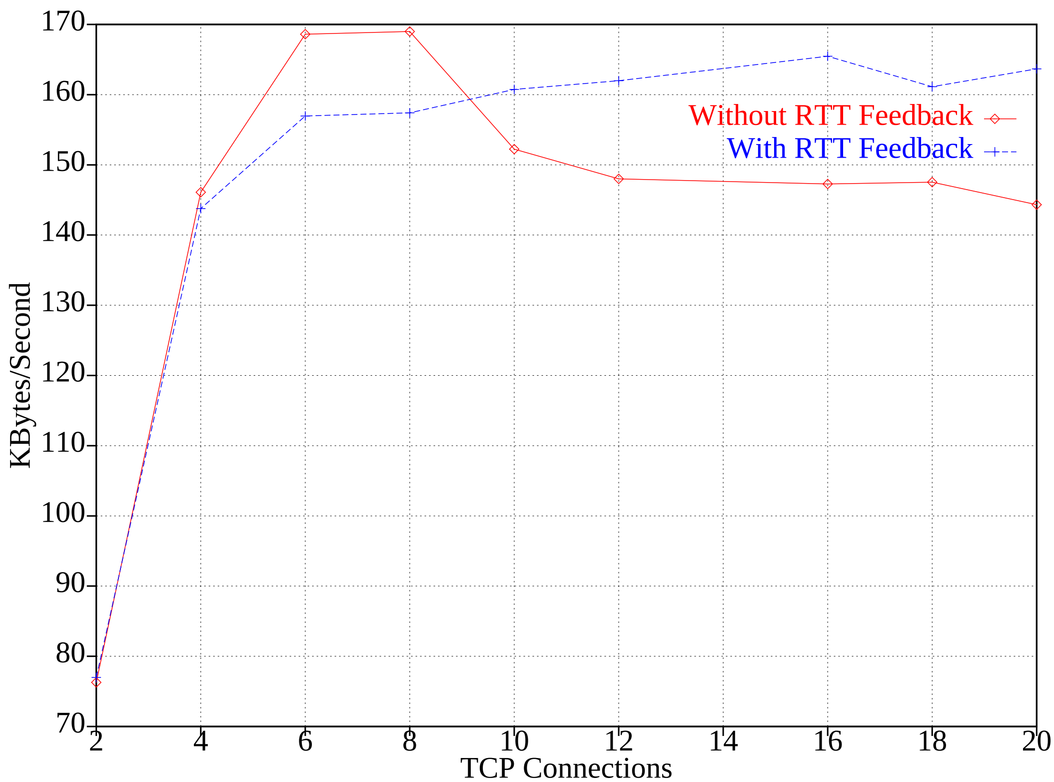


Dynamic Multiplicity Control

- XFTP monitors RTT to control the number of TCP connections in use over time
  - RTT gathered using UDP "echo" packets
  - Try to keep RTT between α and β
    - α is the expected RTT if each connection kept one "extra" segment in the network
    - β is the expected RTT if each connection kept three "extra" segments in the network
    - The concept is similar to TCP Vegas
  - α and β roughly correspond to too little and too much data in the network
  - If the observed RTT falls below α, a connection is added (up to the maximum number of connections)
  - If the observed RTT exceeds β, half the connections currently in use are "turned off"

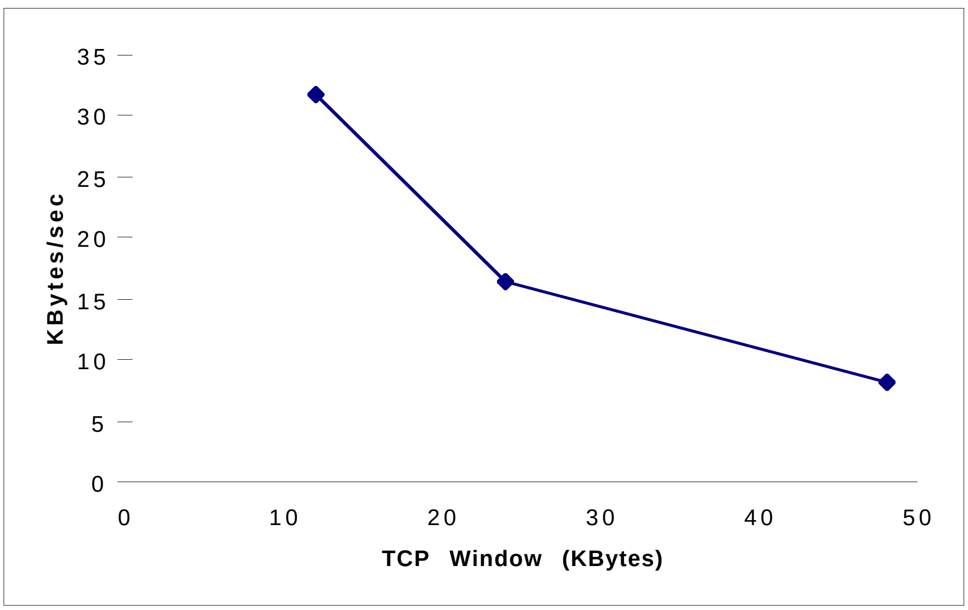
Results Using α and β Controls

- By monitoring the RTT, a version of XFTP that adapts the number of connections in use achieves improved average throughput



Satellite Error Characteristics and Satellite Links

- Damaged segments can be more likely over satellite links than over terrestrial links
  - Spreading segment losses across more connections improves throughput
    - Fewer connections slow down



- Selective ACKs will likely turn out to be a better solution to the problem
  - RFC 2018 recently released as a proposed standard

Future Work

- We're currently testing experimental TCP versions
  - Selective Acknowledgments
  - Large windows
  - Modified slow-start
  - FACK
- Experimental environments
  - Software simulator
  - Software emulator
  - Hardware emulator
  - NASA ACTS satellite
- Still working to fine tune the α and β mechanism in XFTP

For Further Information

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