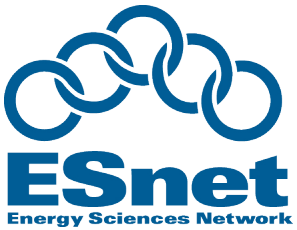


Bulk Data Transfer Techniques for High-Speed Wide-Area Networks

Brian L. Tierney

ESnet

Lawrence Berkeley National Laboratory

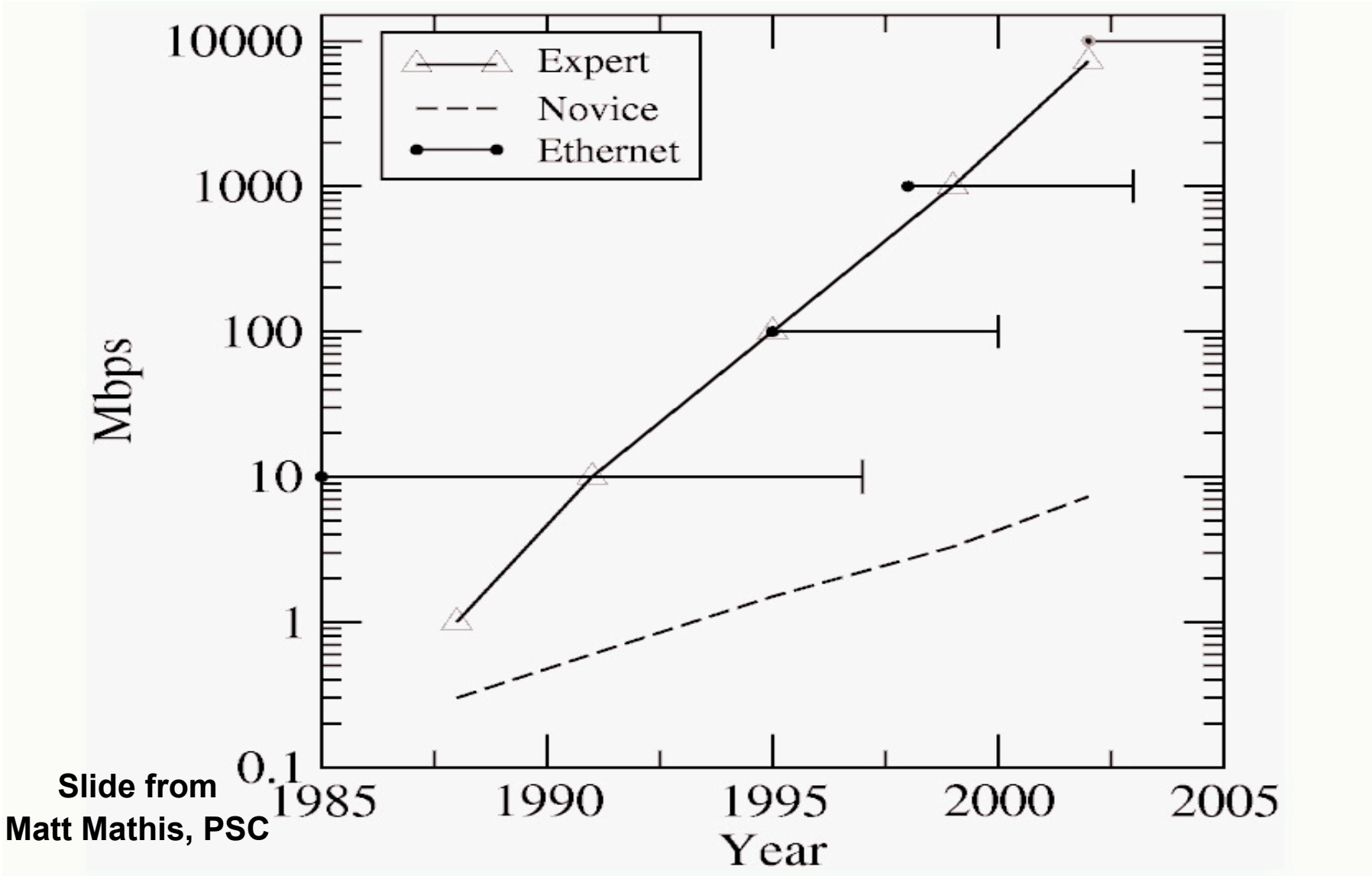
slides at http://fasterdata.es.net/talks/JT.ppt

Why does the Network seem so slow?

U.S. Department of Energy
Office of Science

Wizard Gap

ESnet
Energy Sciences Network



Slide from
Matt Mathis, PSC

U.S. Department of Energy
Office of Science

Today's Talk

ESnet
Energy Sciences Network

- **This talk will cover:**
  - **Some Information to help you become a "wizard"**
  - **Work being done so you don't have to be a wizard**
- **Goal of this talk:**
  - **Help you fully optimize wide area bulk data transfers**
    - or help your users do this
- **Outline**
  - **TCP Issues**
  - **Bulk Data Transfer Tools**
  - **Network Monitoring Tools**
  - **New TCP Stacks**
    - how they help with, but not eliminate, the "wizard gap"

U.S. Department of Energy
Office of Science

Time to Copy 1 Terabyte

ESnet
Energy Sciences Network

- 10 Mbps network : 300 hrs (12.5 days)
- 100 Mbps network : 30 hrs
- 1 Gbps network : 3 hrs
- 10 Gbps network : 20 minutes
  - need fast disk array for this

- Compare these speeds to:
  - USB 2.0 portable disk
    - 60 MB/sec (480 Mbps) peak
    - 20 MB/sec (160 Mbps) reported on line
    - 5-10 MB/sec reported by colleagues
    - 15-40 hours to load 1 Terabyte

U.S. Department of Energy
Office of Science

Bandwidth Requirements

ESnet
Energy Sciences Network

Bandwidth Requrements to move Y Bytes of data in Time X

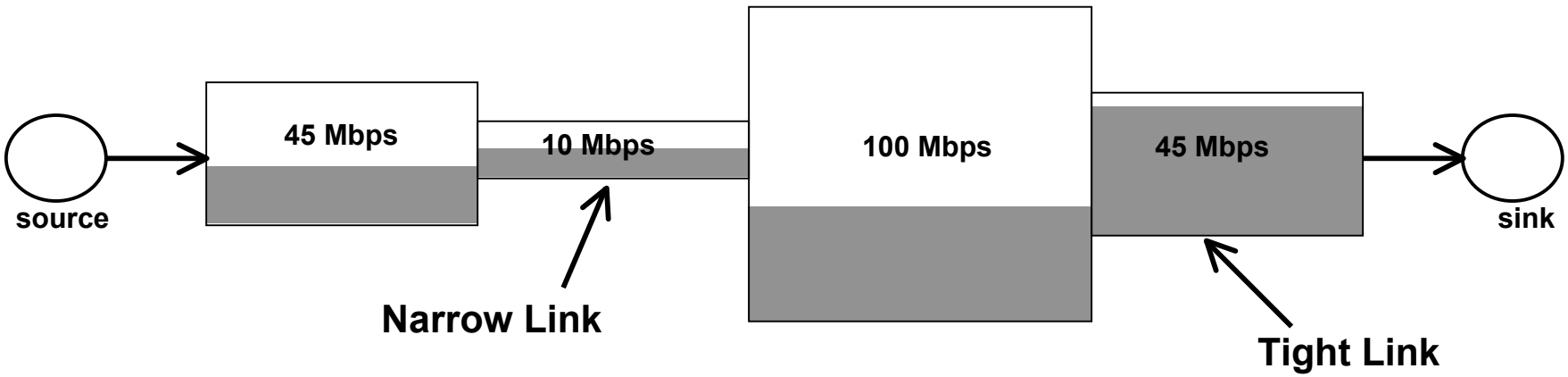
Bits per Second Requirements

	1H	8H	24H	7Days	30Days
10PB	25,020.0 Gbps	3,127.5 Gbps	1,042.5 Gbps	148.9 Gbps	34.7 Gbps
1PB	2,502.0 Gbps	312.7 Gbps	104.2 Gbps	14.9 Gbps	3.5 Gbps
100TB	244.3 Gbps	30.5 Gbps	10.2 Gbps	1.5 Gbps	339.4 Mbps
10TB	24.4 Gbps	3.1 Gbps	1.0 Gbps	145.4 Mbps	33.9 Mbps
1TB	2.4 Gbps	305.4 Mbps	101.8 Mbps	14.5 Mbps	3.4 Mbps
100GB	238.6 Mbps	29.8 Mbps	9.9 Mbps	1.4 Mbps	331.4 Kbps
10GB	23.9 Mbps	3.0 Mbps	994.2 Kbps	142.0 Kbps	33.1 Kbps
1GB	2.4 Mbps	298.3 Kbps	99.4 Kbps	14.2 Kbps	3.3 Kbps
100MB	233.0 Kbps	29.1 Kbps	9.7 Kbps	1.4 Kbps	0.3 Kbps

This table available at http://fasterdata.es.net

Terminology

- **The term "Network Throughput" is vague and should be avoided**
  - **Capacity: link speed**
    - Narrow Link: link with the lowest capacity along a path
    - Capacity of the end-to-end path = capacity of the narrow link
  - **Utilized bandwidth: current traffic load**
  - **Available bandwidth: capacity – utilized bandwidth**
    - Tight Link: link with the least available bandwidth in a path
  - **Achievable bandwidth: includes protocol and host issues**



U.S. Department of Energy
Office of Science

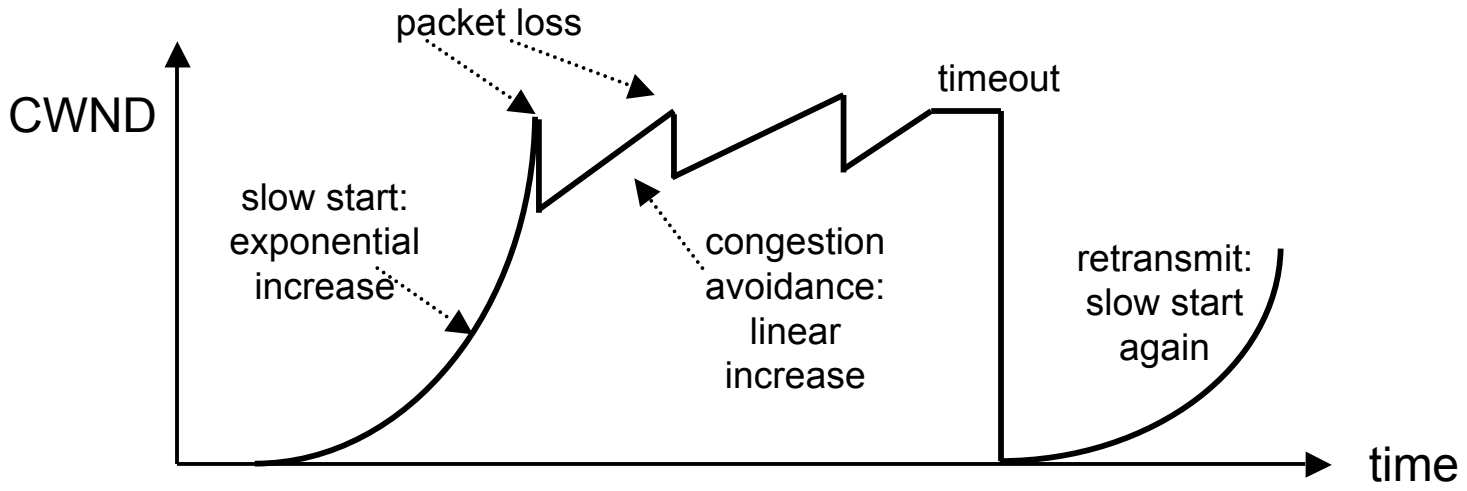
More Terminology

ESnet
Energy Sciences Network

- Latency: time to send 1 packet from the source to the destination
- RTT: Round-trip time
- Bandwidth*Delay Product = BDP
  - The number of bytes in flight to fill the entire path
  - Example: 100 Mbps path; ping shows a 75 ms RTT
    - BDP = 100 * 0.075 = 7.5 Mbits (940 KBytes)
- LFN: Long Fat Networks
  - A network with a large BDP

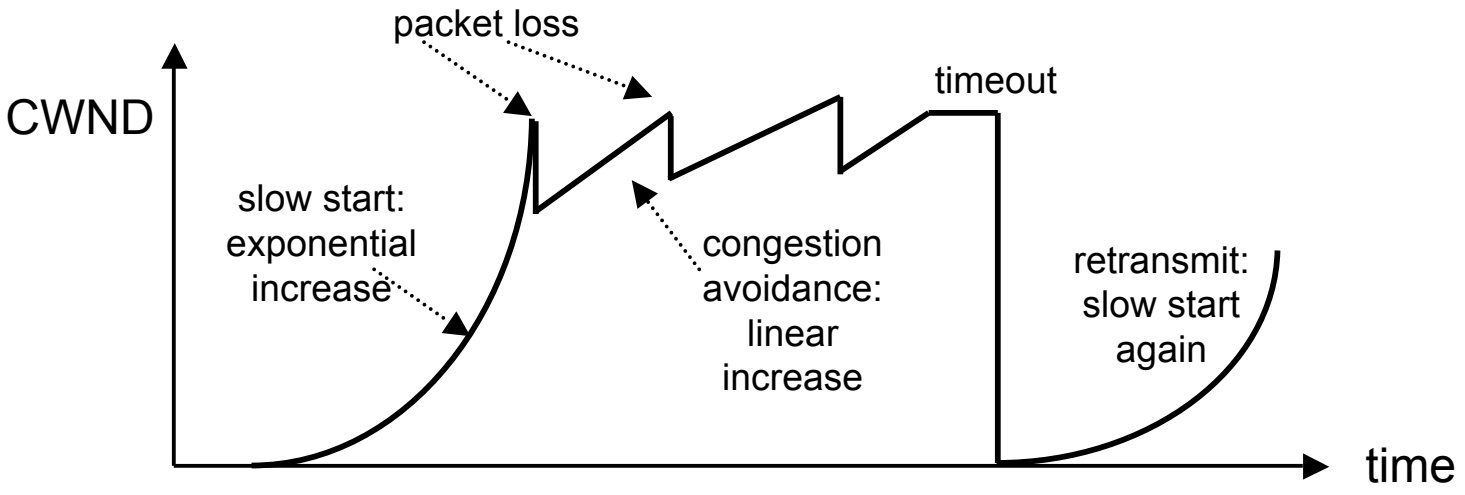
How TCP works: A very short overview

- **Congestion window (CWND) = the number of packets the sender is allowed to send**
  - **The larger the window size, the higher the throughput**
    - Throughput = Window size / Round-trip Time
- **TCP Slow start**
  - **exponentially increase the congestion window size until a packet is lost**
    - this gets a rough estimate of the optimal congestion window size



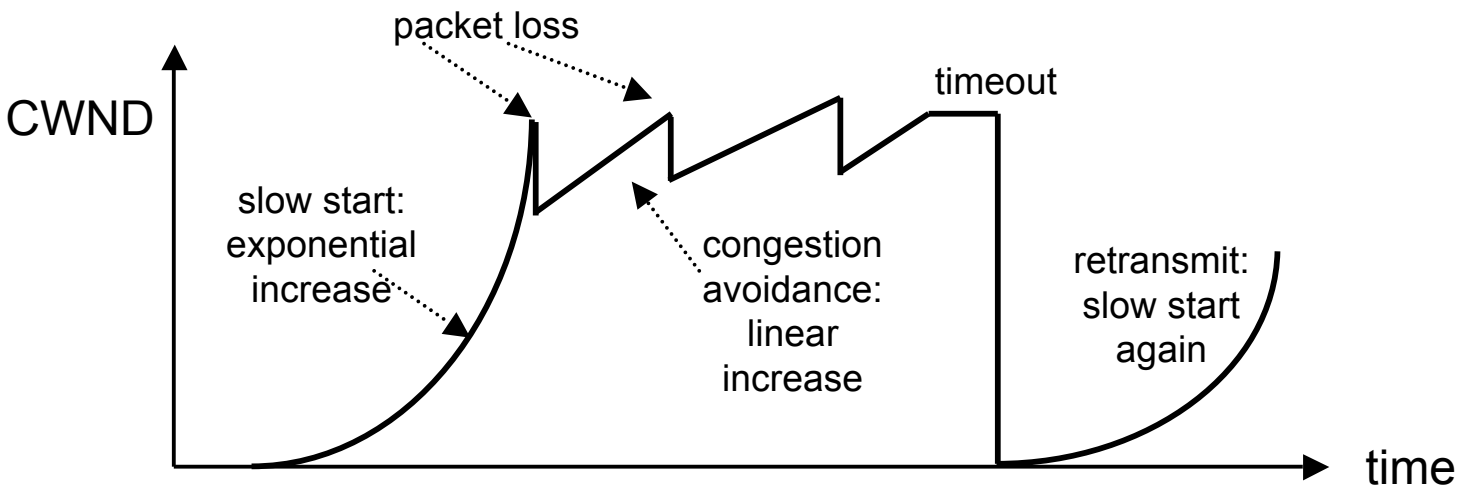
TCP Overview

- Congestion avoidance
  - additive increase: starting from the rough estimate, linearly increase the congestion window size to probe for additional available bandwidth
  - multiplicative decrease: cut congestion window size aggressively if a timeout occurs



TCP Overview

- Fast Retransmit: retransmit after 3 duplicate acks (got 3 additional packets without getting the one you are waiting for)
  - this prevents expensive timeouts
  - no need to go into "slow start" again
- At steady state, CWND oscillates around the optimal window size
- With a retransmission timeout, slow start is triggered again

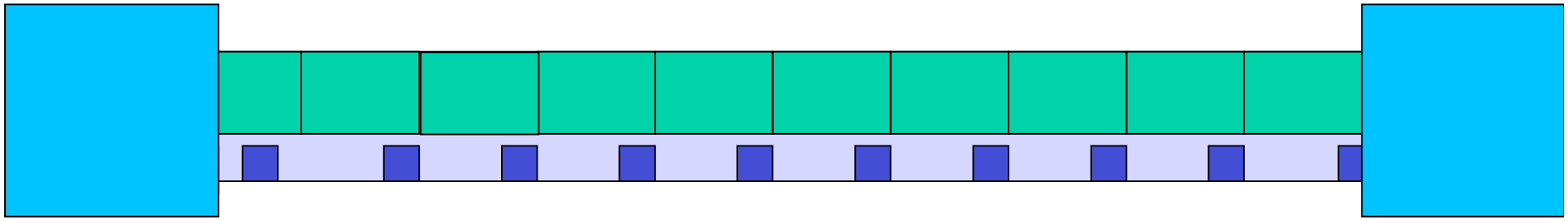


U.S. Department of Energy
Office of Science

TCP Window and ACKs

Small TCP Buffer Size

ESnet
Energy Sciences Network



Data Packet

Acknowledgement

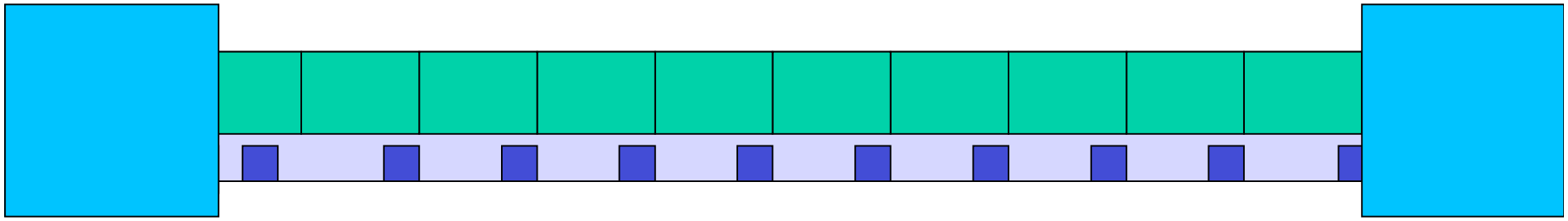
Animated Slide from Globus Project, ANL

U.S. Department of Energy
Office of Science

TCP Window and ACKs

Optimized TCP Buffer Size

ESnet
Energy Sciences Network



Animated Slide from Globus Project, ANL

U.S. Department of Energy
Office of Science

TCP Performance Issues

ESnet
Energy Sciences Network

- Getting good TCP performance over high-latency high-bandwidth networks is not easy!
- You must keep the TCP window full
  - the size of the window is directly related to the network latency
- Easy to compute max throughput:
  - Throughput = buffer size / latency
  - eg: 64 KB buffer / 40 ms path = 1.6 KBytes (12.8 Kbits) / sec

U.S. Department of Energy
Office of Science

Setting the TCP buffer sizes

ESnet
Energy Sciences Network

- **It is critical to use the optimal TCP send and receive socket buffer sizes for the link you are using.**
  - **Recommended size to fill the pipe**
    - 2 x Bandwidth Delay Product (BDP)
  - **Recommended size to leave some bandwidth for others**
    - around 20% of (2 x BPB) = .4 * BDP
- **Default TCP buffer sizes are way too small for today's high speed networks**
  - **Until recently, default TCP send/receive buffers were typically 64 KB**
  - **tuned buffer to fill LBL to BNL link: 10 MB**
    - 150X bigger than the default buffer size
  - **with default TCP buffers, you can only get a small % of the available bandwidth!**

U.S. Department of Energy
Office of Science

Buffer Size Example

ESnet
Energy Sciences Network

- Optimal Buffer size formula:
  - buffer size = 20% * (2 * bandwidth * RTT)
- ping time (RTT) = 50 ms
- Narrow link = 500 Mbps (62 MBytes/sec)
  - e.g.: the end-to-end network consists of all 1000 BT ethernet and OC-12 (622 Mbps)
- TCP buffers should be:
  - .05 sec * 62 * 2 * 20% = 1.24 MBytes

U.S. Department of Energy
Office of Science

Socket Buffer Autotuning

ESnet
Energy Sciences Network

- To solve the buffer tuning problem, based on work at LANL and PSC, Linux OS added TCP Buffer autotuning
  - Sender-side TCP buffer autotuning introduced in Linux 2.4
  - Reciever-side autotuning added in Linux 2.6
- Many other OS's now include TCP autotuning
  - TCP send buffer starts at 64 KB
  - As the data transfer takes place, the buffer size is continuously re-adjusted up max autotune size
- Current OS Autotuning default maximum buffers
  - Linux 2.6: 256K to 1MB, depending on version
  - FreeBSD 7: 256K
  - Windows Vista: 16M
  - Mac OSX 10.5: 8M

U.S. Department of Energy
Office of Science

Autotuning Settings

ESnet
Energy Sciences Network

- **Linux 2.6**

```
net.core.rmem_max = 16777216
net.core.wmem_max = 16777216
# autotuning min, default, and max number of bytes to use
net.ipv4.tcp_rmem = 4096 87380 16777216
net.ipv4.tcp_wmem = 4096 65536 16777216
```

- **FreeBSD 7.0**

```
net.inet.tcp.sendbuf_auto=1
net.inet.tcp.recvbuf_auto=1
net.inet.tcp.sendbuf_max=16777216
net.inet.tcp.recvbuf_max=16777216
```

- **Windows Vista**

```
netsh interface tcp set global autotunninglevel=normal
```

  - **max buffer fixed at 16MB**

- **OSX 10.5 ("Self-Tuning TCP)**

```
kern.ipc.maxsockbuf=16777216
```

- **For more info, see: http://acs.lbl.gov/TCP-Tuning/**

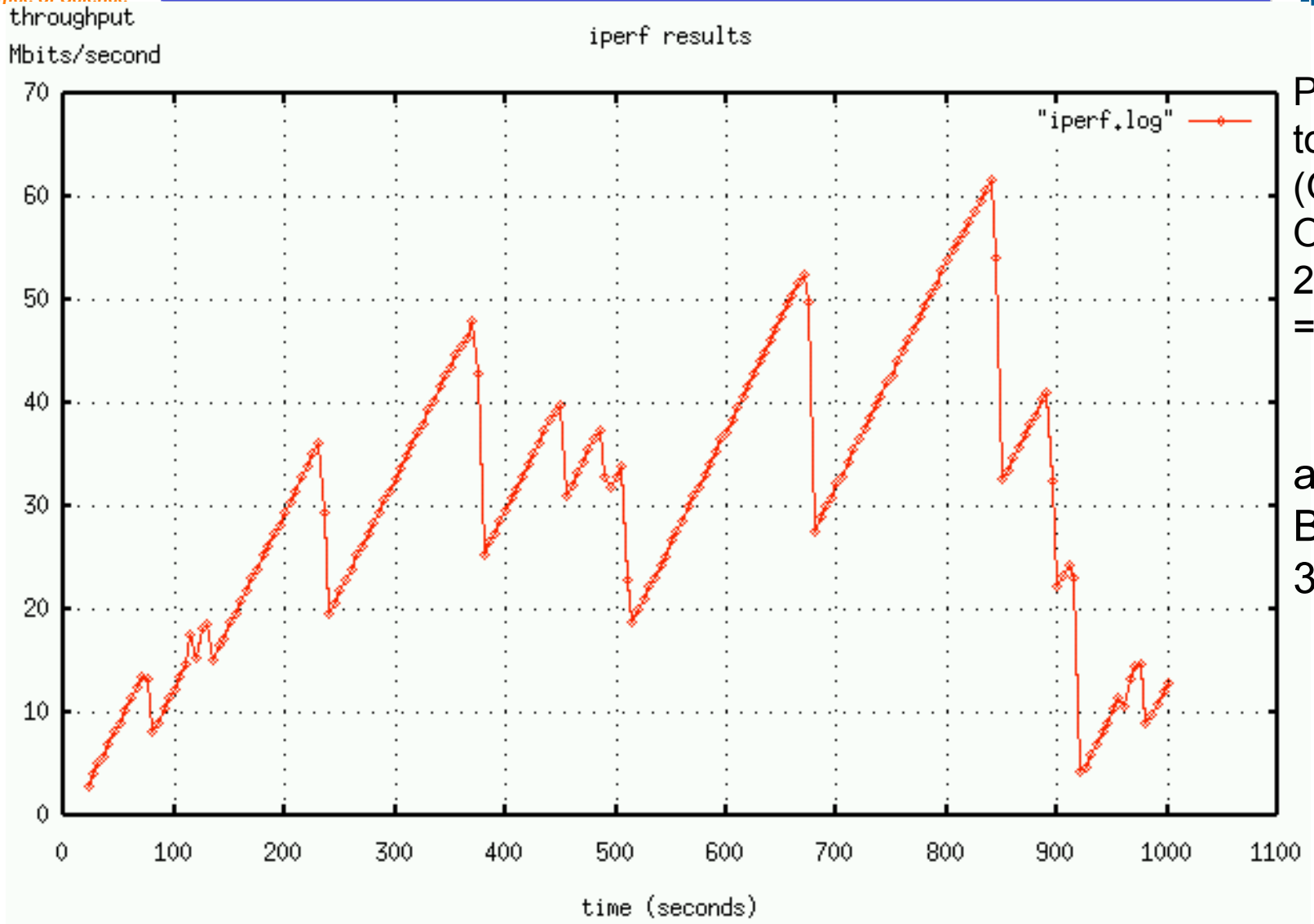
U.S. Department of Energy
Office of Science

Sample Buffer Sizes

ESnet
Energy Sciences Network

- LBL to (50% of pipe)
  - SLAC (RTT = 2 ms, narrow link = 1000 Mbps) : 256 KB
  - BNL: (RTT = 80 ms, narrow link = 1000 Mbps): 10 MB
  - CERN: (RTT = 165 ms, narrow link = 1000 Mbps): 20.6 MB
- Note: default buffer size is usually only 64 KB, and default maximum autotuning buffer size for is often only 256KB
  - Linux/FreeBSD Autotuning default max = 256 KB (recently increased to 1 MB);
  - 10-150 times too small!
- Home DSL, US to Europe (RTT = 150, narrow link = 2 Mbps): 38 KB
  - Default buffers are OK.

More Problems: TCP congestion control



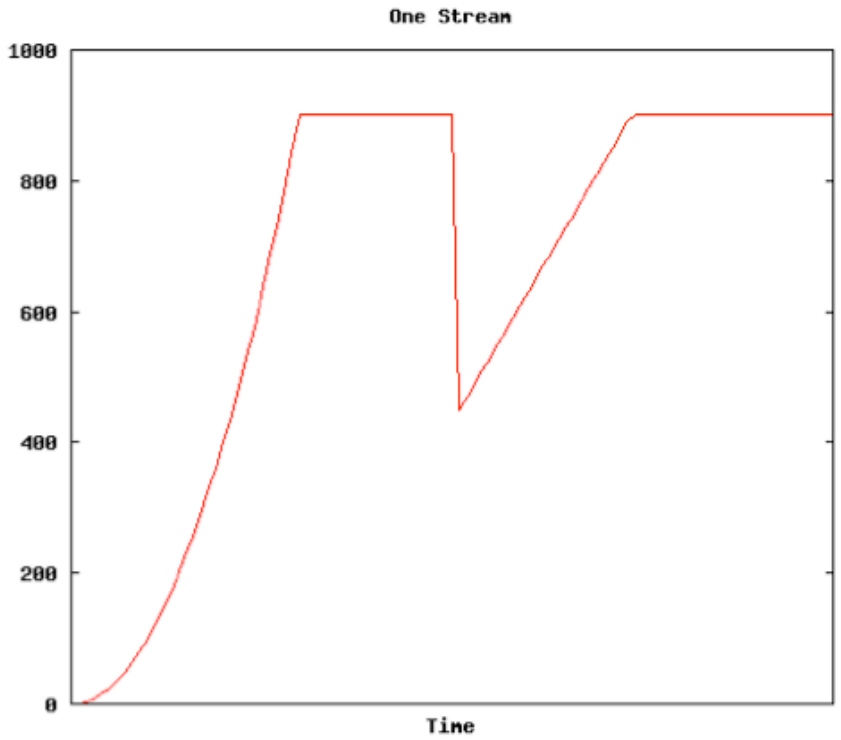
Path = LBL to CERN (Geneva) OC-3, (in 2000), RTT = 150 ms

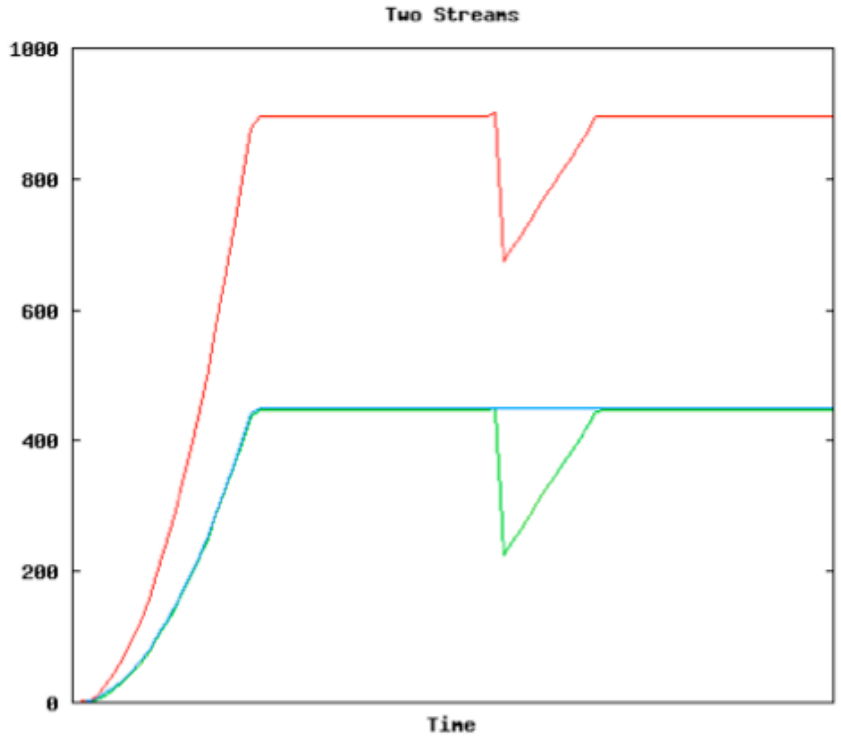
average BW = 30 Mbps

U.S. Department of Energy
Office of Science

Parallel Streams Can Help

ESnet
Energy Sciences Network

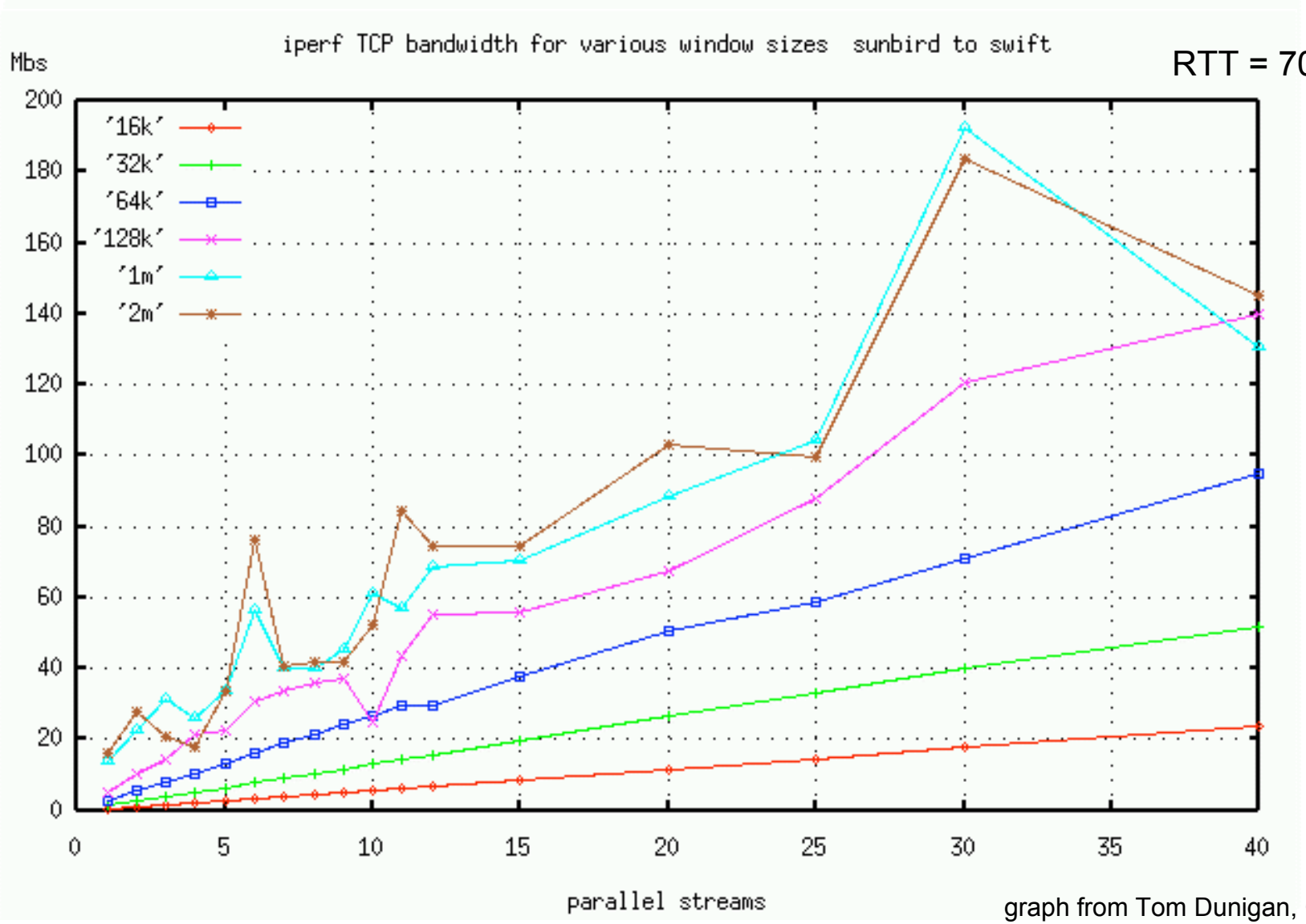




U.S. Department of Energy
Office of Science

Parallel Streams Results with various TCP window sizes

ESnet
Energy Sciences Network



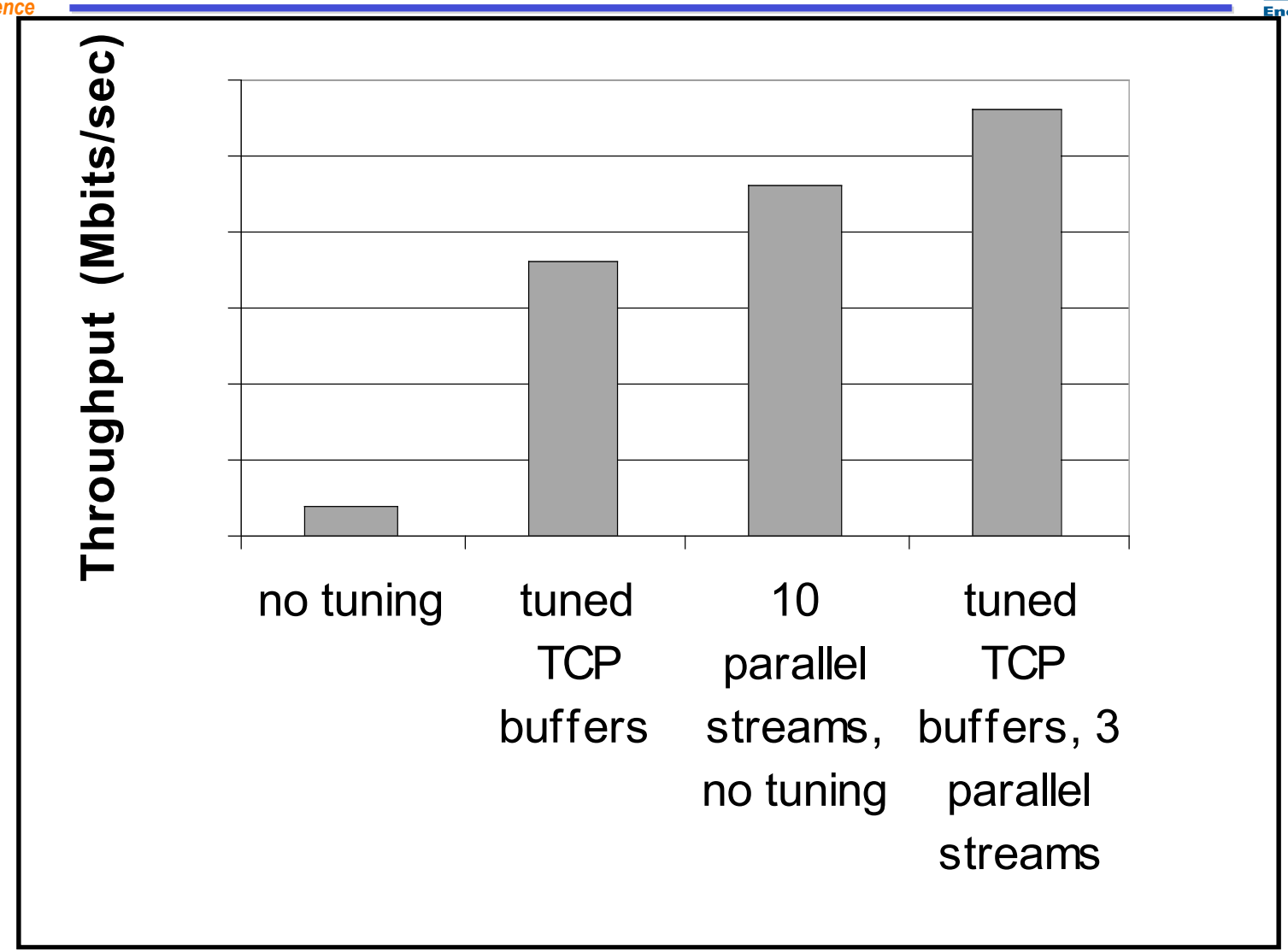
RTT = 70 ms

graph from Tom Dunigan, ORNL

U.S. Department of Energy
Office of Science

Tuned Buffers vs. Parallel Steams

ESnet
Energy Sciences Network

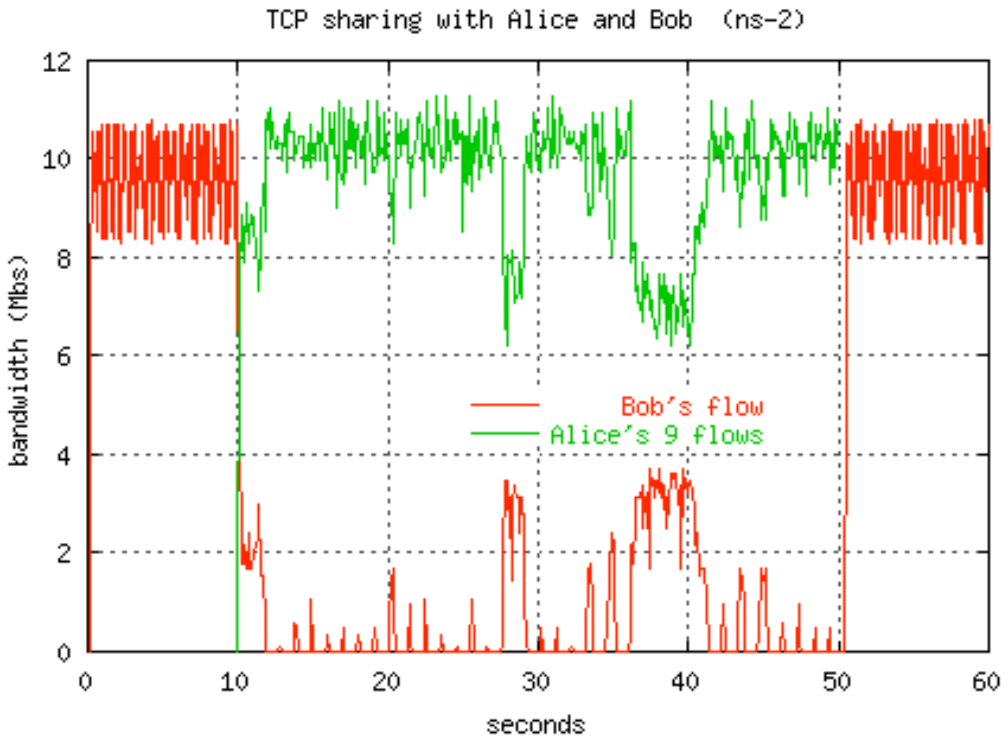


U.S. Department of Energy
Office of Science

Parallel Streams Issues

ESnet
Energy Sciences Network

- Potentially unfair
- Places more load on the end hosts
- But they are necessary when you don't have root access, and can't convince the sysadmin to increase the max TCP buffers



graph from Tom Dunigan, ORNL

U.S. Department of Energy
Office of Science

Summary so far

ESnet
Energy Sciences Network

- To optimize TCP throughput, do the following:
  - Use a newer OS that supports TCP buffer autotuning
  - increase the maximum TCP autotuning buffer size
  - use a few parallel streams if possible

- But also, try to 'play nice':
  - Leave some bandwidth for others.
  - e.g.: Don't try to completely fill your networks 1000BT uplink
  - Good 'rule of thumb':
    - Try for 100-200 Mbps per stream, and use around 4 streams

Bulk Transfer Tools

U.S. Department of Energy
Office of Science

Sample Data Transfer Results: LBL to BNL

ESnet
Energy Sciences Network

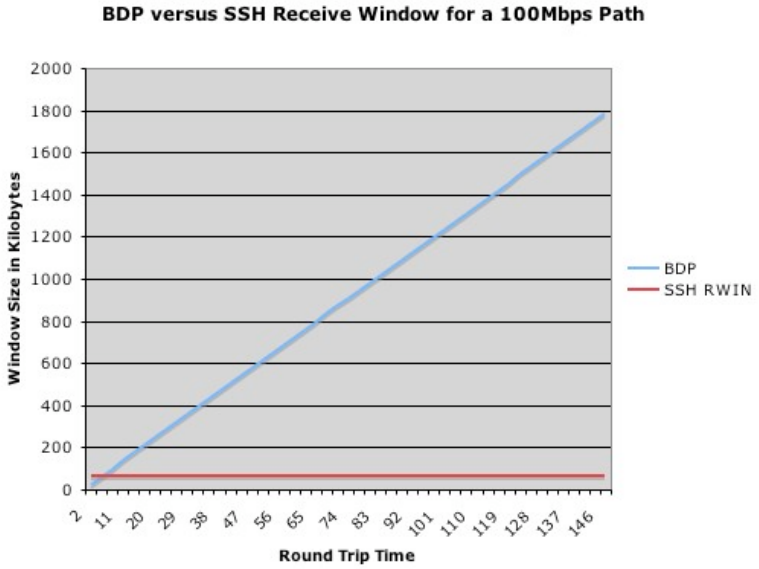
- **Using the right tool is very important**
  - **scp / sftp : 10 Mbps**
    - standard Unix file copy tools
    - fixed 64 KB TCP window in openSSL
  - **ftp : 400-500 Mbps**
    - assumes TCP buffer autotuning
  - **parallel stream FTP: 800-900 Mbps**

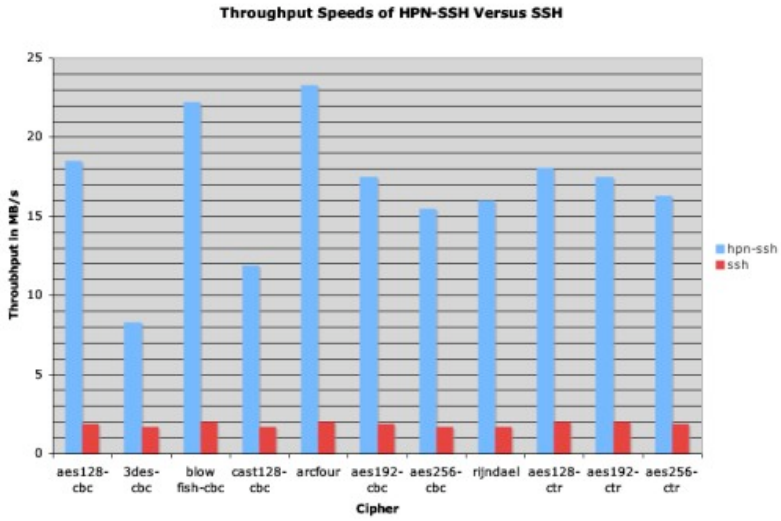
U.S. Department of Energy
Office of Science

scp

ESnet
Energy Sciences Network

- Don't use scp to copy large files across a WAN!
  - scp has its own internal 64KB buffering/windowing that prevents it from ever being able to fill LFNs!
- Explanation of problem and openssh patch solution from PSC:
  - http://www.psc.edu/networking/projects/hpn-ssh/





sftp

- Uses libopenssl, so don't use sftp WAN transfers unless you have installed the HPN patch from PSC
- But even with the patch, SFTP has yet another flow control mechanism
  - By default, sftp limits the total number of outstanding messages to 16 32KB messages.
  - Since each datagram is a distinct message you end up with a 512KB outstanding data limit.
  - You can increase both the number of outstanding messages ('-R') and the size of the message ('-B') from the command line though.
- Sample command for a 128MB window:
  - sftp -R 512 -B 262144 user@host:/path/to/file outfile

U.S. Department of Energy
Office of Science

GridFTP

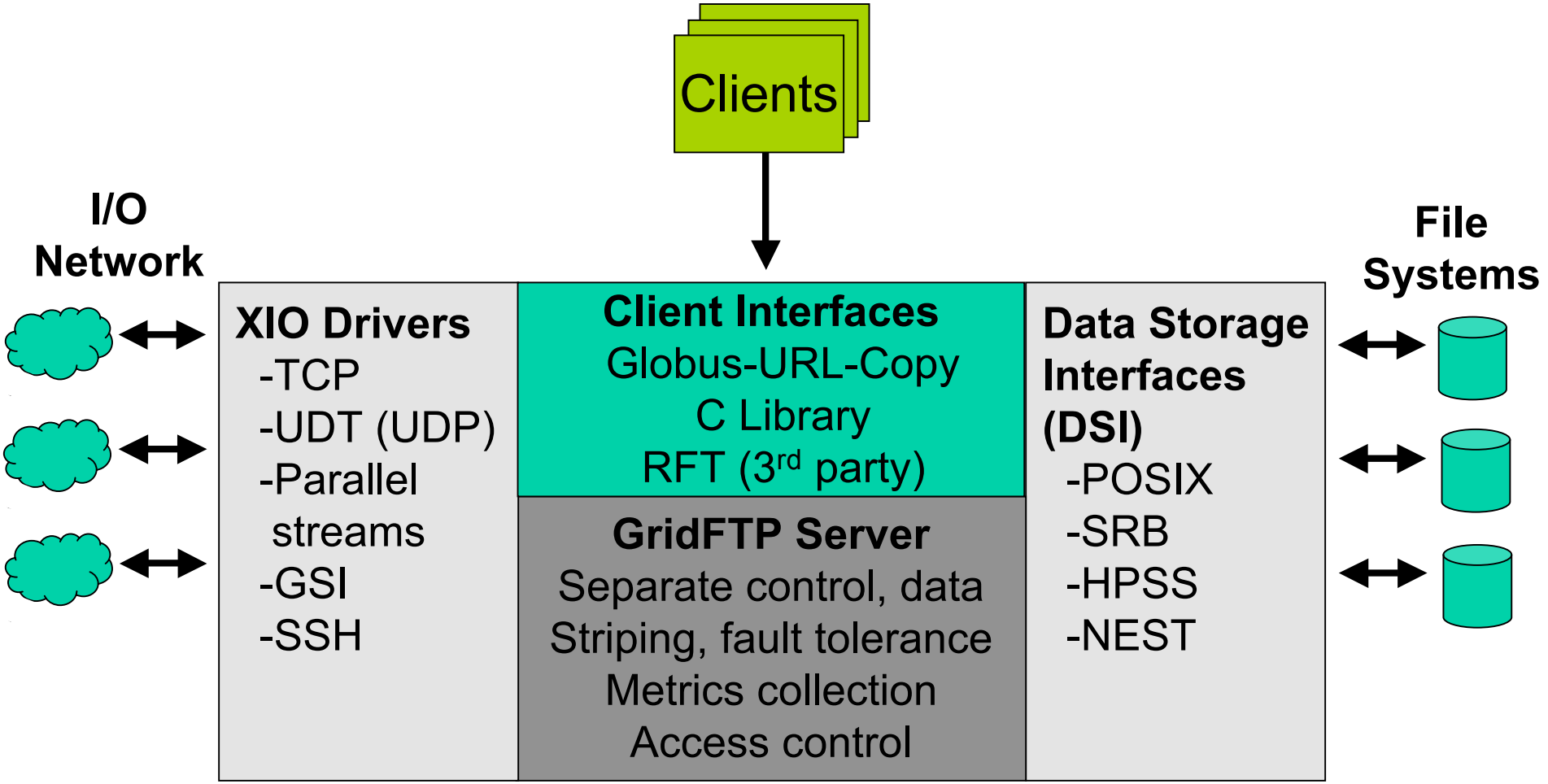
ESnet
Energy Sciences Network

- GridFTP from ANL has everything needed to fill the network pipe
  - Buffer Tuning
  - Parallel Streams
- Supports multiple authentication options
  - anonymous
  - ssh (available in starting with Globus Toolkit version 4.2)
  - X509
- Ability to define a range of data ports
  - helpful to get through firewalls
- Sample Use:
  - `globus-url-copy -p 4 sshftp://data.lbl.gov/home/mydata/myfile file://home/mydir/myfile`
- Available from: http://www.globus.org/toolkit/downloads/

U.S. Department of Energy
Office of Science

GridFTP

ESnet
Energy Sciences Network



www.gridftp.org

U.S. Department of Energy
Office of Science

new GridFTP Features

ESnet
Energy Sciences Network

- **New ssh authentication option**
  - **Not all users need or want to deal with X.509 certificates**
  - **Solution: Use SSH for Control Channel**
    - Data channel remains as is, so performance is the same
  - **see http://fasterdata.es.net/gridftp.html for a quick start guide**
- **Optimizations for small files**
  - **Pipelining: for cases where many transfer requests are outstanding at once**
    - Client sends next request before the current completes
    - Latency of request is hidden in data transfer time
  - **Cached Data channel connections**
    - Reuse established data channels (Mode E)
    - No additional TCP or GSI connect overhead
- **Support for UDT protocol**

U.S. Department of Energy
Office of Science

new GridFTP “bottleneck detector”

ESnet
Energy Sciences Network

- new command line option for globus-url-copy, "-nlb”
  - nlb = NetLogger bottleneck
  - Uses NetLogger libraries for analysis of network and disk I/O
    - http://acs.lbl.gov/NetLogger
- Possible "Bottleneck:" results are:
  - network: somewhere in the network
  - disk read: sender's disk
  - disk write: receiver's disk
  - unknown: disk/network are about the same and/or highly variable

U.S. Department of Energy
Office of Science

new GridFTP "bottleneck detector"

ESnet
Energy Sciences Network

- **Sample Output:**

Total instantaneous throughput:
  disk read = 1235.7 Mbits/s
  disk write = 2773.0 Mbits/s
  net read = 836.3 Mbits/s
  net write = 1011.7 Mbits/s
Bottleneck: network

- **Ignore the "net write" value**
  - **the time to write to the network is strongly influenced by system and TCP buffer artifacts.**

- ***instantaneous throughput* is the average # of bytes divided by the time spent blocking on the system call.**

- ***instantaneous throughputs* are higher than the overall throughput of the transfer:**
  - **does not include the time waiting for data to be available**
  - **primarily useful for comparison and not as absolute numbers**

U.S. Department of Energy
Office of Science

new GridFTP "bottleneck detector"

ESnet
Energy Sciences Network

- -nlb not enabled by default
  - use ./configure --enable-netlogger
  - additional server configuration flags needed
  - instructions at:
    - http://www.cedps.net/index.php/Gridftp-netlogger

bbftp

- bbftp (from the HEP "Babar") project also everything needed to fill the network pipe
  - Buffer Tuning
  - Parallel Streams
- Supports ssh authentication options
- Supports on-the-fly compression
- Sample Use:
  - `bbftp -p 4`
    `bbftp://data.lbl.gov/home/mydata/myfile`
    `file://home/mydir/myfile`
- Available from: http://doc.in2p3.fr/bbftp/

U.S. Department of Energy
Office of Science

Other Tools

ESnet
Energy Sciences Network

- bbcp: http://www.slac.stanford.edu/~abh/bbcp/
  - supports parallel transfers and socket tuning
  - bbcp -P 4 -v -w 2M myfile remotehost:filename
- lftp: http://lftp.yar.ru/
  - parallel file transfer, socket tuning, HTTP transfers, and more.
  - lftp -e 'set net:socket-buffer 4000000; pget -n 4 [http|ftp]://site/path/file; quit'
- axel: http://wilmer.gaast.net/main.php/axel.html
  - simple parallel accelerator for HTTP and FTP.
  - axel -n 4 [http|ftp]://site/file

U.S. Department of Energy
Office of Science

Download Managers

ESnet
Energy Sciences Network

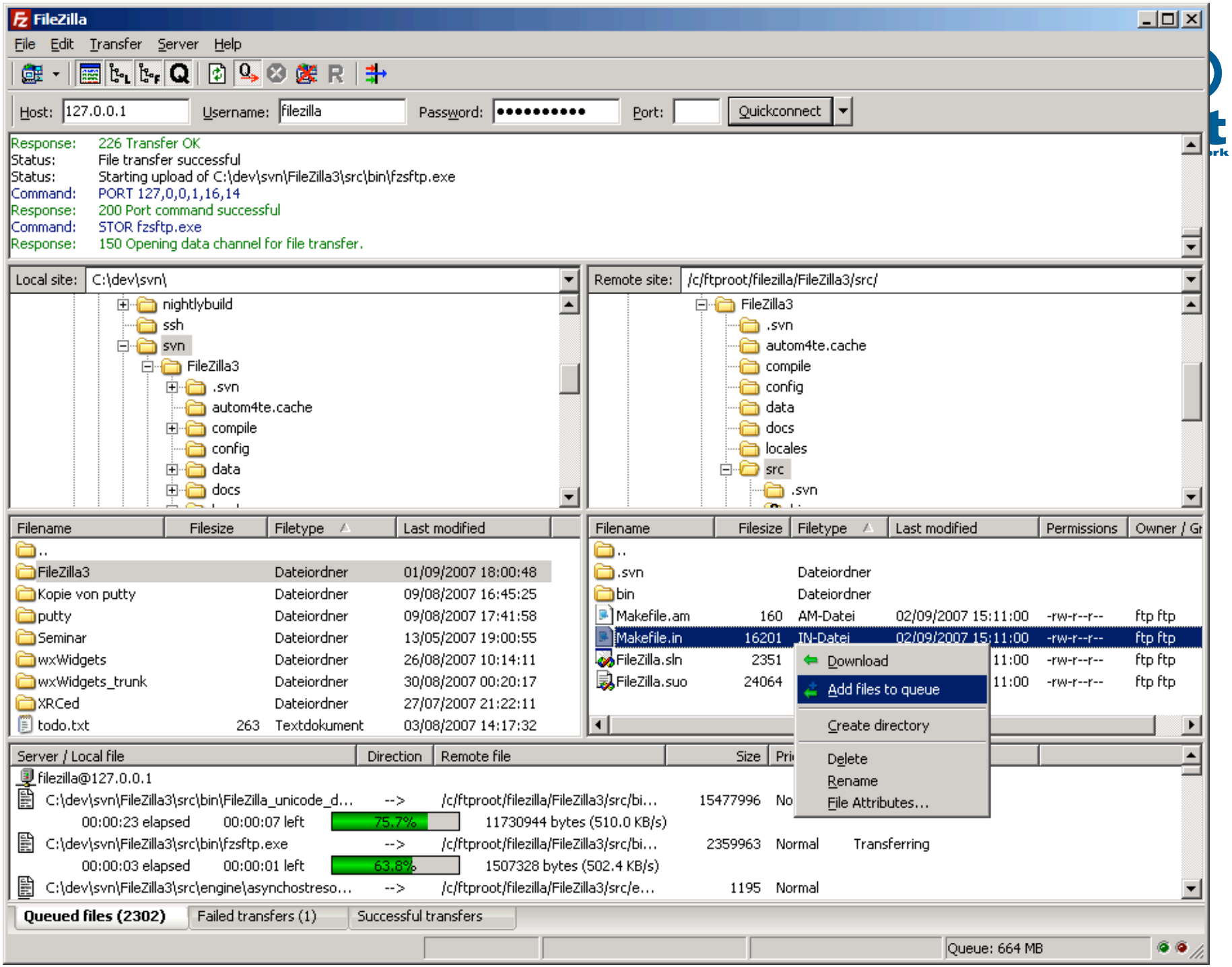
- There are a number of nice browser plugins that can be used to speed up web-initiated data transfers
  - all support parallel transfers
- Firefox add-on (All OSes):
  - DownThemAll : http://www.downthemall.net
  - this is my favorite: probably the best/simplest solution
- For Linux:
  - aria: http://aria-rpm.sourceforge.net
- For Windows:
  - FDM: http://www.freedownloadmanager.org
  - Stardownloader: http://www.stardownloader.com/
- For OSX:
  - Speed Download: http://www.yazsoft.com/ ($25)

U.S. Department of Energy
Office of Science

MS Windows Tool: Filezilla

ESnet
Energy Sciences Network

- Open Source:
  - http://filezilla-project.org/
  - includes client and server
- Features:
  - ability to transfer multiple files in parallel
- Issues:
  - uses libopenssl in secure mode, so has buffer limitations


FileZilla
File Edit Transfer Server Help
Host: 127.0.0.1 Username: filezilla Password: •••••••••• Port: Quickconnect
Response: 226 Transfer OK
Status: File transfer successful
Status: Starting upload of C:\dev\svn\FileZilla3\src\bin\fzsftp.exe
Command: PORT 127,0,0,1,16,14
Response: 200 Port command successful
Command: STOR fzsftp.exe
Response: 150 Opening data channel for file transfer.
Local site: C:\dev\svn\
nightlybuild
ssh
svn
FileZilla3
.svn
autom4te.cache
compile
config
data
docs
Remote site: /c/ftproot/filezilla/FileZilla3/src/
FileZilla3
.svn
autom4te.cache
compile
config
data
docs
locales
src
.svn
Filename Filesize Filetype Last modified
.. Dateiordner
FileZilla3 Dateiordner 01/09/2007 18:00:48
Kopie von putty Dateiordner 09/08/2007 16:45:25
putty Dateiordner 09/08/2007 17:41:58
Seminar Dateiordner 13/05/2007 19:00:55
wxWidgets Dateiordner 26/08/2007 10:14:11
wxWidgets_trunk Dateiordner 30/08/2007 00:20:17
XRCed Dateiordner 27/07/2007 21:22:11
todo.txt 263 Textdokument 03/08/2007 14:17:32
Filename Filesize Filetype Last modified Permissions Owner / Gr
.. Dateiordner
.svn Dateiordner
bin Dateiordner
Makefile.am 160 AM-Datei 02/09/2007 15:11:00 -rw-r--r-- ftp ftp
Makefile.in 16201 IN-Datei 02/09/2007 15:11:00 -rw-r--r-- ftp ftp
FileZilla.sln 2351 11:00 -rw-r--r-- ftp ftp
FileZilla.suo 24064 11:00 -rw-r--r-- ftp ftp
Download
Add files to queue
Create directory
Delete
Rename
File Attributes...
Server / Local file Direction Remote file Size
filezilla@127.0.0.1
C:\dev\svn\FileZilla3\src\bin\FileZilla_unicode_d... --> /c/ftproot/filezilla/FileZilla3/src/bi... 15477996
00:00:23 elapsed 00:00:07 left 75.7% 11730944 bytes (510.0 KB/s)
C:\dev\svn\FileZilla3\src\bin\fzsftp.exe --> /c/ftproot/filezilla/FileZilla3/src/bi... 2359963 Normal Transferring
00:00:03 elapsed 00:00:01 left 63.8% 1507328 bytes (502.4 KB/s)
C:\dev\svn\FileZilla3\src\engine\asynchostreso... --> /c/ftproot/filezilla/FileZilla3/src/e... 1195 Normal
Queued files (2302)
Failed transfers (1)
Successful transfers
Queue: 664 MB

U.S. Department of Energy
Office of Science

Special Purpose Data Transfer Tools

ESnet
Energy Sciences Network

- **HPSS Tools: HSI and pftp**
  - **both support buffer tuning and parallel transfers**
    - per destination buffer tuning must be done by HPSS admin
- **SRM from SDSC**
  - **supports buffer tuning and parallel transfers**

U.S. Department of Energy
Office of Science

Other Bulk Data Transfer Issues

ESnet
Energy Sciences Network

- **Firewalls**
  - **many firewalls can't handle 1 Gbps flows**
    - designed for large number of low bandwidth flow
    - some firewalls even strip out TCP options that allow for TCP buffers > 64 KB
- **Disk Performance**
  - **In general need a RAID array to get more than around 500 Mbps**
- **Other subtle issues start to come up at speeds above 2 Gbps**
  - **Router buffering, TCP congestion control, disk tuning, etc.**

U.S. Department of Energy
Office of Science

Selecting a bulk data transfer tool

ESnet
Energy Sciences Network

- First, determine which security model you require
  - anonymous: (e.g.: FTP, HTTP) anyone can access the data
  - simple password: (e.g.: FTP, HTTP) most sites no longer allow this method since the password can be easily captured
  - password encrypted: (e.g.: bbcp, bbftp, GridFTP) control channel is encrypted, but data is unencrypted
  - everything encrypted: (e.g.: scp, sftp, GridFTP, HTTPS-based web server) both control and data channels are encrypted
- Most open science projects seem to prefer option #3.
- If you require option #4, tools that perform well over a WAN are limited to:
  - GridFTP with X509 keys,
  - HPN-patched versions of scp/sftp.

Network Monitoring Tools

traceroute

```
>traceroute pcgiga.cern.ch
    traceroute to pcgiga.cern.ch (192.91.245.29), 30 hops max, 40 byte packets
     1  ir100gw-r2.lbl.gov (131.243.2.1)  0.49 ms   0.26 ms   0.23 ms
     2  er100gw.lbl.gov (131.243.128.5)  0.68 ms   0.54 ms   0.54 ms
     3  198.129.224.5 (198.129.224.5)  1.00 ms  *d9*  1.29 ms
     4  lbl2-ge-lbnl.es.net (198.129.224.2)  0.47 ms   0.59 ms   0.53 ms
     5  snv-lbl-oc48.es.net (134.55.209.5)  57.88 ms   56.62 ms   61.33 ms
     6  chi-s-snv.es.net (134.55.205.102)  50.57 ms   49.96 ms   49.84 ms
     7  ar1-chicago-esnet.cern.ch (198.124.216.73)  50.74 ms  51.15 ms  50.96 ms
     8  cernh9-pos100.cern.ch (192.65.184.34)  175.63 ms   176.05 ms   176.05 ms
     9  cernh4.cern.ch (192.65.185.4)  175.92 ms   175.72 ms   176.09 ms
    10 pcgiga.cern.ch (192.91.245.29)  175.58 ms   175.44 ms   175.96 ms
```

Can often learn about the network from the router names:

- **ge = Gigabit Ethernet**
- **oc48 = 2.4 Gbps (oc3 = 155 Mbps, oc12=622 Mbps)**

U.S. Department of Energy
Office of Science

Iperf

ESnet
Energy Sciences Network

- iperf : nice tool for measuring end-to-end TCP/UDP performance
  - http://dast.nlanr.net/Projects/Iperf/
  - Can be quite intrusive to the network
- Example:
  - Server: iperf -s -w 2M
  - Client: iperf -c hostname -i 2 -t 20 -l 128K -w 2M

```
Client connecting to hostname
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0- 2.0 sec  66.0 MBytes   275 Mbits/sec
[  3]  2.0- 4.0 sec   107 MBytes   451 Mbits/sec
[  3]  4.0- 6.0 sec   106 MBytes   446 Mbits/sec
[  3]  6.0- 8.0 sec   107 MBytes   443 Mbits/sec
[  3]  8.0-10.0 sec   106 MBytes   447 Mbits/sec
[  3] 10.0-12.0 sec   106 MBytes   446 Mbits/sec
[  3] 12.0-14.0 sec   107 MBytes   450 Mbits/sec
[  3] 14.0-16.0 sec   106 MBytes   445 Mbits/sec
[  3] 16.0-24.3 sec  58.8 MBytes  59.1 Mbits/sec
[  3]  0.0-24.6 sec   871 MBytes   297 Mbits/sec
```

U.S. Department of Energy
Office of Science

pathrate / pathload

ESnet
Energy Sciences Network

- Nice tools from Georgia Tech:
  - pathrate: measures the capacity of the narrow link
  - pathload: measures the available bandwidth
- Both work pretty well.
  - pathrate can take a long time (up to 20 minutes)
  - These tools attempt to be non-intrusive
- Open Source; available from:
  - http://www.pathrate.org/

U.S. Department of Energy
Office of Science

Duplex Mismatch Issues

ESnet
Energy Sciences Network

- A common source of trouble with Ethernet networks is that the host is set to full duplex, but the Ethernet switch is set to half-duplex, or visa versa.
- Most newer hardware will auto-negotiate this, but with some older hardware, auto-negotiation sometimes fails
  - result is a working but very slow network (typically only 1-2 Mbps)
  - best for both to be in full duplex if possible, but some older 100BT equipment only supports half-duplex
- NDT is a good tool for finding duplex issues:
  - http://e2epi.internet2.edu/ndt/

U.S. Department of Energy
Office of Science

tcpdump / tcptrace

ESnet
Energy Sciences Network

- **tcpdump: dump all TCP header information for a specified source/destination**
  - **http://www.tcpdump.org/**

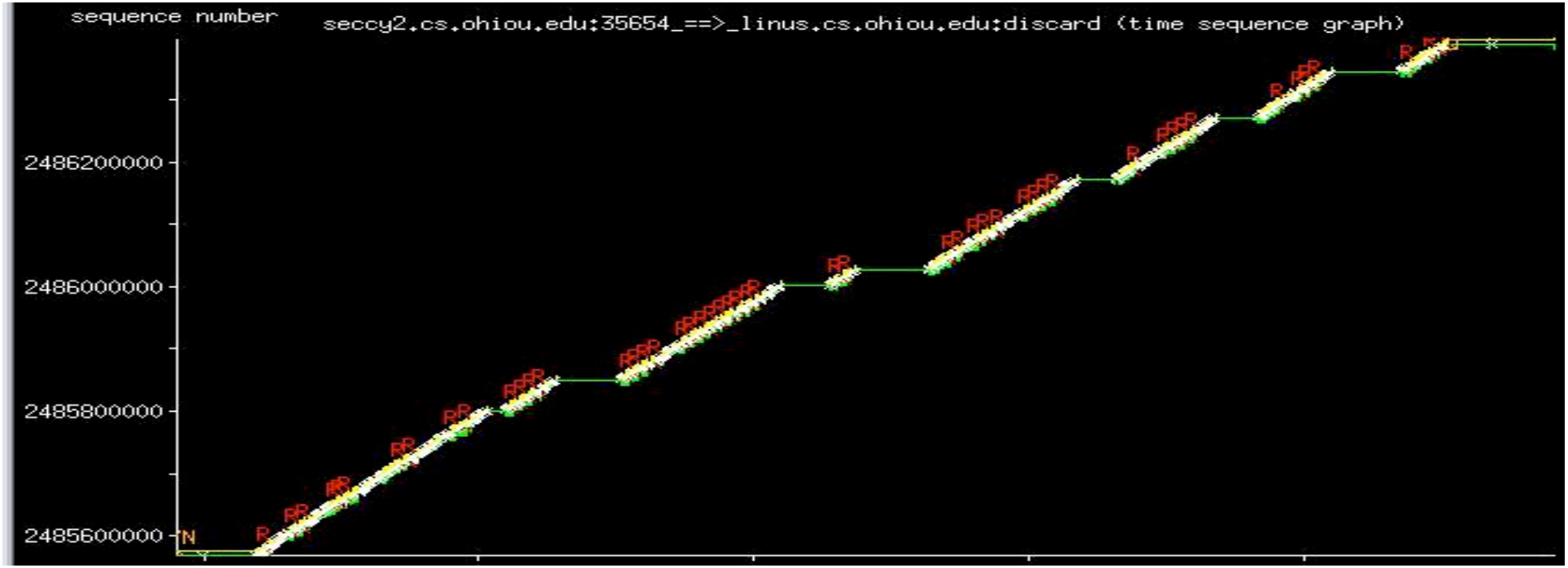
- **tcptrace: format tcpdump output for analysis using xplot**
  - **http://www.tcptrace.org/**

- **Sample use:**

```
tcpdump -s 100 -w /tmp/tcpdump.out host hostname
tcptrace -Sl /tmp/tcpdump.out
xplot /tmp/a2b_tsg.xpl
```

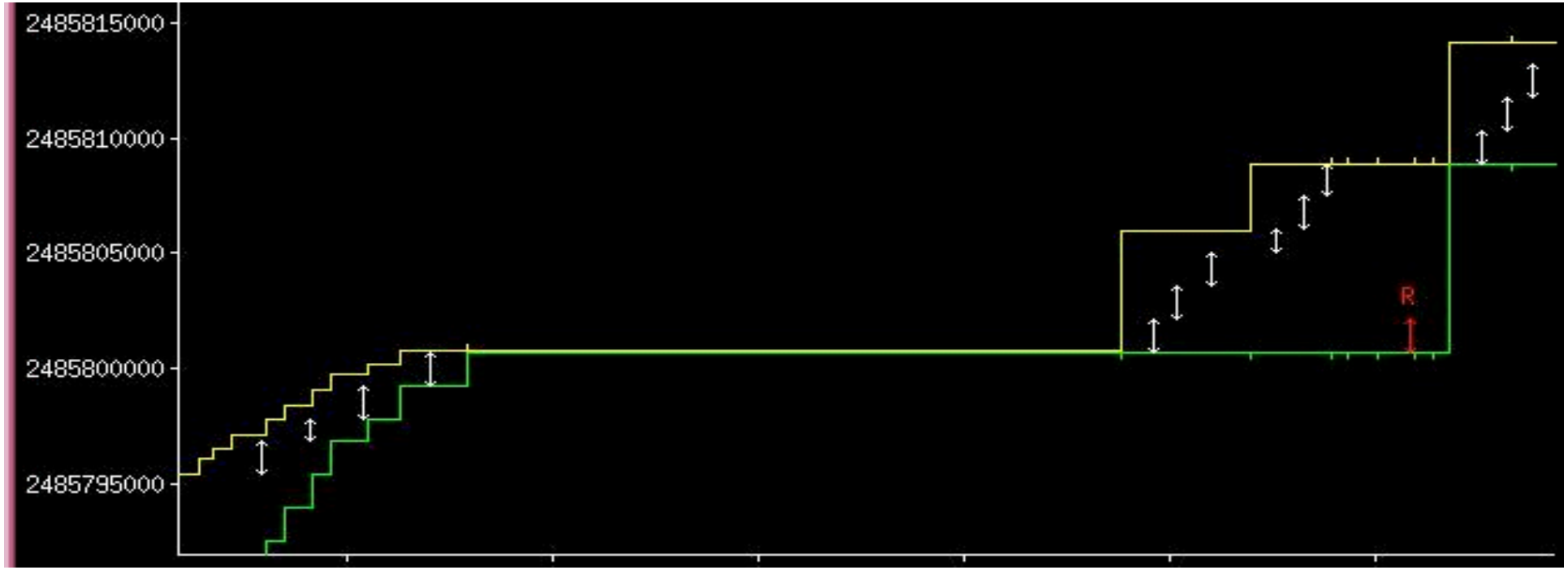
tcptrace and xplot

- X axis is time
- Y axis is sequence number
- the slope of this curve gives the throughput over time.
- xplot tool make it easy to zoom in



Zoomed In View

- Green Line: **ACK values received from the receiver**
- Yellow Line **tracks the receive window advertised from the receiver**
- Green Ticks **track the duplicate ACKs received.**
- Yellow Ticks **track the window advertisements that were the same as the last advertisement.**
- White Arrows **represent segments sent.**
- Red Arrows (R) **represent retransmitted segments**



U.S. Department of Energy
Office of Science

Jumbo Frames

ESnet
Energy Sciences Network

- Standard Ethernet packet is 1500 bytes (aka: MTU)
- Some gigabit Ethernet hardware supports "jumbo frames" (jumbo packet) up to 9 KBytes
  - Helps performance by reducing the number of host interrupts
  - Esnet, Internet2, and GEANT are all 9KB "jumbo-clean"
    - But many sites have not yet enabled Jumbo Frames
    - Some jumbo frame implementations do not interoperate
- First Ethernet was 3 Mbps (1972)
- First 10 Gbit/sec Ethernet hardware: 2001
  - Ethernet speeds increased 3000x since the 1500 byte frame was defined
  - Computers now have to work 3000x harder to fill the network
- To see if your end-to-end path is jumbo clean:
  - ping -M do -s 8972 192.0.2.254 (FreeBSD)
  - ping -D -s 8972 192.0.2.254
  - header math: 20 bytes IP + 8 bytes ICMP + 8972 bytes payload = 9000

Recent TCP Work

U.S. Department of Energy
Office of Science

TCP Response Function

ESnet
Energy Sciences Network

- **Well known fact that TCP reno does not scale to high-speed networks**
- **Average TCP congestion window = $1.2/\sqrt{p}$ segments**
  - **p = packet loss rate**
  - **see: http://www.icir.org/floyd/hstcp.html**
- **What this means:**
  - **For a TCP connection with 1500-byte packets and a 100 ms round-trip time**
    - filling a 10 Gbps pipe would require a congestion window of 83,333 packets,
    - a packet drop rate of at most one drop every 5,000,000,000 packets.
  - **requires at most one packet loss every 6000s, or 1h:40m to keep the pipe full**

U.S. Department of Energy
Office of Science

Proposed TCP Modifications

ESnet
Energy Sciences Network

- **Many Proposed Solutions:**
  - **High Speed TCP: Sally Floyd**
    - http://www.icir.org/floyd/hstcp.html
  - **BIC/CUBIC:**
    - http://www.csc.ncsu.edu/faculty/rhee/export/bitcp/
  - **LTCP (Layered TCP)**
    - http://students.cs.tamu.edu/sumitha/research.html
  - **HTCP: (Hamilton TCP)**
    - http://www.hamilton.ie/net/htcp/
  - **Scalable TCP**
    - http://www-lce.eng.cam.ac.uk/~ctk21/scalable/

U.S. Department of Energy
Office of Science

Linux 2.6.12 Results

ESnet
Energy Sciences Network

- BIC-TCP is included in Linux 2.6
  - results up to 100x faster than un-tuned!

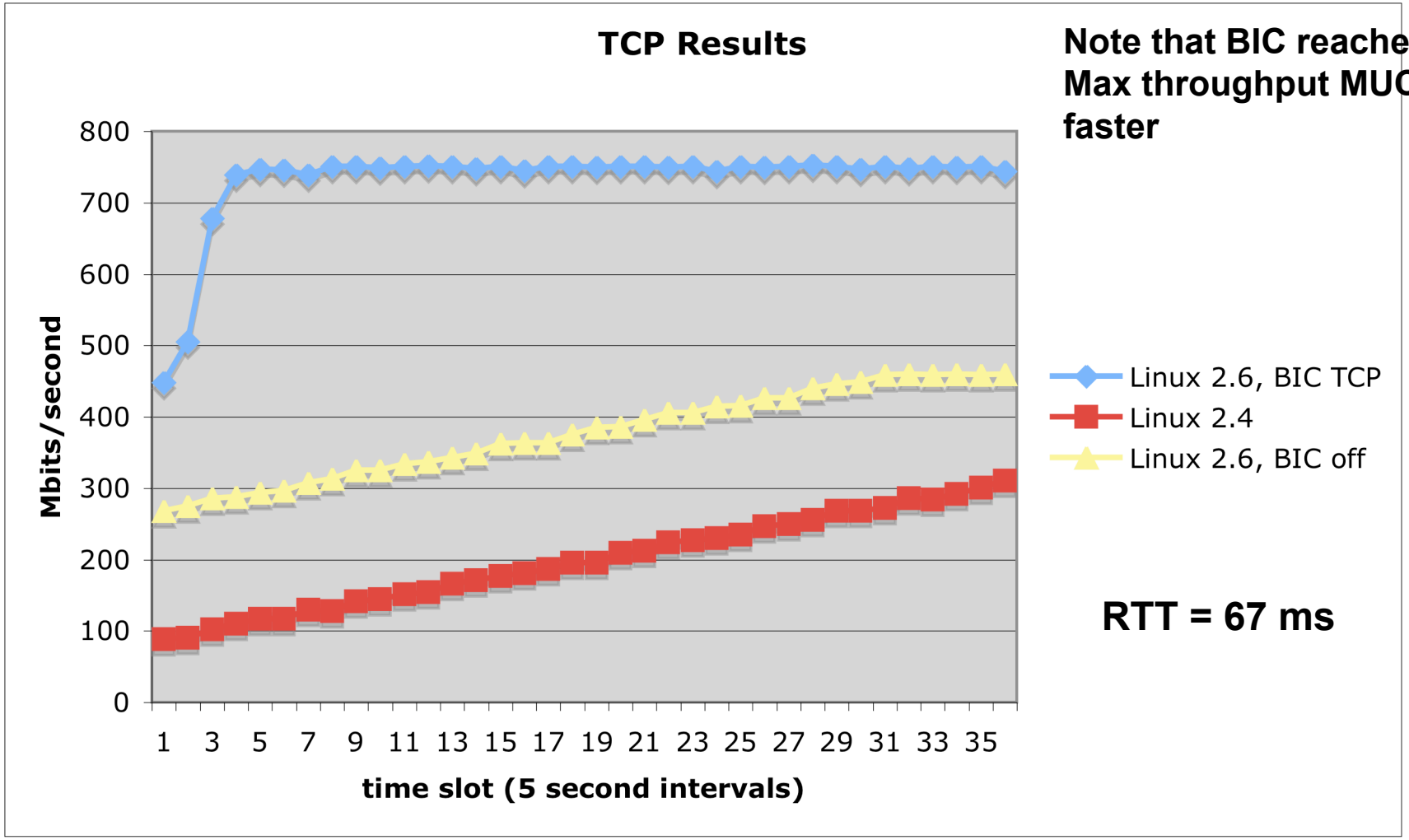
Path	Linux 2.4 Un-tuned	Linux 2.4 Hand-tuned	Linux 2.6 with BIC	Linux 2.6, no BIC
LBL to ORNL RTT = 67 ms	10 Mbps	300 Mbps	700 Mbps	500 Mbps
LBL to PSC RTT = 83 ms	8 Mbps	300 Mbps	830 Mbps	625 Mbps
LBL to IE (Ireland) RTT = 153 ms	4 Mbps	70 Mbps	560 Mbps	140 Mbps

- Results = Peak Speed during 3 minute test
- Must increase default max TCP send/receive buffers
- Sending host = 2.8 GHz Intel Xeon with Intel e1000 NIC

U.S. Department of Energy
Office of Science

Linux 2.6.12 Results

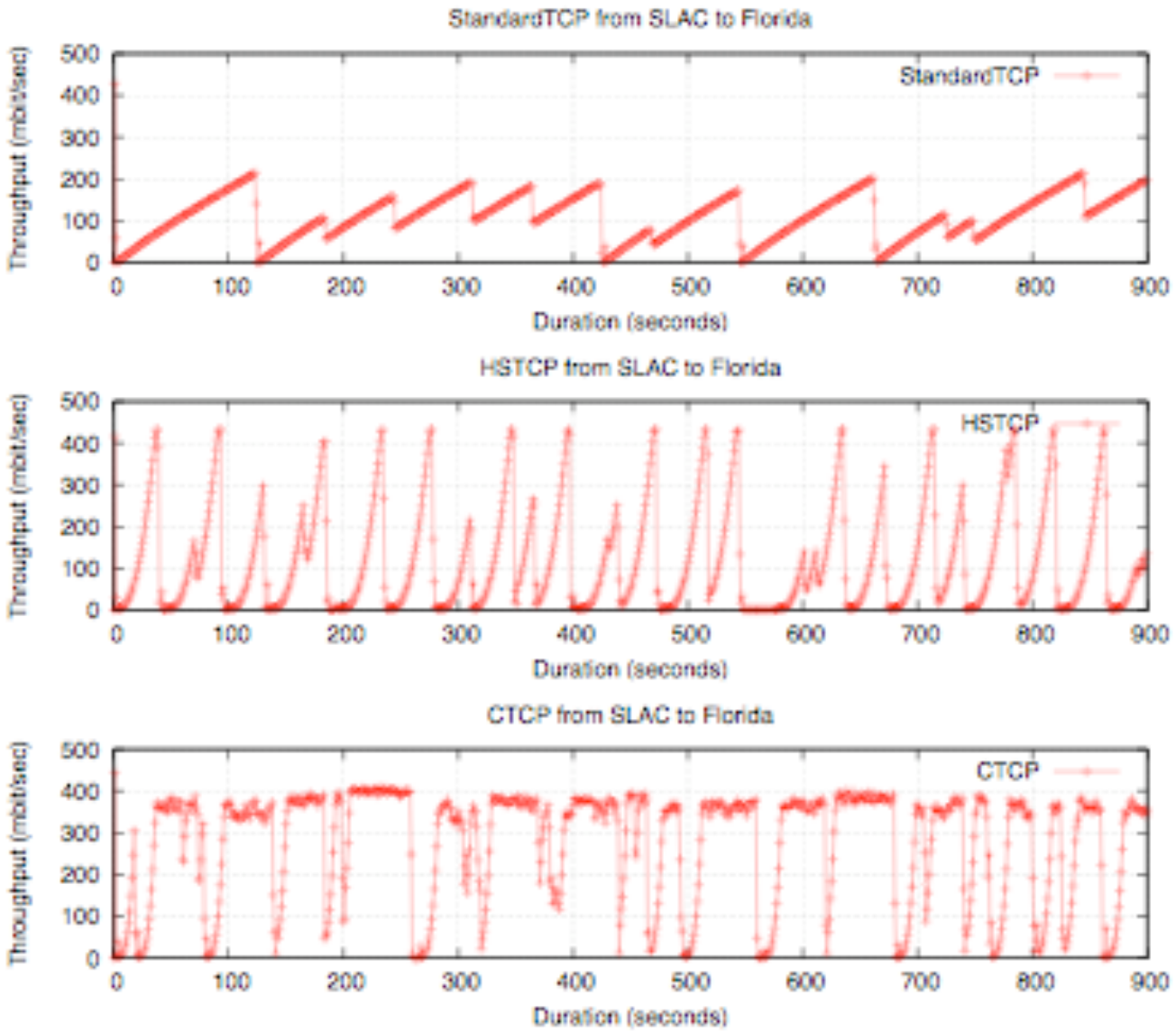
ESnet
Energy Sciences Network



U.S. Department of Energy
Office of Science

Comparison of Various TCP Congestion Control Algorithms

ESnet
Energy Sciences Network



Selecting TCP Congestion Control in Linux

- To determine current configuration:

```
sysctl -a | grep congestion
```

```
net.ipv4.tcp_congestion_control = cubic
net.ipv4.tcp_available_congestion_control = cubic
reno
```

- Use /etc/sysctl.conf to set to any available congested congestion control.
- Supported options (may need to enabled by default in your kernel):
  - CUBIC, BIC, HTCP, HSTCP, STCP, LTCP, more..

Selecting TCP Congestion Control in Windows Vista

- Vista includes "Compound TCP (CTCP)", which is similar to cubic on Linux.
- To enable this, set the following:

```
netsh interface tcp set global congestionprovider=ctcp"
```

Application Performance Issues

U.S. Department of Energy
Office of Science

Techniques to Achieve High Throughput over a WAN

ESnet
Energy Sciences Network

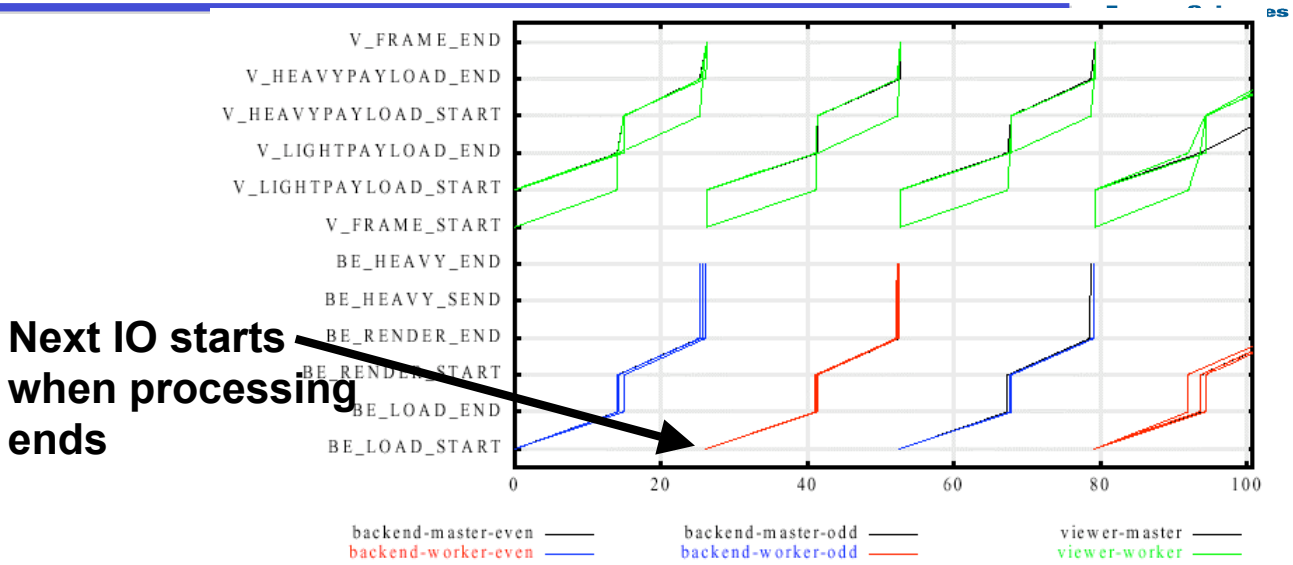
- Consider using multiple TCP sockets for the data stream
- Use a separate thread for each socket
- Keep the data pipeline full
  - use asynchronous I/O
    - overlap I/O and computation
  - read and write large amounts of data (> 1MB) at a time whenever possible
  - pre-fetch data whenever possible
- Avoid unnecessary data copies
  - manipulate pointers to data blocks instead

U.S. Department of Energy
Office of Science

Use Asynchronous I/O

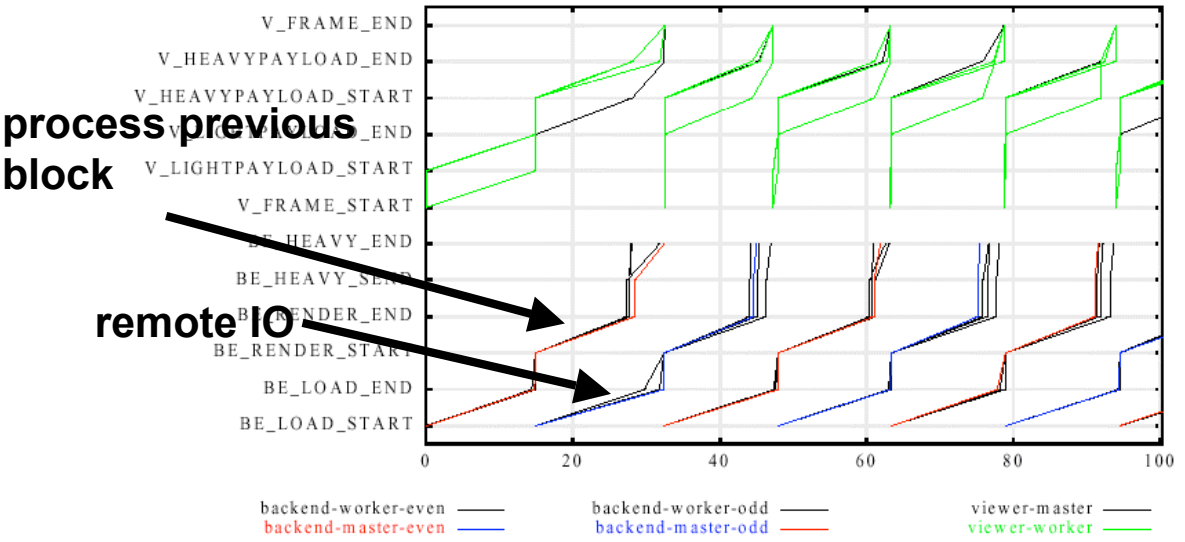
ESnet

- I/O followed by processing



Next IO starts when processing ends

- overlapped I/O and processing



process previous block

remote IO

almost a 2:1 speedup

U.S. Department of Energy
Office of Science

Conclusions

ESnet
Energy Sciences Network

- The wizard gap is starting to close (slowly)
  - If max TCP autotuning buffers are increased
- Tuning TCP is not easy!
  - no single solution fits all situations
    - need to be careful to set TCP buffers properly
    - sometimes parallel streams help throughput, sometimes they hurt
  - Autotuning helps a lot
- Lots of options for bulk data tools
  - Choose the one that fills your requirements
  - Don't use unpatched scp!

U.S. Department of Energy
Office of Science

More Information

ESnet
Energy Sciences Network

- http://fasterdata.es.net/
- http://acs.lbl.gov/TCP-tuning/
- email: BLTierney@es.net

Extra (advanced) slides