FTP-like Streams for 9P

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Abstract

The 9P protocol used by Plan 9 suffers from poor performance under high-latency conditions, such as those which exist on the Internet. The more common HTTP and FTP protocols far outstrip it in terms of transfer speed. This work proposes and demonstrates a novel addition to 9P which allows the use of FTP-like streams to improve transfer performance.

Background: Plan 9

- Research operating system from Bell Labs
- Includes features not found in UNIX:
  - Private namespaces
  - Unified filesystem protocol[1]
  - **Everything** is a file
  - Graphics and networking support

Private Namespaces

- Each process has its own namespace
- It may bind different filesystems to this namespace
- Union directories are possible
- To user programs, the heterogeneous namespace appears homogeneous

9P

- Unified filesystem protocol for Plan 9[6]
- RPC transactions
  - Client sends T-message
  - Server responds with R-message
- Messages map closely to libc function calls

Default 9P Messages

Message Name	Function
Tversion/Rversion	Exchanges client/server 9P version numbers
Tauth/Rauth	Authenticates client with server
Rerror	Indicates an error (includes error string)
Tflush/Rflush	Aborts a previous request
Tattach/Rattach	Establishes a connection to a file tree
Twalk/Rwalk	Descends a directory hierarchy
Topen/Ropen	Opens a file or directory
Tcreate/Rcreate	Creates a file
Tread/Rread	Reads data from an open file
Twrite/Rwrite	Writes data to an open file
Tclunk/Rclunk	Closes an open file
Tremove/Rremove	Removes a file
Tstat/Rstat	Requests information about a file
Twstat/Rwstat	Changes information about a file

Source: [1]

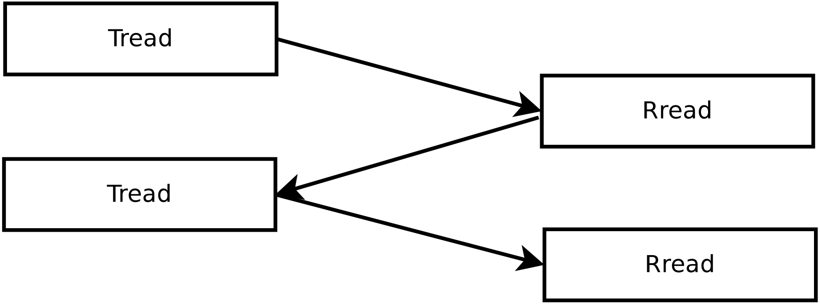
File Servers in Plan 9

- "File server" is a generic term for a program that responds to 9P requests
- Files do not necessarily have to reside on a physical medium
  - `ftpfs`
  - `rio`
  - `gpsfs`
- File servers typically communicate using a TCP connection or a local pipe
- To the kernel, the connection to the filesystem appears as a generic `Chan` (channel)

The Problem with 9P

- Copying files via 9P is slow.
- Why? 9P waits for a single response for every message sent.
- Over high-latency links, the waiting becomes problematic.
  - Client sends a `Tread` and starts waiting
  - 50 ms later, `Tread` arrives at server, which responds
  - Another 50 ms later, the `Rread` arrives at the client
- The client spends 100 ms waiting for each chunk of data read!

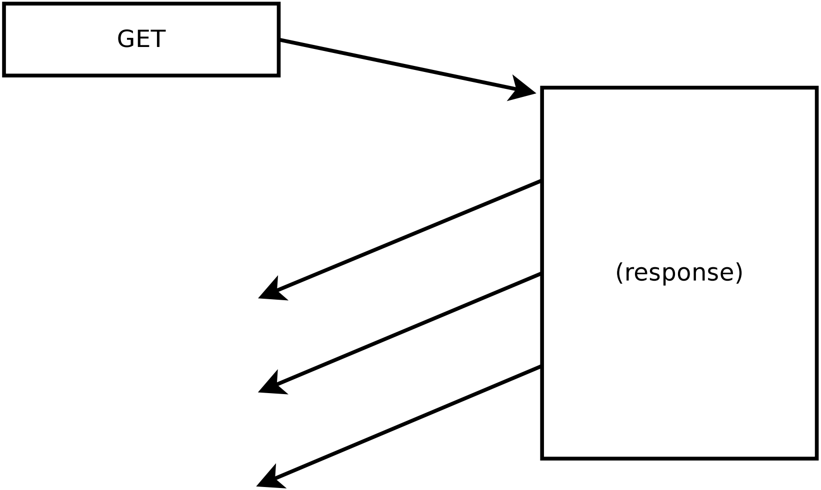
The 9P Model



Sequential Reading, FTP and HTTP

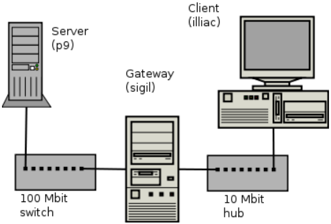
- Sequentially reading or writing a file is one of the most common cases
- 9P makes no concessions to sequential file I/O
- HTTP and FTP are focused on sequential I/O
  - Both are significantly limited compared to 9P
  - Both are quite fast over high-latency links
  - The trick: send all the data at once, don't wait for the client to ask
- Specifically, FTP in passive mode negotiates a separate TCP connection for data transfer.[7]

The HTTP Model

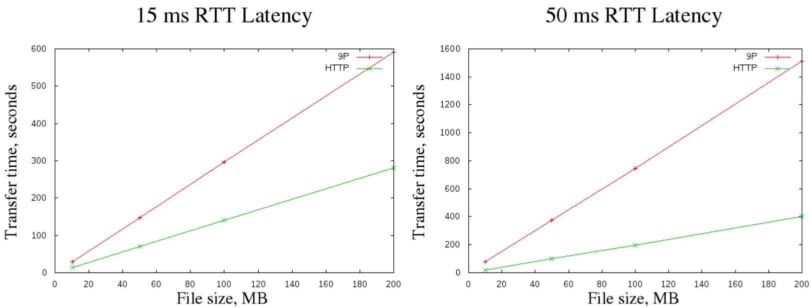


Motivation

- HTTP and 9P were compared for transferring files over high-latency links.
- To control the experiment, a high latency connection was simulated over a LAN
- Latency induced using a Linux gateway running `netem`



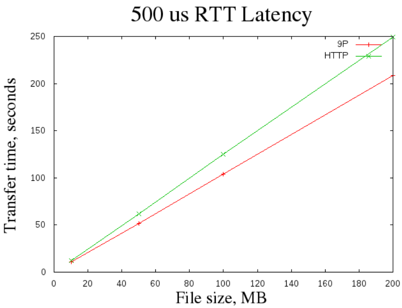
High-latency Results



Copying a 200 MB file over 9P across a 50ms RTT link took more than 25 minutes. The same operation required less than 7 minutes with HTTP.

Low-latency Results

Over low-latency links, 9P outperformed HTTP



Streams

- Give programmers the option of having FTP-like behavior
- Augment the `Tmessage/Rmessage/Tmessage/Rmessage` paradigm
- Negotiate an out-of-band channel for data
  - TCP already provides in-order, guaranteed delivery with flow control.
  - One TCP connection per file
- In the case of non-streaming servers, regular reads and writes can provide compatibility
- Streams negotiated using `Tstream/Rstream` messages
  - `size[4] Tstream tag[2] fid[4] isread[1] offset[8]`
  - `size[4] Rstream tag[2] count[4] data[count]`
- Others ([2], [3], [4], [5], [8]) have attempted to improve filesystem speeds transparently–Streams do it explicitly, at the programmer's discretion

User-Level Functions

- User programs create and interact with streams using three new libc functions
  - `Stream* stream(int fd, vlong offset, char isread)`
  - `long sread(Stream* s, void* buf, long len)`
  - `long swrite(Stream* s, void* buf, long len)`
- The `Stream` structure contains the following elements:
  - `int ofd`: The file descriptor of the underlying file
  - `int conn`: A file descriptor for the TCP connection
  - `char *addr`: The IP and port used by the TCP stream
  - `vlong offset`: The current offset of the stream in the file
  - `char isread`: Flag indicating read/write status of stream; 1 indicates read
  - `char compatibility`: Flag indicating that compatibility mode should be used

`stream` Function

- Sets up a new Stream
- Expects an open file descriptor and a desired offset into the file
- Calls the `pstream` system call
- If streaming is allowed, system call indicates such by returning 0
    - Syscall also sets the `addr` field of the Stream struct
    - `stream` function then calls `dial` with address to get a TCP connection
- If streaming is not allowed, system call returns -1
    - `stream` function sets `compatibility` flag in the Stream struct
    - Any reads or writes on the stream will actually be emulated

`sread` and `swrite` Functions

- Read or write from a Stream
- If the compatibility flag is not set, reads and writes are done on the TCP connection in the Stream structure
- If the compatibility flag is set, reads and writes are done by calling the `pread` and `pwrite` functions
  - Reads and writes are done on the `ofd` file descriptor
  - The `offset` struct member is updated and used to specify offsets when performing emulated streaming

System Call

- Was necessary to add a new system call
- `pstream` called by the `stream` libc function
- Provides an interface between user-level code and devices which actually set up streams
- Takes a file descriptor, pointer to a buffer, an offset, and a read/write flag
- Returns -1 or 0 based on streaming capability of device/server
- If streaming is supported, buffer is filled with a "dial" string upon return
    - Example: "tcp!129.21.0.123!23456"

Devices

- Individual devices are responsible for setting up streams
- Most devices are local; streams don't make sense, so compatibility mode is used
- The `devmnt` device is the most important
    - `devmnt` connects to remote filesystems
    - Attaches filesystems to the local namespace

devmnt Modifications

- Was necessary to update 9P version
  - Originally spoke "9P2000"
  - Now reports as speaking "9P2000.s"
- When stream setup function in `devmnt` is called:
  - Version of remote server is checked
  - If version is not 9P2000.s, compatibility mode must be used, -1 is returned
  - Otherwise, a `Tstream` message is sent out
  - Message requests a new stream for the specified file, starting at a given offset
  - `isread` flag in the `Tstream` message identifies requested stream as read or write

The `exportfs` file server

- The `exportfs` file server was modified to serve streams
- `exportfs` exports a server's namespace to a client
  - Simple design
  - Very commonly used
- 9P message handler modified to recognize `Tstream` messages
- If a stream is requested:
  - `exportfs` begins listening on an unused TCP port
  - Sends back the IP address and port number in the `Rstream` reply
  - Waits until client connects to the port
  - In the case of a read stream, continually send file data over the TCP connection until EOF.
  - In the case of a write stream, continually read data over the TCP connection until no data remains.

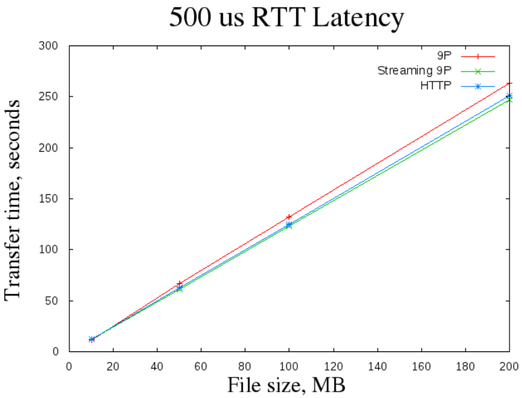
Streaming `cp`

- Standard `cp` opens source and destination files, then copies 8 KB at a time using `read` and `write`
- In modified "streaming `cp`", or `scp`, both files are opened, then streams are created on the open files
- The source file is set up as a read stream
- Destination file is set up as a write stream
- `sread` and `swrite` are called to read 8 KB at a time from the read stream and write it back out to the write stream
- Compatibility mode allows use with non-streaming servers
- Modifications required the addition of 2 lines of code and slight changes to 2 other lines

Testing Setup

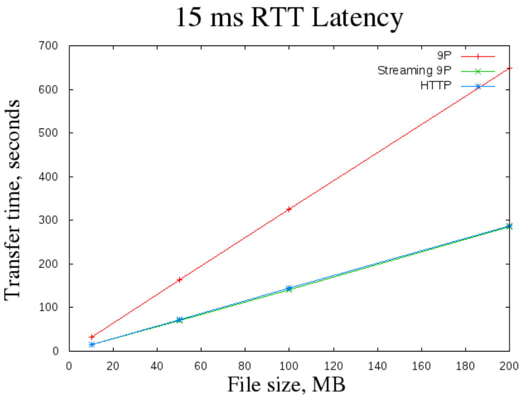
- Used same setup as preliminary HTTP vs. 9P measurements
- Tests consisted of copying files over HTTP, streaming 9P, and non-streaming 9P
- As before, randomly-generated test files of 10MB, 50MB, 100MB, and 200MB were transferred
- Tests were performed with latencies of 500 μs, 15 ms, and 50 ms RTT

500 μs RTT



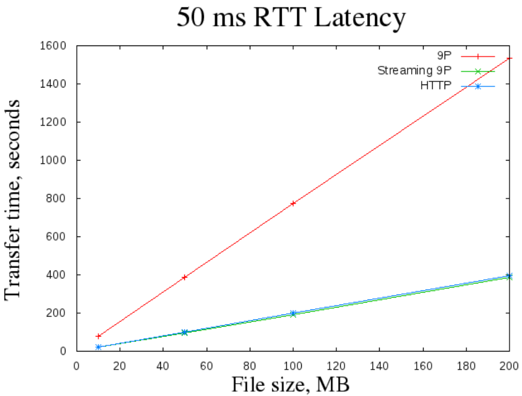
File Size (MB)	9P (sec.)	Streaming 9P (sec.)	HTTP (sec.)
10	11.36	12.21	12.56
50	67.23	61.29	62.41
100	132.34	123.32	124.49
200	263.33	247.34	251.22

15 ms RTT



File Size (MB)	9P (sec.)	Streaming 9P (sec.)	HTTP (sec.)
10	31.77	14.38	15.15
50	163.45	71.00	72.56
100	324.46	140.68	144.96
200	647.92	284.71	287.23

50 ms RTT



File Size (MB)	9P (sec.)	Streaming 9P (sec.)	HTTP (sec.)
10	78.82	21.80	21.45
50	387.92	96.19	98.39
100	773.03	192.60	198.14
200	1535.81	385.69	395.53

Future Work

- Other 9P servers, such as Fossil and Venti, should be converted to use streams
- User programs which can benefit from streaming should be modified:
  - `page` document and image viewer
  - `mp3dec` music player
- Design may eventually be included in the Plan 9 distribution

Conclusions

- Streaming 9P has demonstrated that it can match the performance of HTTP
- POSIX file semantics have been expanded to give attention to sequential file I/O
- Rather than try to improve performance transparently, explicit library functions let the programmer choose when streaming is important
- Requires very small programmer effort for large performance gains

Bibliography I

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