A Low-bandwidth Network File System

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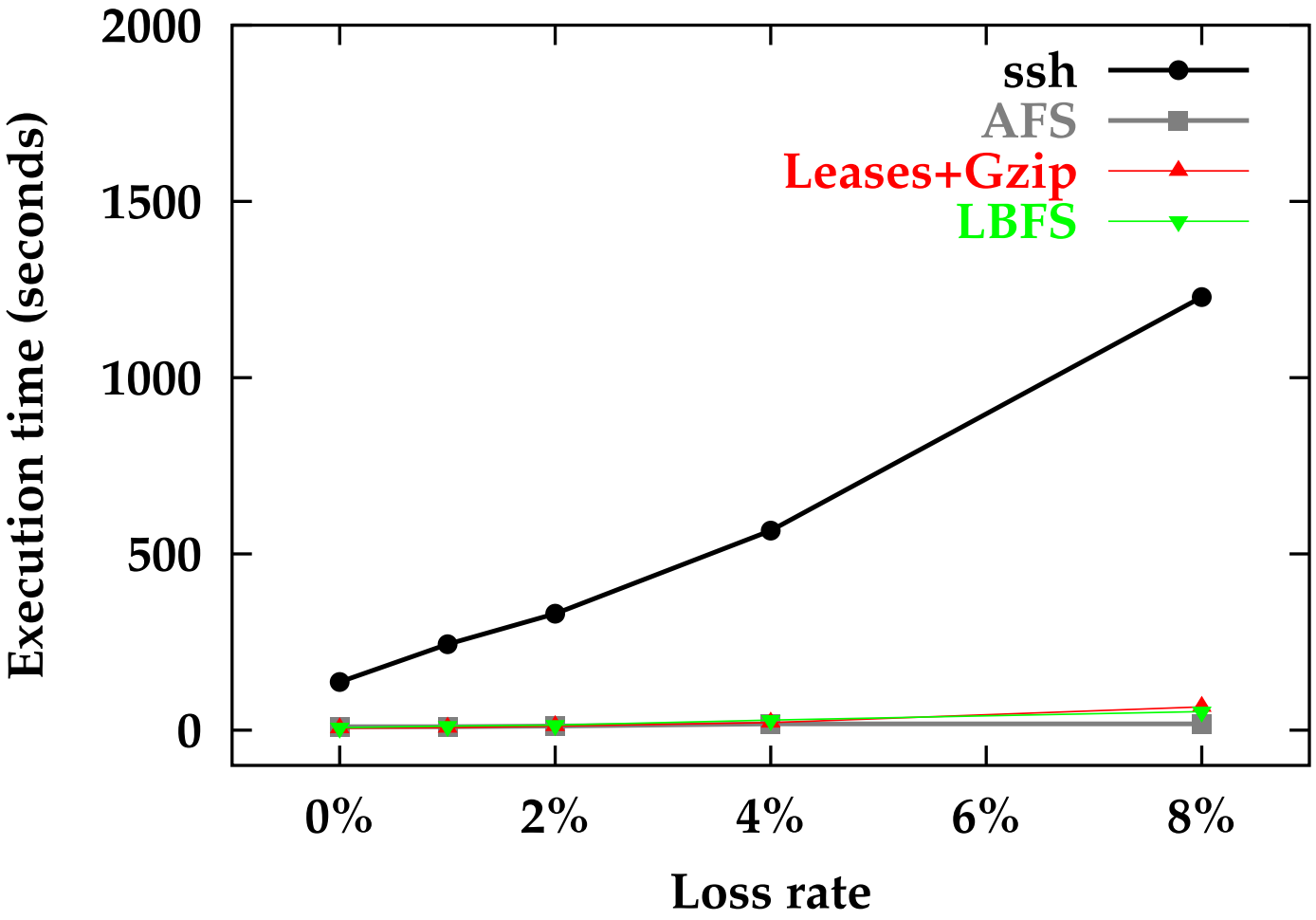
Motivation

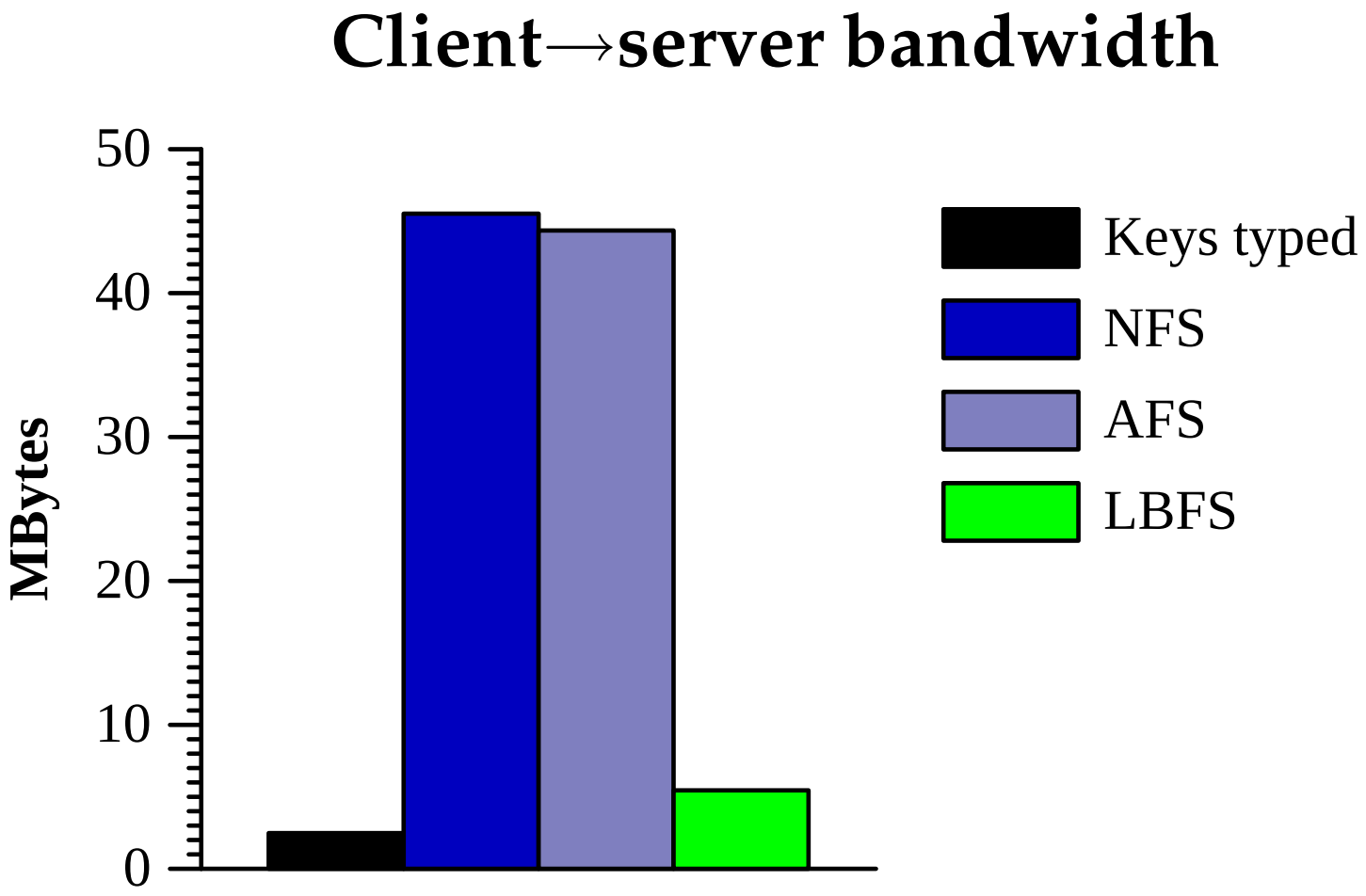
- **Network file systems are a useful abstraction…**
- **But few people use them over wide-area networks**
  - Many people at SOSP probably use network file systems
  - Few are currently accessing those file systems over 802.11b
  - Any FS used here likely provides non-traditional semantics
- **Network file systems require too much bandwidth**
  - Saturate bottleneck links
  - Interfere with other users
  - Block processes for seconds while waiting for network

Other ways of accessing remote data

- **Relax consistency semantics (CODA, CVS, . . .)**
  - Many applications need strict consistency (email, RCS, . . .)
- **Copy files back and forth to work on them**
  - Threatens consistency—where is latest version?
  - Not all files will work if copied (symlinks, `CVS/Root`, . . .)
- **Use remote login to work on files remotely**
  - Graphical applications require too much bandwidth (figure editors, postscript previewers, . . .)
  - Interactive programs sensitive to latency and packet loss
  - Delayed character echoes are extremely frustrating!

Remote login frustration!




Client→server bandwidth
MBytes
50
40
30
20
10
0
Keys typed
NFS
AFS
LBFS

Observation: Much inter-file commonality

- **Editing/word processing workloads**
  - Often only modify one part of a large file
  - Generate "autosave" files with mostly redundant content
- **Software development workloads**
  - Modify header & recompile → recreate similar object files
  - Concatenate object files into a library
- **LBFS: Exploit commonality to save bandwidth**
  - Won't always work, but big potential savings

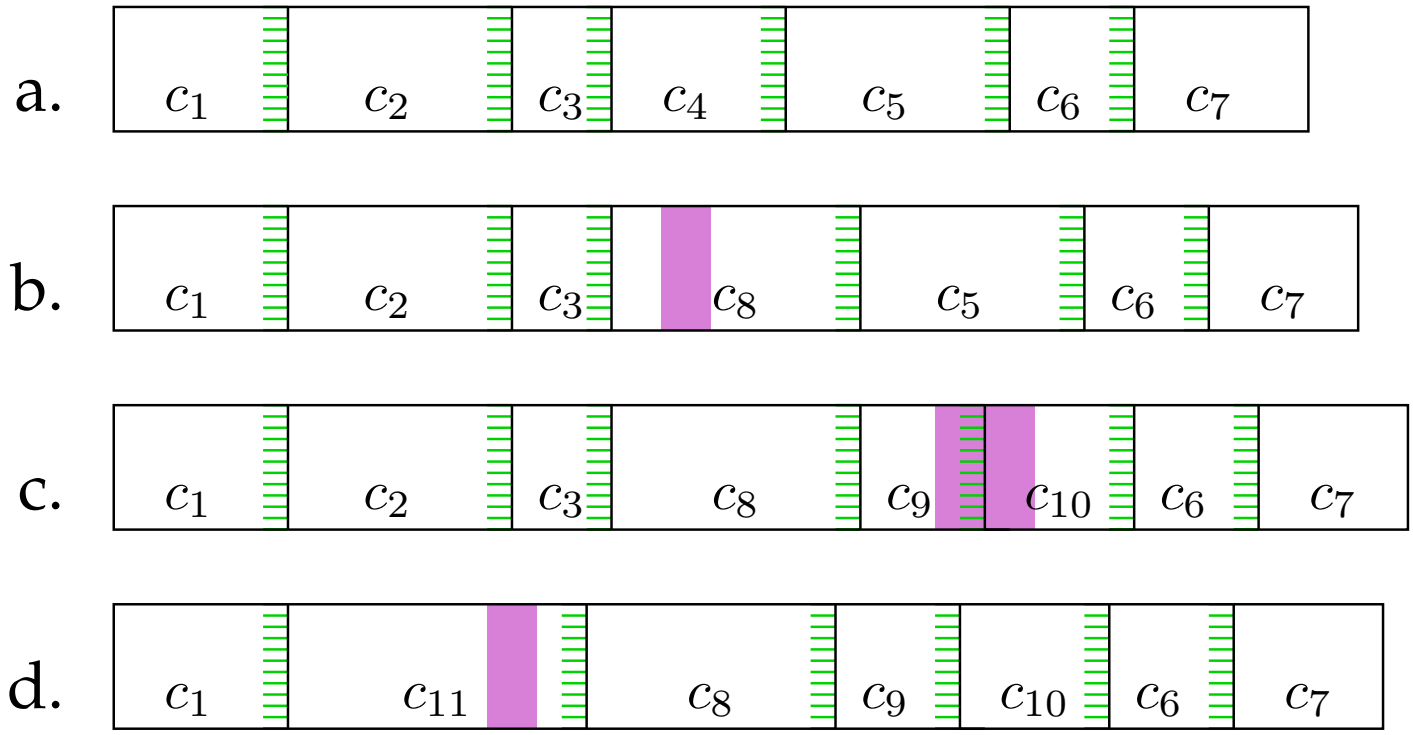
Avoiding redundant data transfers

- **Identify blocks by collision-resistant hash**
- **To transfer a file between client and server**
  - Break file into ∼8K data chunks
  - Send hashes of the file's chunks
  - Only send chunks actually needed by recipient
- **Index file system and client cache to find chunks**
  - Keep database mapping hash → ⟨file, offset, len⟩
  - Use chunks from any file in reconstructing any other

Dividing files into chunks

- **Straw man: Split file into aligned 8K chunks**
  - Inserting one byte at start of file changes all chunks
- **Base chunks on file contents, not position**
  - Allow variable-length chunks
  - Compute running hash of every overlapping 48-byte region
  - If hash mod 8K is special value, create chunk boundary
- **Chunk boundaries insensitive to shifting offsets**
  - Inserting/deleting data only effects surrounding chunk(s)

Example: Breaking a file into chunks



Pathological cases

- **Tiny chunks**
  - E.g., caused by unlucky 48-byte region repeated
  - Sending hashes consume more bandwidth than data
- **Enormous chunks**
  - E.g., long run of all zeros
  - Hard to handle (can't hold chunks in memory)
- **Solution: Impose min/max chunk sizes (2K/64K)**
  - Could conceivably derail alignment
  - Just an optimization, can afford low-probability failures
  - "Problem-cases" often very compressible!

LBFS overview

- **Provides traditional file system semantics**
  - Close-to-open consistency
  - Data safely stored on server before close returns
- **Large client cache holds users working set**
  - Eliminates all communication not required for consistency
  - When user modifies file, must write through to server
  - When different client modifies file, download new version
- **Elides transfers of redundant data**
- **Conventionally compresses remaining traffic**

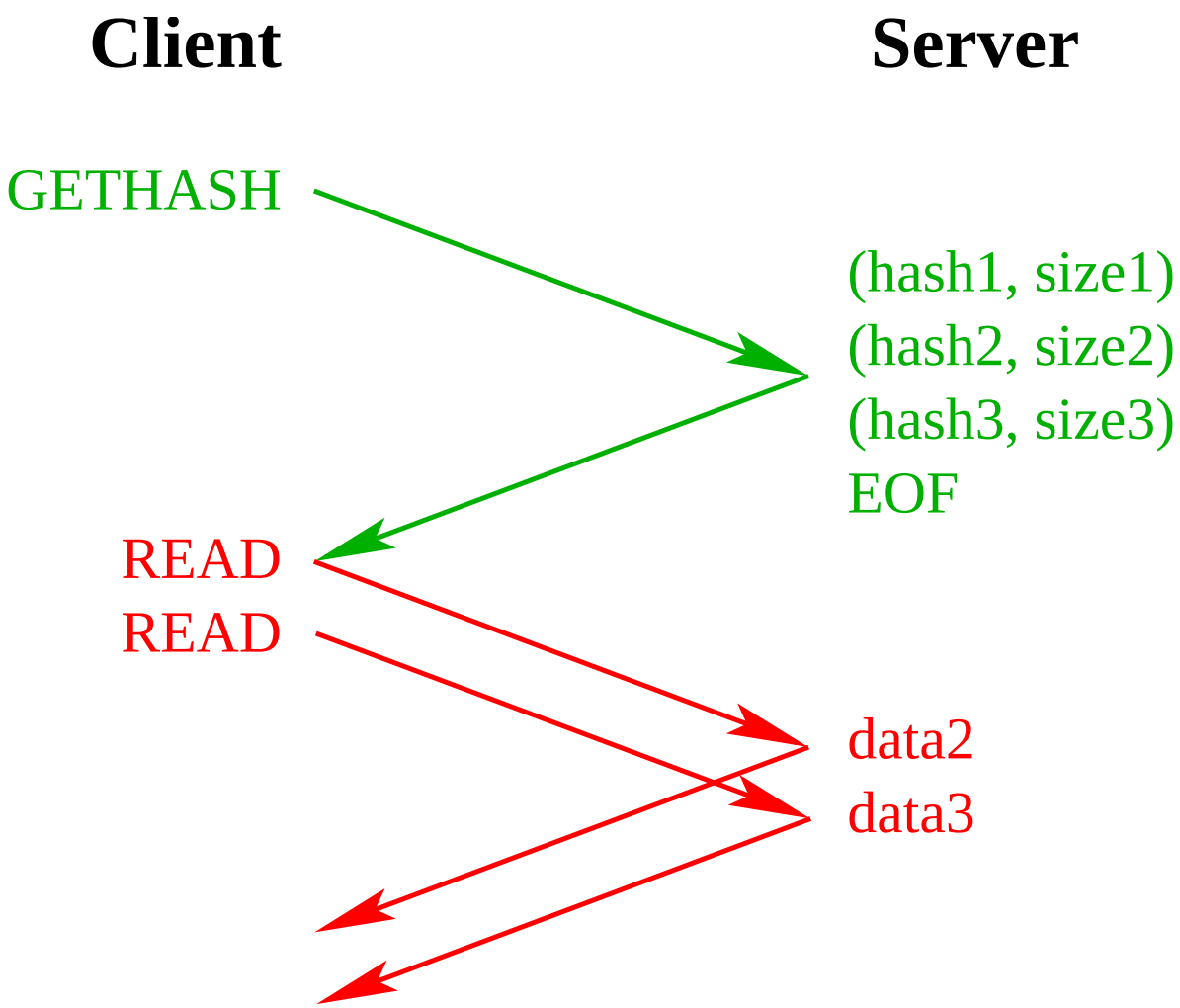
LBFS protocol

- **Derived from the NFS protocol**
- **Adds more aggressive caching**
  - Persistent, on-disk cache holds user's entire working set
  - Callbacks & Leases save an RPC for many open/stat calls
- **Client and server index data chunks with a B-tree**
- **Five new RPCs exploit inter-file commonality**
  - GETHASH – like read, but returns hashes not data
  - CONDWRITE – a write that takes a hash instead of data
  - 3 RPCs for atomic file updates

Read caching

- **Leases let client validate cached attributes**
  - Most file operations grant client a lease on attributes
  - Server must notify client if attributes change while leased
- **Attributes let client validate cached file contents**
  - Check modification/change times
- **When client must downloaded a file**
  - Retrieve file's chunk hashes with GETHASH
  - Request chunks not already in cache using normal READs
  - Update the local chunk index to reflect new cache data

Read protocol



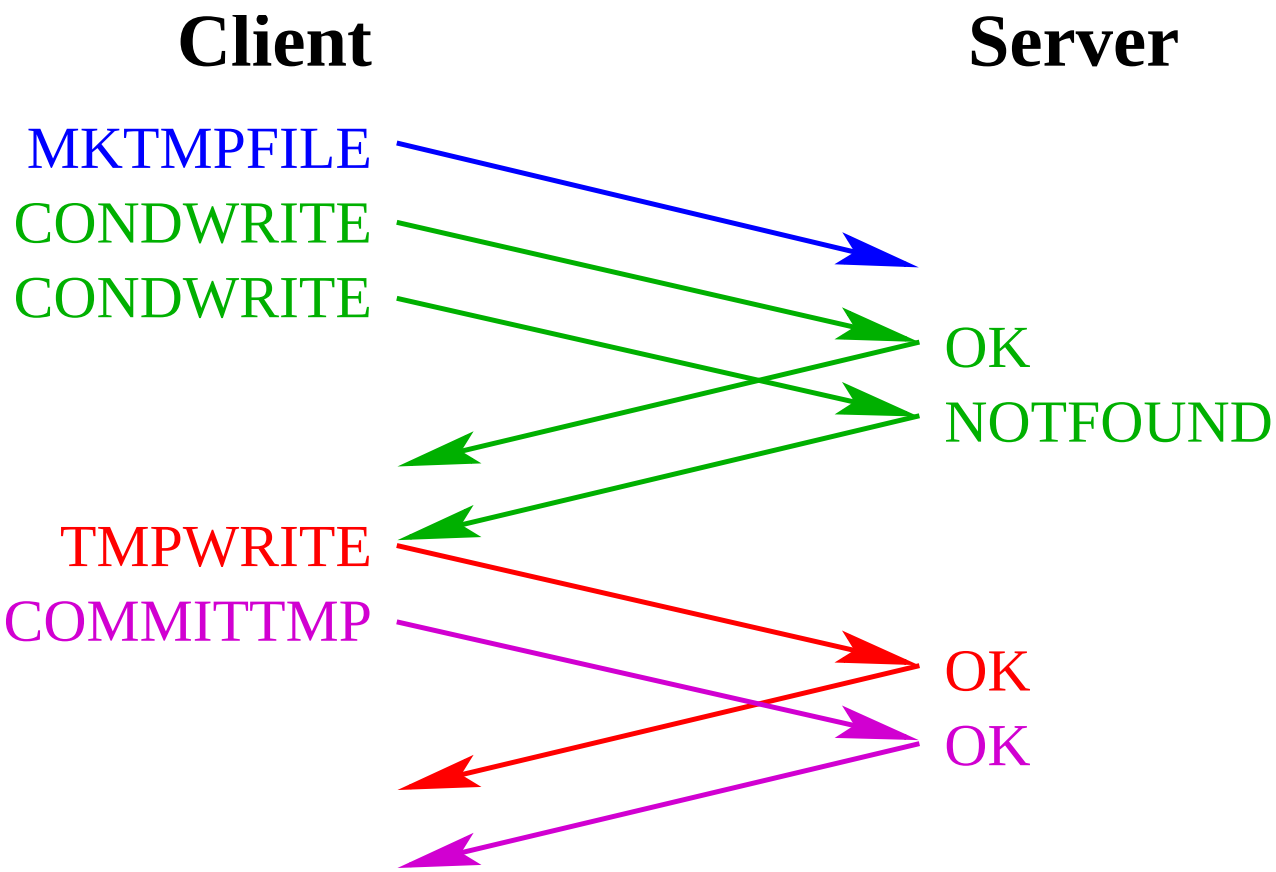
Writing back a modified file

- **Idea: First send hashes, then missing data**
- **Complications:**
  - New file likely contains many chunks it is overwriting
  - Unaligned writes can be expensive (cause disk read)
  - Reordering writes creates confusing intermediary states
  - What if client crashes in the middle of sending file?
- **Solution: Atomic updates**
  - Write data to new temporary file
  - Commit contents of temporary file to file being written

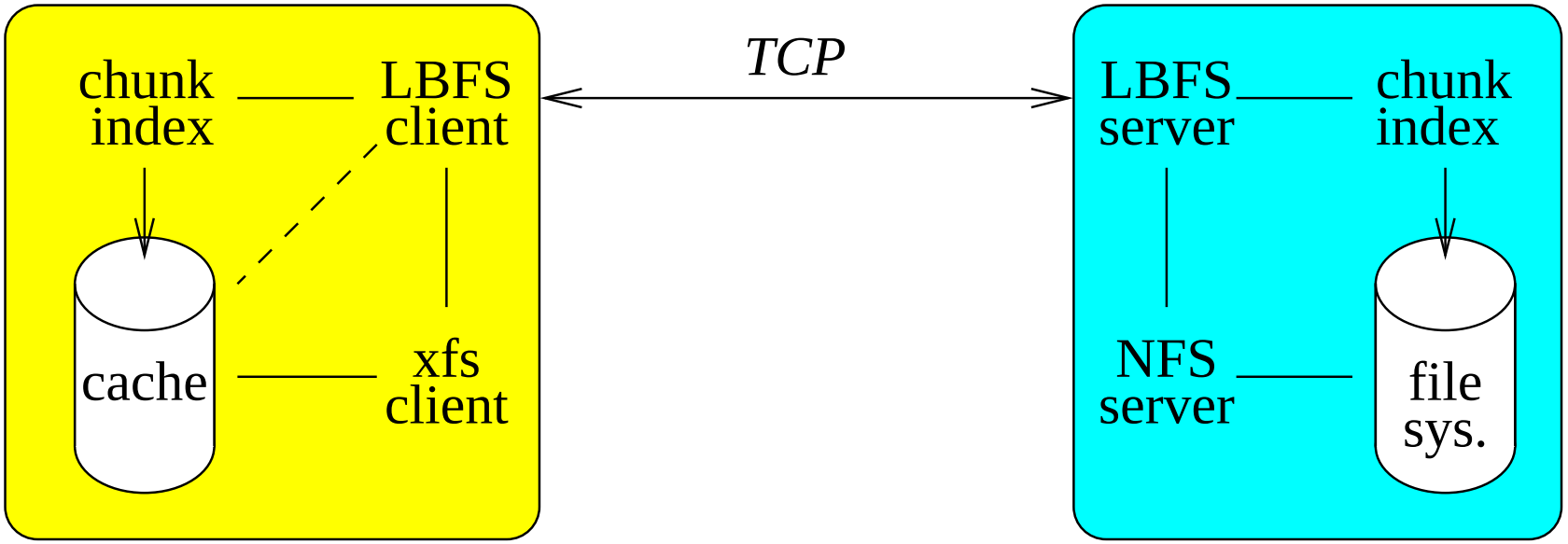
Atomic update RPCs

- **MKTMPFILE RPC creates a temporary file**
  - File named by client-chosen descriptor
- **CONDWRITE sends hashes of chunks**
  - Can be immediately pipelined behind MKTMPFILE
  - Server writes chunk if in DB, else returns NOTFOUND
- **TMPWRITE sends data for NOTFOUND chunks**
- **COMMITTMP copies temporary file to target file**
- **Server updates chunk index**

Update protocol



Implementation

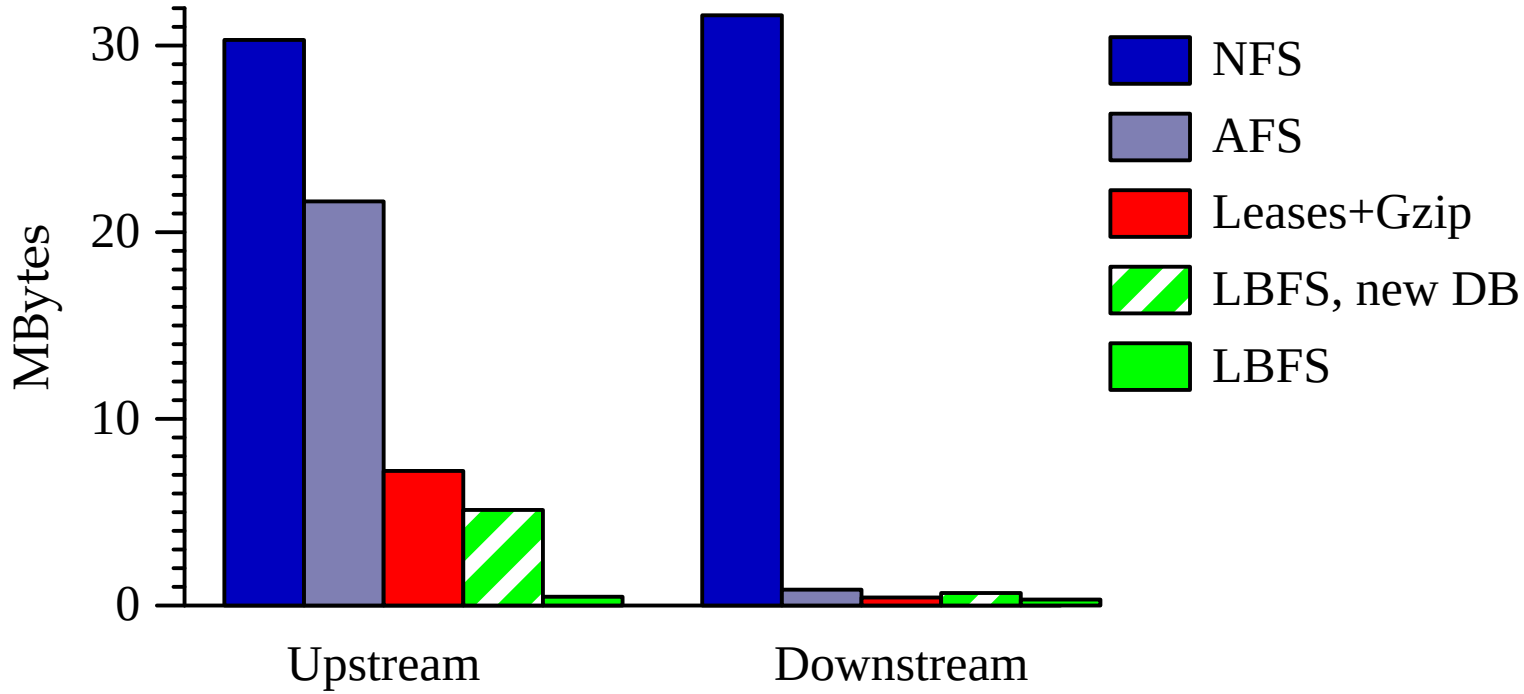


- **Client – uses *xfs*, device driver of ARLA AFS clone**
- **Server – accesses FS by pretending to be NFS client**
- **Index – uses BerkeleyDB B-tree**

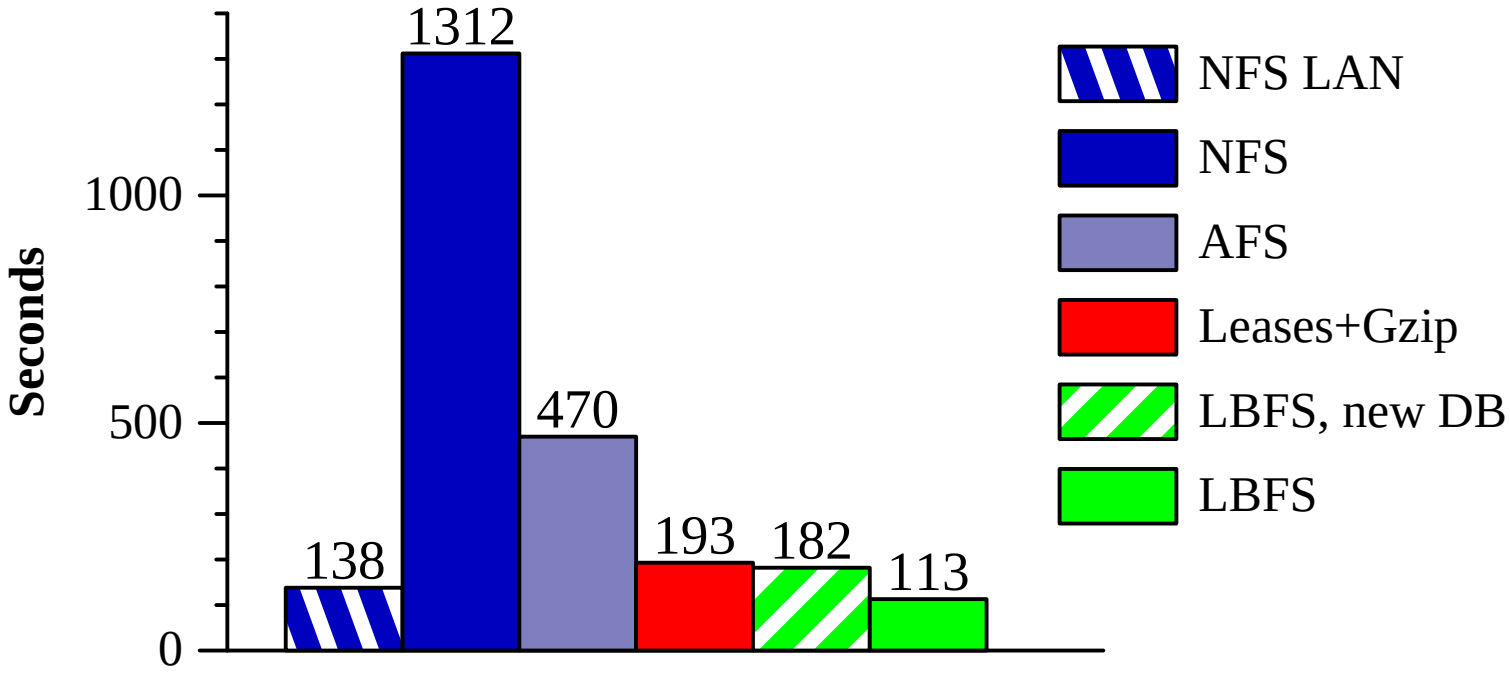
Implementation details

- **Never assume chunk index is correct**
  - Automatically fix errors as encountered
  - No need for expensive crash-recovery precautions
  - Allows server to be updated by non-LBFS clients
- **Keep old temporary files around**
  - Often contain useful chunks for subsequent files
  - Move to trash directory, evict in FIFO order
- **Background thread deletes invalid DB entries**

Bandwidth: emacs recompile

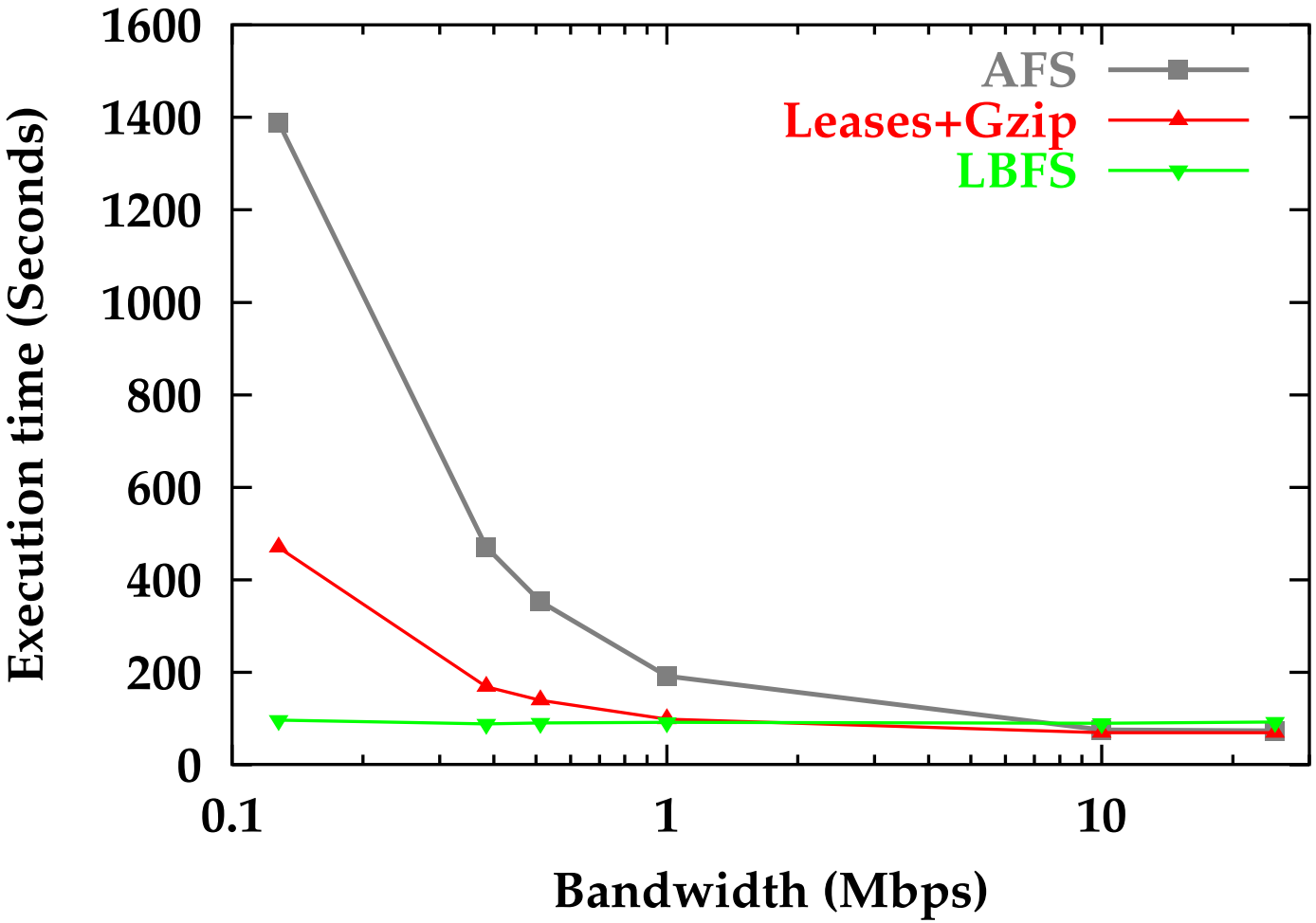


Performance: emacs recompile

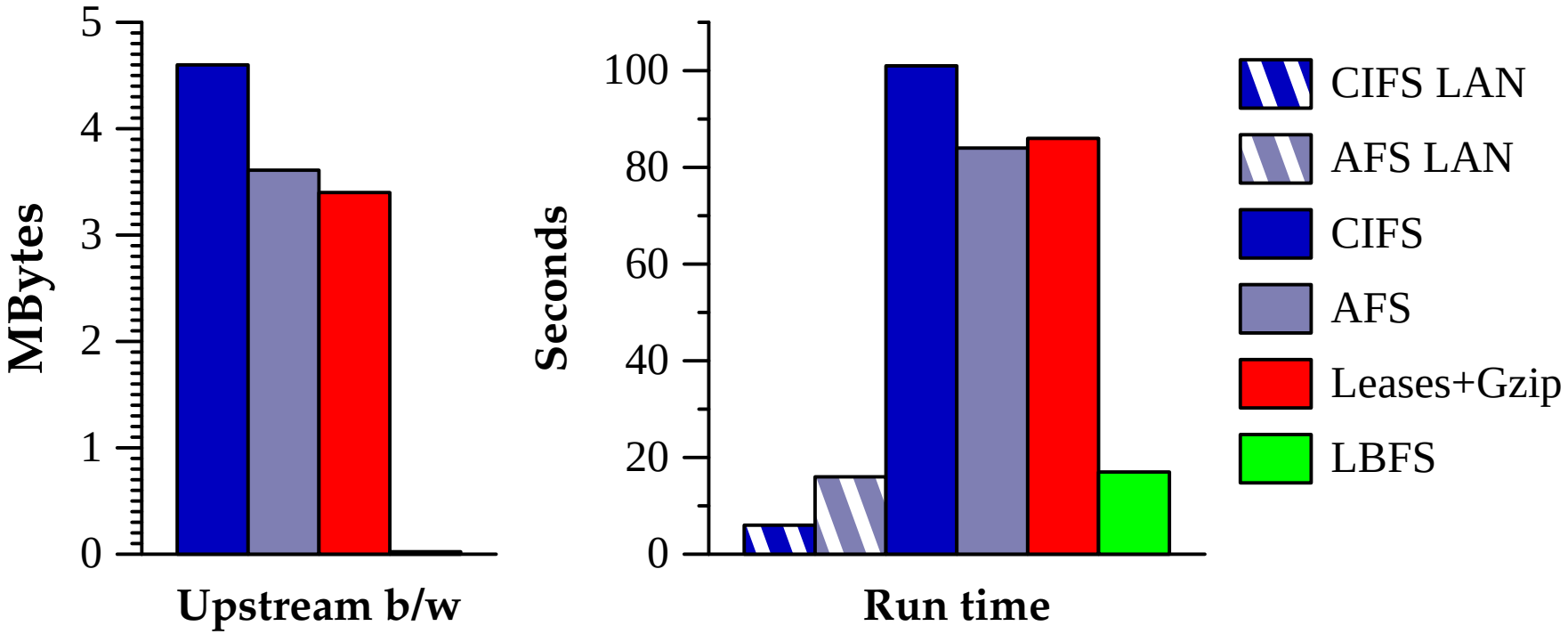


- **Evaluated over simulated ADSL line**
  - 1.5 Mbit/sec downstream, 348 Kbit upstream, 30 ms latency
  - LBFS on ADSL beats NFS on 100Mbit/sec LAN

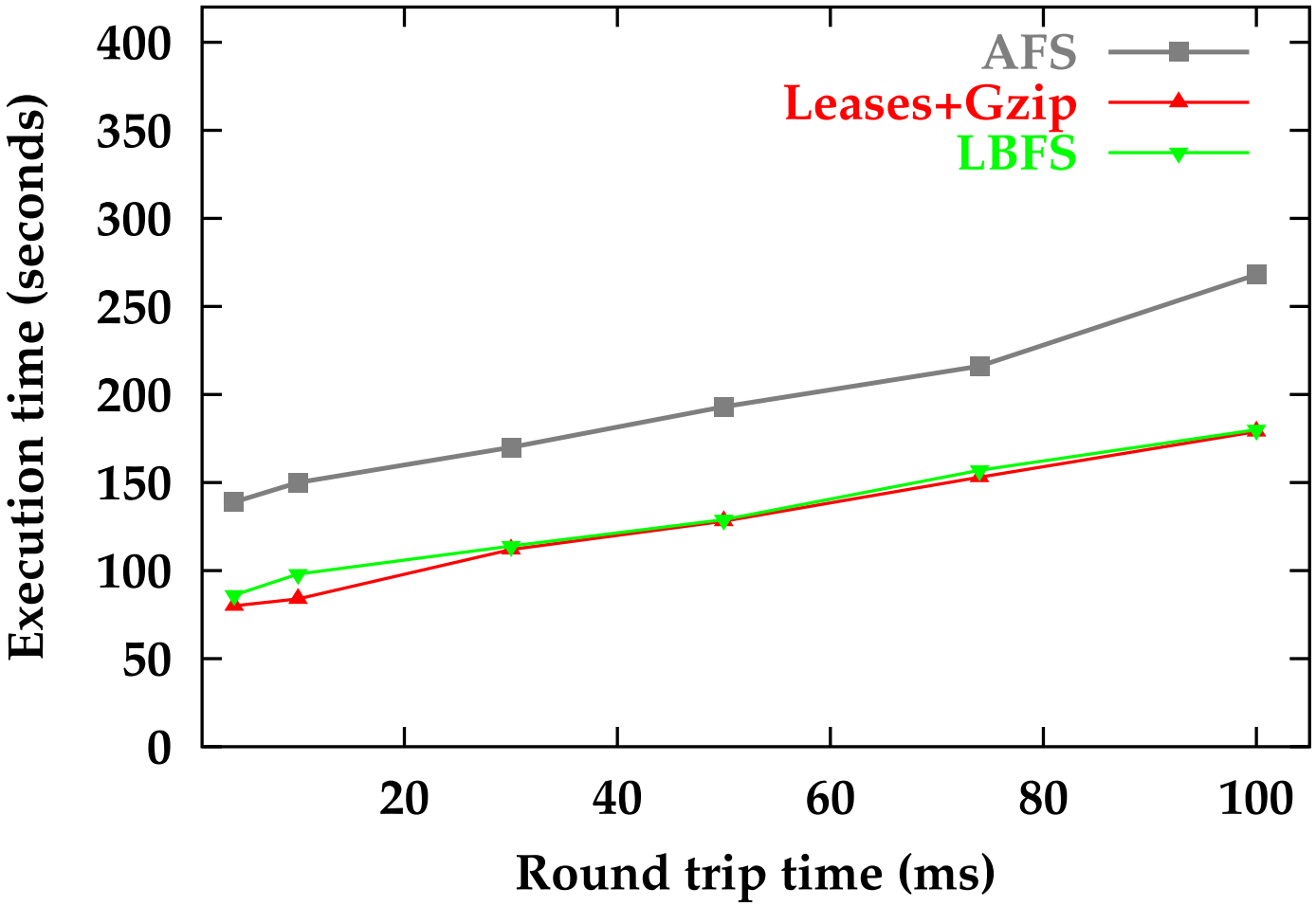
Compile time vs. bandwidth



Saving 1.4 MByte MSWord doc



Effect of network latency on performance



Related work

- **Weaken consistency (CODA)**
- **Send deltas (Diff/patch, CVS, xdelta)**
  - Requires server to keep around old versions of files
- **The rsync algorithm (synchronize two files)**
  - One file often contains chunks of many files (e.g., ar)
  - Not obvious which file to choose at receiving end (emacs: `#foo#`→`foo`, RCS: `_1v22825`→`foo,v,...`)

Conclusions

- **Network file system often best way to access data**
  - Copying files back and forth threatens consistency
  - Remote login frustrating given latency or packet loss
- **Most file systems too bandwidth-hungry for WAN**
- **LBFS exploits file commonality to save bandwidth**
  - Break files into variable-size chunks based on contents
  - Index chunks in file system and client cache
  - Avoid sending chunks already present in other files
- **LBFS works where other file systems impractical**

LBFS home page

http://www.fs.net/lbfs