Security of Cloud Storage: - Deduplication vs. Privacy

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Remote storage and security

- "Easy" to encrypt data, but
  - Encryption is not so easy in practice
  - There are benefits to storing unencrypted data
    $\Rightarrow$ no encryption at the client level
    $\Rightarrow$ privacy issues

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Deduplication, Security and Clouds Highlight Data Storage News

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The news in the storage networking industry this week wasn't all VPlex and EMC World. A number of other data storage vendors had some significant news of their own.

Cloud backup services

- Online file backup and synchronization is huge
- Mozy
  - Over one million customers and 50,000 business customers. Over 75 PetaByte stored.
- Dropbox
  - Over three million customers.

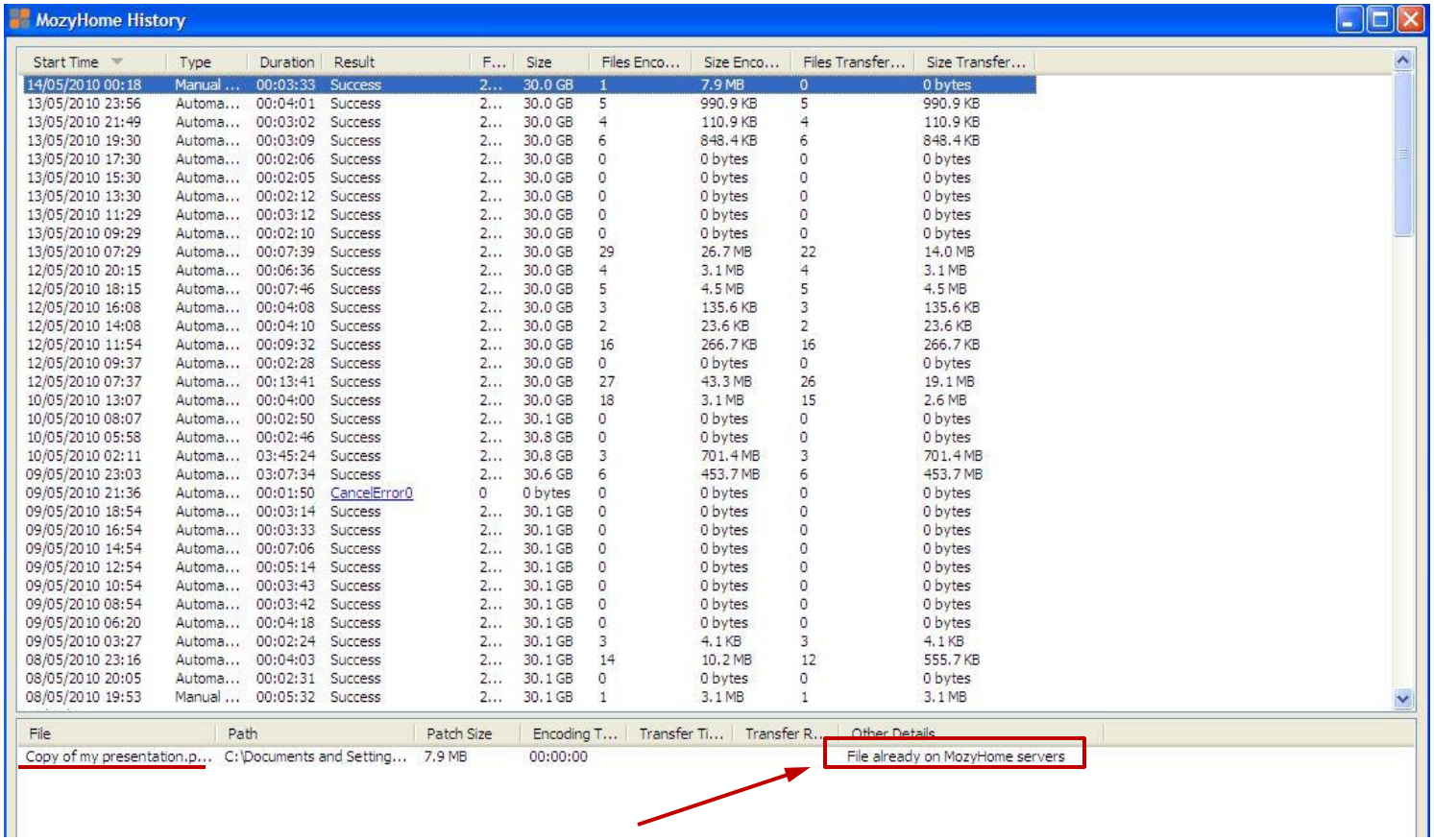
- And many more… many services geared towards enterprises.

Mozy

- I use MozyHome
  - You get 2GB backup for free
  - You used to pay only $4.95 per month for unlimited storage! (until very recently)

Mozy

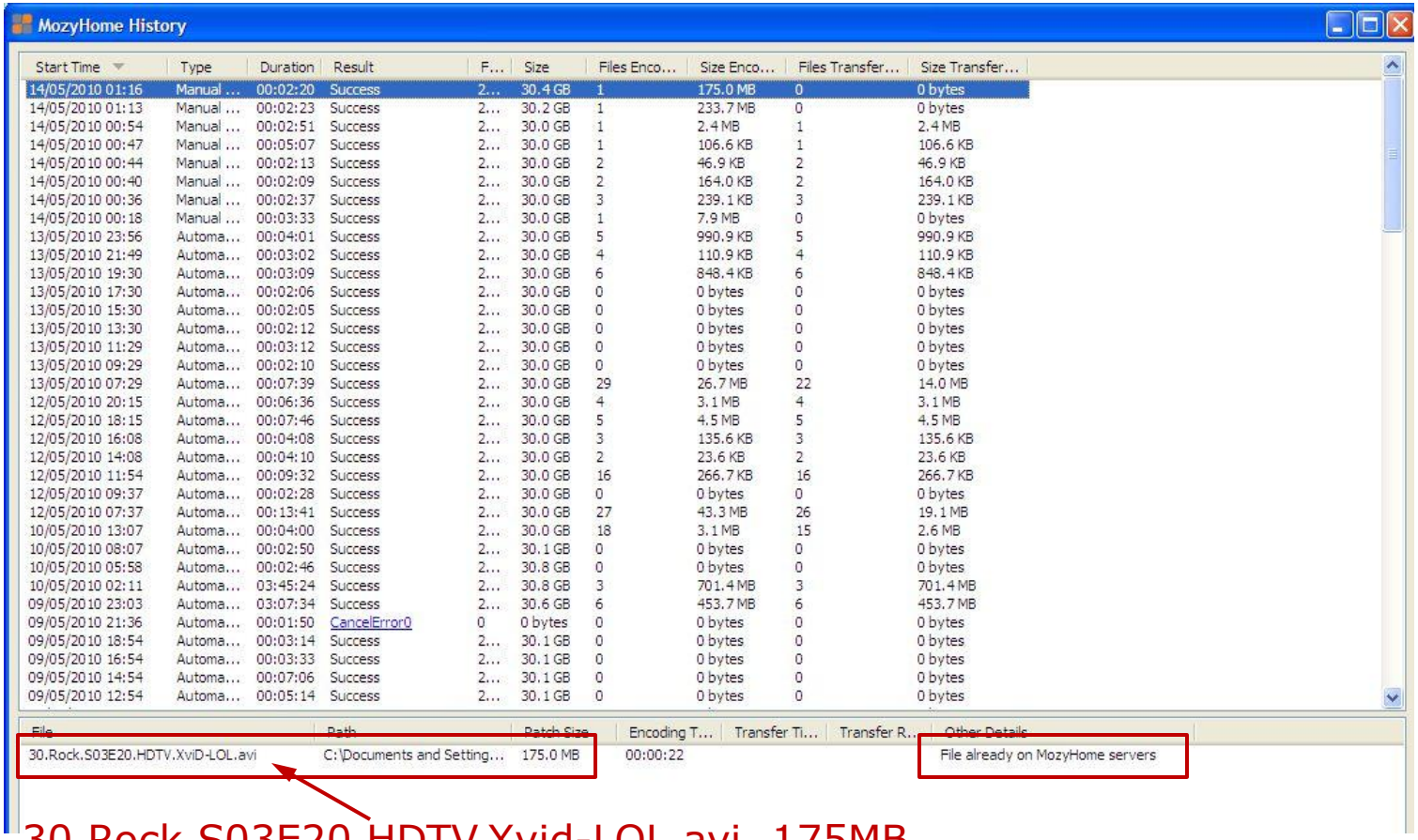
- You can examine your backup history



File already on MozyHome servers

Mozy

- But sometimes strange things happen…



Deduplication

- Deduplication = storing and uploading only a single copy of redundant data
  - Applied at the file or block level
  - Saves more than 90% in common business scenarios (90% of 75 PetaBytes…)
  - "most impactful storage technology"
    - July 2009: EMC acquires DataDomain for $2.1B
    - April 2008: IBM acquires Dilligent for $200M

Deduplication and privacy

- Our attacks require the following features:
  - Cross-user deduplication
    - If two or more users store the same file, only a single copy is stored.
  - Source-based deduplication
    - Deduplication is performed at the client side.
    - Saves bandwidth as well as storage.
- It is easy to check whether your storage service uses these features.

Deduplication and privacy

- The storage service is an oracle, which answers the following query
  - "Has any other user previously uploaded this file?"
- Rather limited
  - Does not tell who uploaded the file
  - The attacker can only ask this query once – afterwards the file is always deduped *(but this issue can be solved!)*
- Still, many attacks are possible

Repeating the attack

- Naively, the attacker can only check once whether a file has been previously uploaded
  - Attempt to backup the file.
  - If no upload occurs, then someone must have previously uploaded the file.
  - If an upload occurs, then no one has uploaded the file before. But now the file is uploaded and it won't be possible to repeat the test ☹
- Solution: When the actual upload begins, terminate the communication.

File Identification Attacks

Attack I – Identifying files

- Alice gives Bob a file, and swears him not to copy it to his home machine (which uses MozyHome/Dropbox/etc.)
- Alice can check if Bob followed this request
- Relevant to the Wikileaks case.
- There is no need for Alice to upload entire sensitive files.
- Easy to implement.

Attack II – Learning contents of files

- Alice and Bob work for the same company, which uses online storage for backup.
- All employees receive a standard form listing their yearly bonus.
- Alice knows that Bob's bonus is a multiple of $500, and is in the range $0 - $100K.
- She generates 201 documents, and runs a backup…

- Essentially a brute force attack. Applicable when the range is of medium size (10^6?)

Attack II – Learning contents of files

- Essentially a side channel

- Possible scenarios
  - Online banking – learning PIN codes or details of transactions
  - Learning results of medical tests
  - Learning bids in auctions
  - Many others examples…

Attack III – covert channel

- Alice installs a malicious software on Bob's machine.
- Bob runs a firewall, blocking network access.
- Bob uses an online storage service.

- To transfer a bit to Alice, the software saves one of two versions of a file.
  - Much more efficient coding is possible.

Consequences

- These are simple attacks
- But no company would be happy if they could be applied to its data

Solution I

- Global policy: Do not perform deduplication.
- Local hack: Bob encrypts his files with a personal key.
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- The cost is too high (both for dedup and for support for lost keys).
  - Services which support encryption with personal keys do not have an all-you-can-eat pricing option.

Side note - encryption

- All online storage services encrypt data
  - But in order to support dedup they do not encrypt stored data with personal keys.
- Dropbox: "Dropbox uses modern encryption… All transmission of data occurs over an encrypted channel (SSL). All files stored on Dropbox servers are encrypted (AES-256) and are inaccessible without your account password."
- Mozy enable users to use personal keys
  - But this is not the default option, and users are strongly advised against using it.
  - Personal key is susceptible to offline brute force attack.

Side note - costs

- Suppose that
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- Suppose that
  - Deduplication currently provides a saving of 95%
  - A solution reduces the savings to 93%
- Costs are increased by 40% !

Solution II

- Perform deduplication at the server.
- Files are always uploaded
  - Users do not notice whether dedup occurs ☺
  - But, high communication costs ☹ (at Amazon S3, cost of uploading is ≈cost of two months of storage).

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- Probably used by all mail services.
- Variant: upload all small files, perform client-side dedup only on large files.
  - After we notified Mozy about our findings, they started using this solution!

More Solutions

- Solution III – randomized approach
  - Server sets a random threshold Tx per file. Only if Tx copies of file are uploaded, dedup occurs.
  - Details omitted.

- Solution IV
  - Give users an interface which enables them to define which files are to be deduped.

Hash values and Proofs of Ownership

Deduplication and hash values

- A different (and more direct) attack

Deduplication and hash values

- A different (and more direct) attack

- During upload
  - Client computes and sends server hash of file
  - If this is the first time server receives this hash value, it tells the client to upload the file
  - Otherwise (dedup), it skips the upload and registers the client as another owner of the file

  - Client is then allowed to download the file…

Implications

- A short hash value serves as a proof of file ownership
  - This hash value is not really meant to be kept secret
  - The hash value is computable from the file using an algorithm shared by all clients

Attack I – Abusing known hash values

- Suppose that the dedup procedure uses a common hash function (e.g., SHA256)
  - Bob is a researcher who writes daily lab reports, and publishes their hash as a time-stamp.
  - He also uses an online backup service.

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  - He also uses an online backup service.

  - Alice signs to the same backup service.
  - She attempts to upload a file. When asked for its hash value, she sends a hash published by Bob.
  - The service forgoes the upload.
  - Alice can now download Bob's lab report.

Attack II – Efficient file leakage

- Malicious software
  - A malicious software running on Bob's machine wishes to *stealthily* leak **all** his files to Alice.
  - Instead of sending huge files to Alice, can send her the short hash values of the files.
  - Alice can then attempt to upload files, present the hash values she received, and obtain access to Bob's files.

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  - The malicious software can even store all Bob's hash values in a single file, and send its hash value to Alice.
    - A 20-32 bytes message can leak all of Bob's files!

Attack III – Content distribution network (CDN)

- Content distribution
  - Alice wishes to send a large file to all her friends, but she has a limited uplink.
  - Instead of sending the file to each of her friends, she can upload the file once and send its hash value to her friends.
  - Each friend can now present the hash value to the server and obtain access to the file.

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  - Each friend can now present the hash value to the server and obtain access to the file.
  - Server essentially serves as a Content Distribution Network (CDN). This might break its cost structure, if it planned on serving only few restore ops.

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- “Solution”: Use a non-standard hash algorithm (e.g. SHA(“service name” | file))
  - All users must still know the hash algorithm. Therefore Attacks II and III are not prevented ☹

"Solutions" to the hash attacks

- The source of the problem is that a single hash value represents the file.

- "Solution": For every client, server picks a random nonce , and asks client to compute SHA(nonce | file)
  - Server, too, must retrieve file from (multi-petabyte) secondary storage, and compute hash ☹

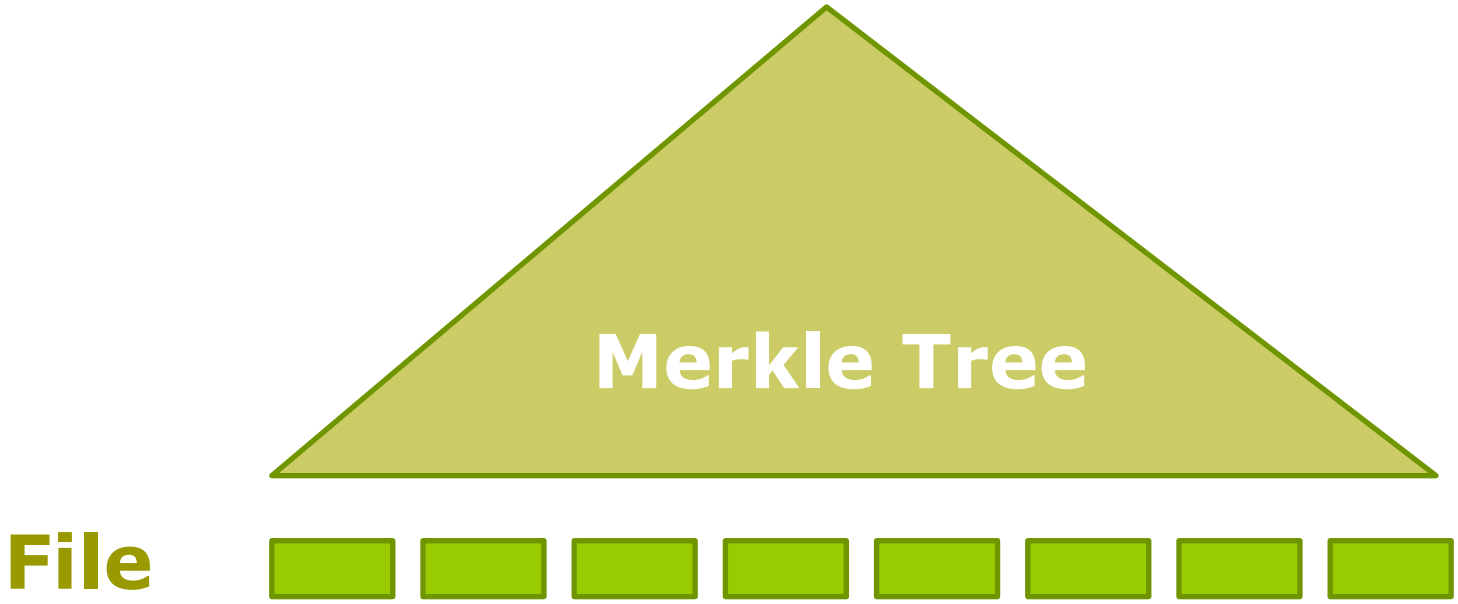
Constraints that must be satisfied by a solution

- Must be bandwidth efficient
- Server cannot retrieve files from secondary storage
  - Must store only a few bytes per file
- Client might need to process huge files
  - File cannot be stored in main memory
- Attacker might have partial knowledge of file (e.g., 95% of file)
- Accomplices might send information to the attacker

Proofs of Ownership (PoWs)

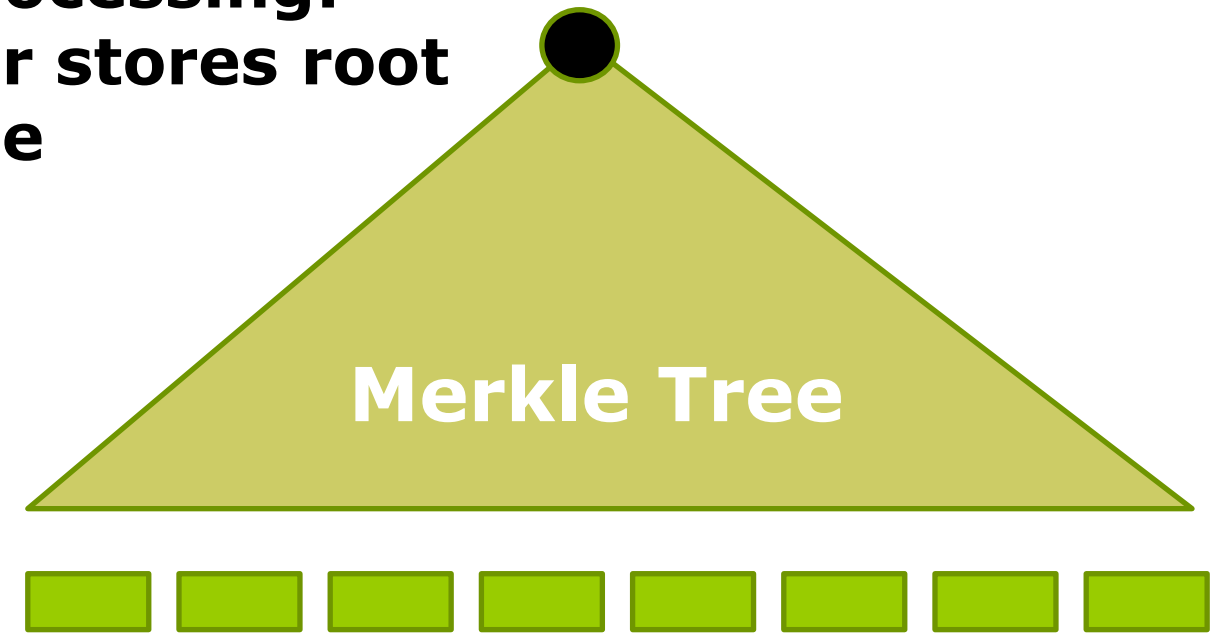
- Server preprocesses file.
- Server then stores some short information per file.
- Client proves ownership of the file
  - Client has access to the file (but not to any preprocessed version of it, as prover has in PoR).
  - Server has only access to short information.
  - Unlike PoRs, do not require extraction.
- Security definition: if min-entropy of file > security parameter, then proof fails whp.

Solution – first attempt



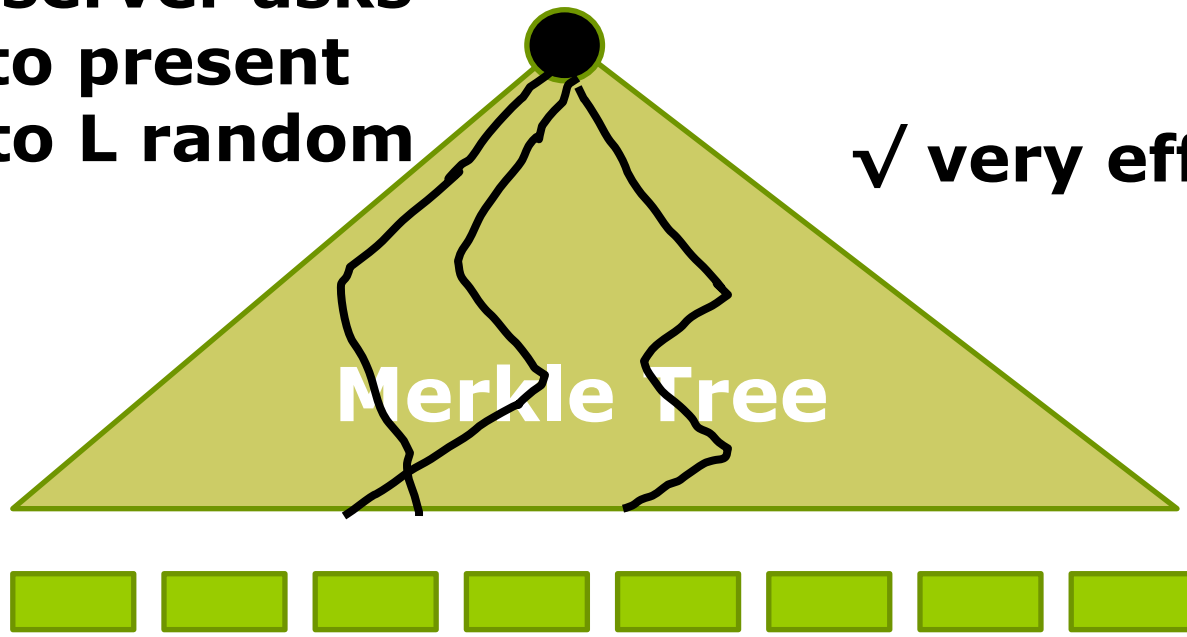
Solution – first attempt

Preprocessing: server stores root of tree



Solution – first attempt

Proof: server asks client to present paths to L random leaves



√ very efficient

A client which knows only a *p* fraction of the file, succeeds with prob < p^L.

Problem and solution

- A client which knows a large fraction of the blocks (say, 95%), can pass the test with reasonable probability ($0.95^{10}=0.6$).
- Solution:

Apply solution to new tree

Ensuring low answer probability of cheating client

- Apply an erasure code to the file, and then construct a Merkle tree over the encoding
  - Erasure code property: knowledge of, say, 50% of the encoding suffices to recover original file.
  - Therefore an attacker who does not know all the file, does not know > 50% of the encoding.
  - Fails in each Merkle tree query w.p. 50%.
  - Cheating probability is now 2^{-L}

Efficient encoding

- Computing an erasure code by the client requires
  - Random access, i.e. storing the file in main memory
  - Or, running many passes over the file
- But the file might be much larger than client's memory… ☹

Protocols with small space

- Relax the requirements
  - Only L bytes are needed for the computation (say, L=64MB)
  - (Therefore leaking L bytes to the attacker by an accomplice, enables it to cheat.)

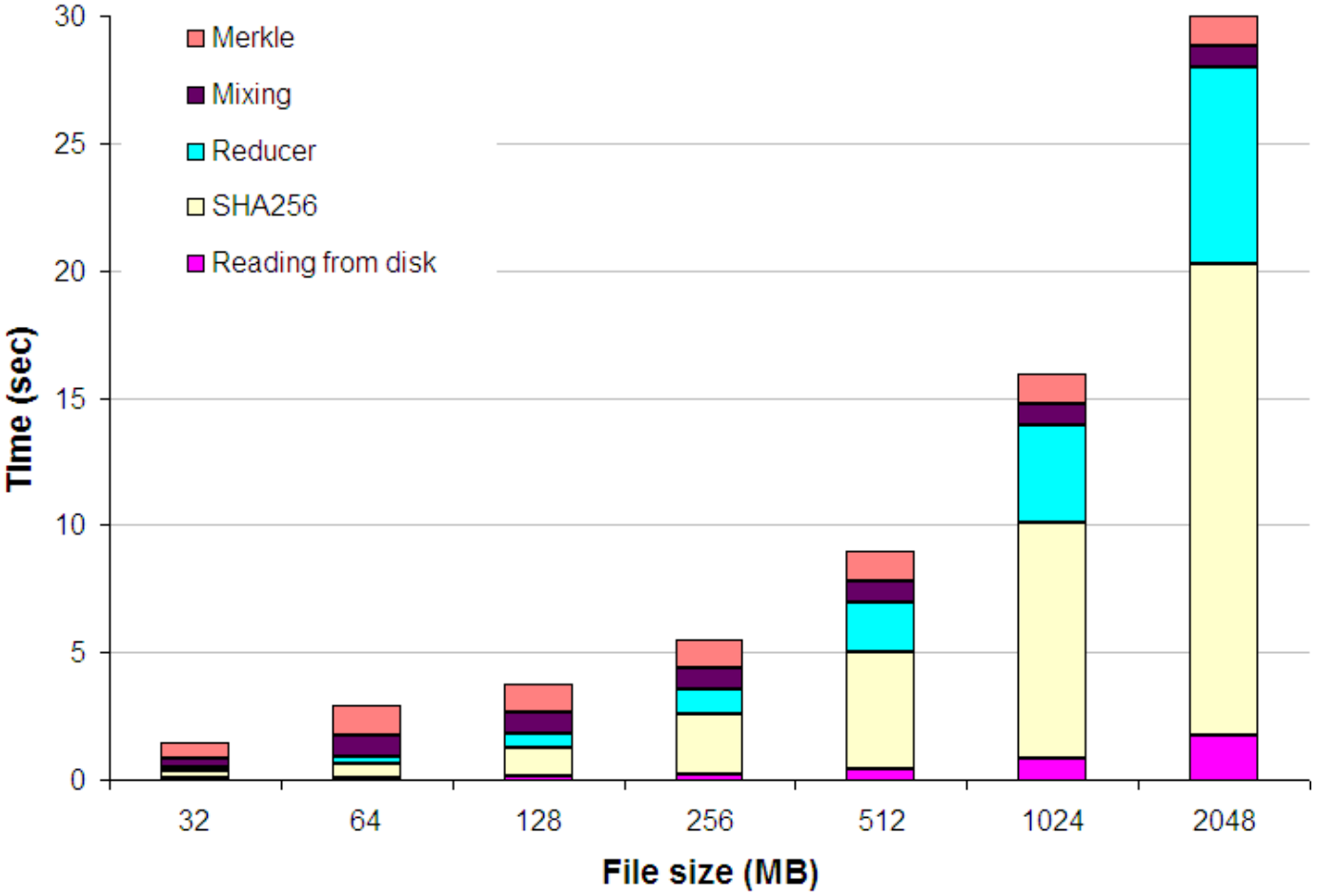
Protocols with small space

- First hash file to a buffer of L bytes. Then construct Merkle-tree over the buffer.

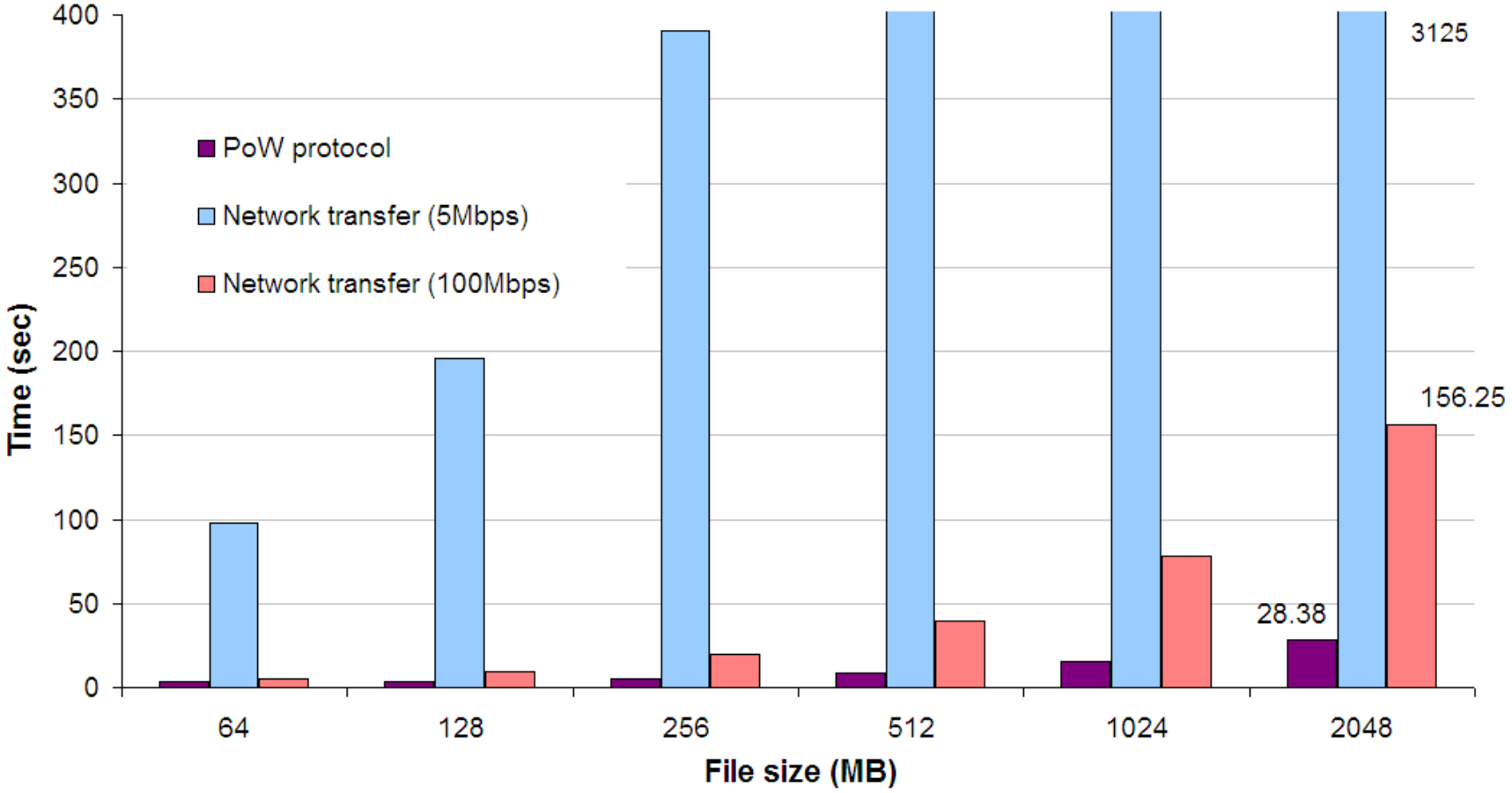
  Challenge: Must be secure even if attacker knows hash function (e.g., can ask for 50% of the L byte buffer).

Apply solution to tree computed over reduced data

Performance of the different phases of the low space PoW



Running the PoW protocol compared to sending the file



Conclusions

- Deduplication offers huge savings and yet might leak information about other users
- Most vendors are not aware of this
- The challenge: offer meaningful privacy guarantees with a limited effect on cost