Athos: Efficient Authentication of Outsourced File Systems

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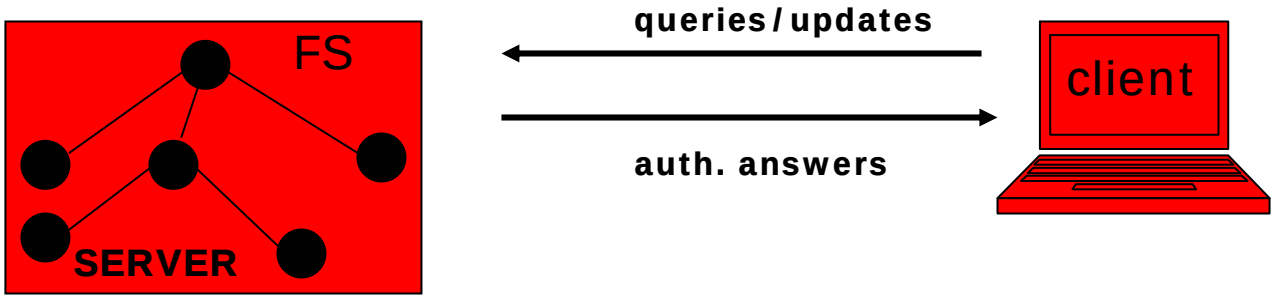
Scope and Problem

- Authenticated File Systems (FS)
- A client C outsources a FS at a server S due to
  - Space limitations/back-up or archiving purposes



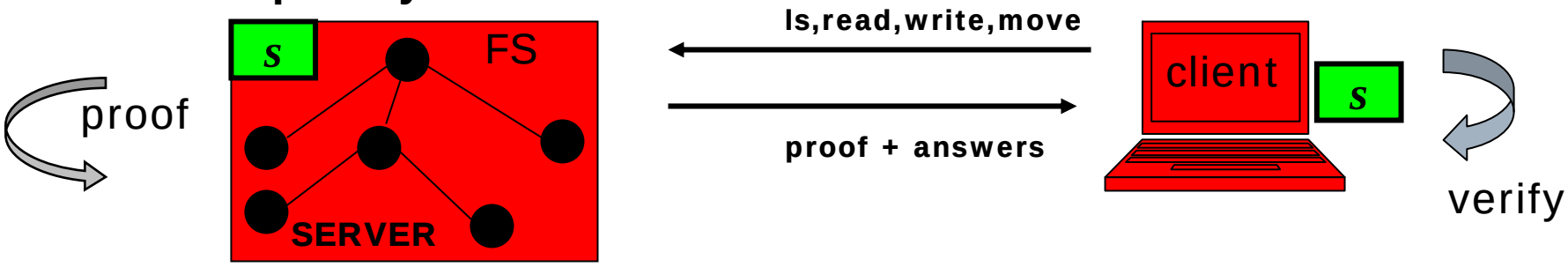
- S is untrusted
- C wants to maintain the integrity of FS, e.g.,
  - When C executes **ls**, nothing is missing
  - Authentication of both **contents** and **hierarchy**
- S should return proofs of correctness for all the above
- This should be done efficiently (e.g., logarithmic cost)

Summary of related work

- Store a hash for each file (e.g., *Miller et al., Cataneo et al.*)
  - Needs $O(n)$ space at the client
  - Authenticates only the content and not the hierarchy
- Build a Merkle Tree on top of FS (e.g., *Yumerefendi and Chase*)
  - Better: Need only $O(1)$ space
  - Needs to rebalance the tree for updates
- Use some trusted hardware (TPM) (e.g., *Oprea and Reiter*)
  - Assumption for some trusted component at the server
- Hashing on the FS tree (e.g., *Goh et al.*)
  - Can authenticate hierarchy
  - Very expensive updates due to unbalanced tree
- SUNDR (*Mazieres et al.*)
  - Solution given is under a different model though
  - Multiple clients can access/update the file system
  - Best you can achieve: Fork consistency
  - S can divide users into different groups that do not see the same state

Model and Contributions

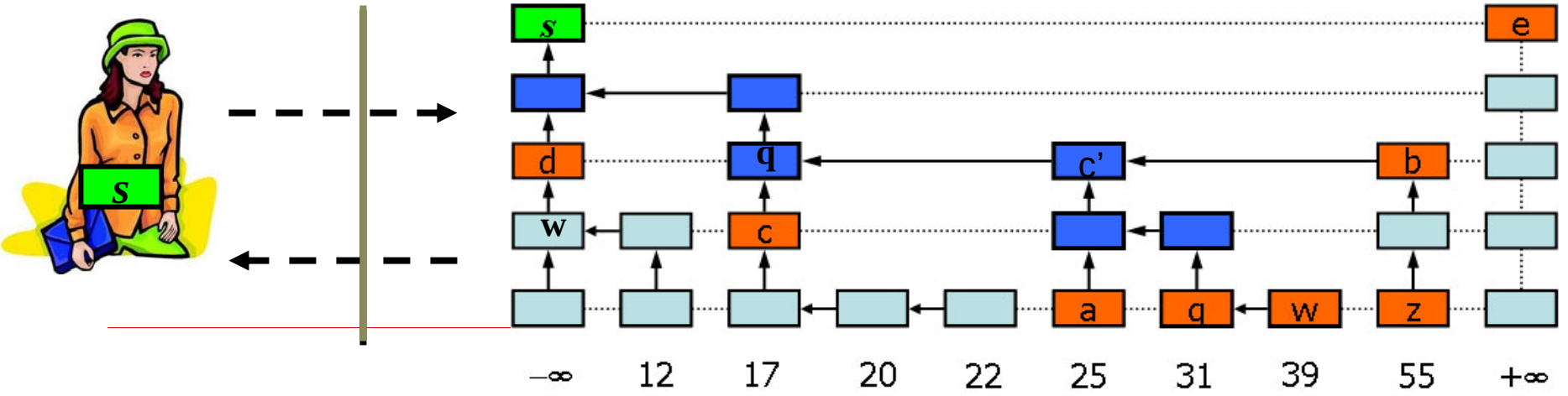
- Two-party model (client - server)
- **Completely** untrusted server



- Client with $O(1)$ trusted storage, ***s*** (state of the file system)
- ***s*** is a function of the FS hierarchy/contents– updated during updates
- Queries, Updates: e.g., **ls**, **read**, **pwd, write**, **move**, **chmod**
- S computes a proof
- C is able to verify by using ***s*** and the proofs returned by S
- Security is based on collision resistant of cryptographic hashing
- Logarithmic costs for verification, auth. updates, communication
- Main building blocks:
  - Two-Party Authenticated Skip List (Papamanthou, Tamassia, ICICS07)
  - Authenticated Dynamic Trees (Goodrich, Tamassia, Triandopoulos, CT-RSA 2003)

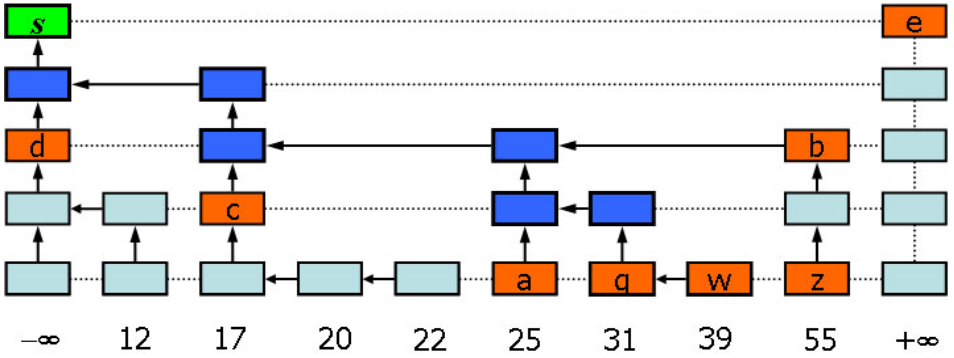
Authenticated Skip List – Flat Directory

- Skip list augmented with cryptographic information
  - Stored by S
  - Used for proofs of correctness for queries/updates
- At node v: $f(v)=h(.,.)$, where h is collision-resistant
  - $f(v)=h([f(right)\ \ell(v)\ \text{key}(v)],[f(down)\ \ell(v)\ \text{key}(v)])$
  - e.g., q = h([c' 2 17],[c 2 17])
- State **s**: label of top left node stored by the client



Query/Verify for file 39

get (39)?



=?

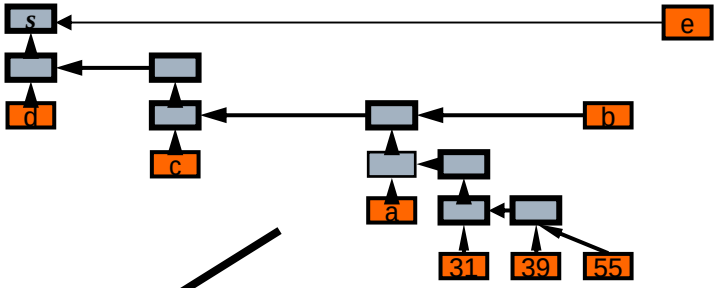
h(,,,)
h(,,)
h(,,)
h(,,)
h(,,)
h(,,)
h(,,)

=

H(.)

f	ℓ	k
55	0	55
39	0	39
31	0	31
a	1	25
b	2	25
c	2	17
d	3	-∞
e	4	-∞

f	ℓ	k
55	0	55
39	0	39
31	0	31
a	1	25
b	2	25
c	2	17
d	3	-∞
e	4	-∞



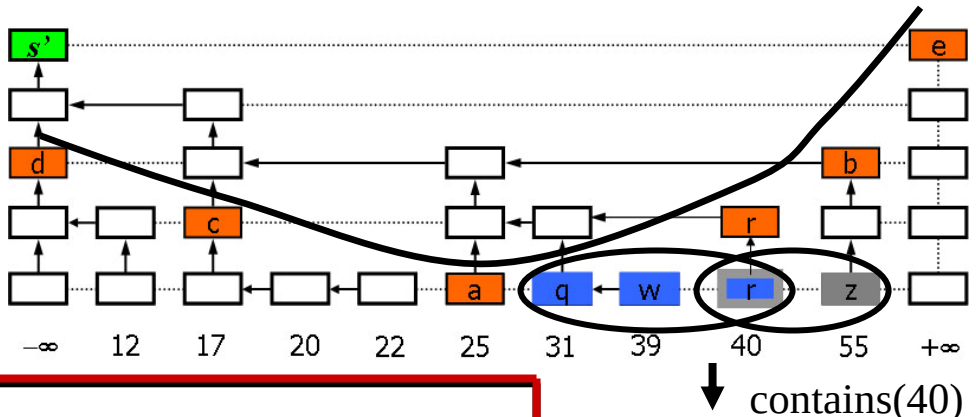
Insert file 40

insert(40)

s' = $H([L\ H(R)\ U])$

s

=?



contains(40)

L= [40 39 31]

R= [55 40]

U= [a b c d e]

f	ℓ	k
55	0	55
40	0	40
39	0	39
31	0	31
a	1	25
b	2	25
c	2	17
d	3	-∞
e	4	-∞

h(,,)
h(,,)
h(,,)
h(,,)
h(,,)
h(,,)
h(,,)

f	ℓ	k
55	0	55
39	0	39
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f	ℓ	k
55	0	55
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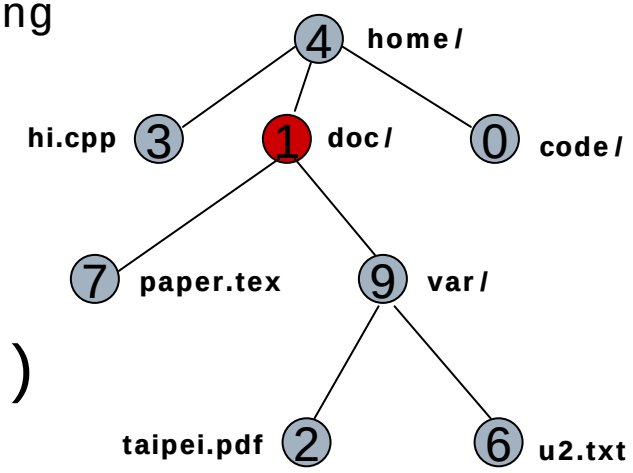
a	1	25
b	2	25
c	2	17
d	3	-∞
e	4	-∞

From skip lists to file systems (local information)

- For each node v of the file system tree
  - Create one entry in the skip list
  - Key is the i-node of the node (unique)
- With each node *v* store a tuple *l*(*v*) with the following fields
  - **name**, the name of the file (or directory)
  - **hash,** hash of the file contents, if file, else **null**
  - **key(parent)**, i-node of the parent
  - **key(sibling)**, i-node of the sibling
  - **key(backsibling)**, i-node of the backsibling
  - **key(child)**, i-node of the first child



(1,[“doc”,null,4,0,3,7])

(3,[“hi.cpp”,h(hi.cpp),4,1,null,null])

Does path "**home/doc/var/u2.txt**" exist?

s

GET(6)

(6,["u2.txt",h(u2.txt),9,null,2,null]) + **proof**

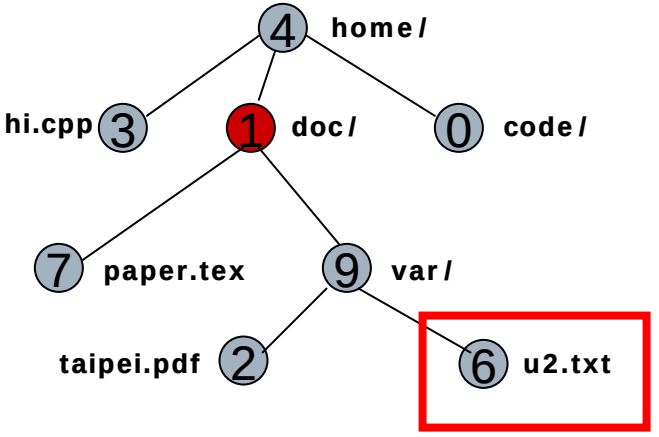
s == hash(**proof**)?

name=="u2.txt"?

Then: parent = 9

(0,["code",null,null,null,1,null])
(1,["doc",null,4,0,3,7])
(2,["taipei.pdf",h(taipei.pdf),9,6,null,null])
(3,["hi.cpp",h(hi.cpp),4,1,null,null])
(4,["home",null,null,null,null,3])
(6,["u2.txt",h(u2.txt),9,null,2,null])
(7,["paper.tex",h(paper.tex),1,9,null,null])
(9,["var",null,1,null,null,2])

s



Does path "**home/doc/var/u2.txt**" exist?

s

GET(9)

(9,["var",null,1,null,null,2]) + **proof**

s == hash(**proof**)?

name=="var"?

Then: parent = 1

(0,["code",null,null,null,1,null])

(1,["doc",null,4,0,3,7])

(2,["taipei.pdf",h(taipei.pdf),9,6,null,null])

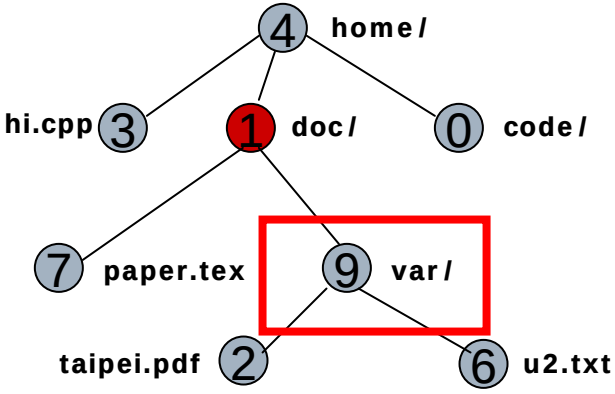
(3,["hi.cpp",h(hi.cpp),4,1,null,null])

(4,["home",null,null,null,null,3])

(6,["u2.txt",h(u2.txt),9,null,2,null])

(7,["paper.tex",h(paper.tex),1,9,null,null])

s (9,["var",null,1,null,null,2])



Does path "**home/doc/var/u2.txt**" exist?

s

GET(1)

(1,["doc",null,4,0,3,7]) + **proof**

(0,["code",null,null,null,1,null])

(1,["doc",null,4,0,3,7])

(2,["taipei.pdf",h(taipei.pdf),9,6,null,null])

(3,["hi.cpp",h(hi.cpp),4,1,null,null])

(4,["home",null,null,null,null,3])

(6,["u2.txt",h(u2.txt),9,null,2,null])

(7,["paper.tex",h(paper.tex),1,9,null,null])

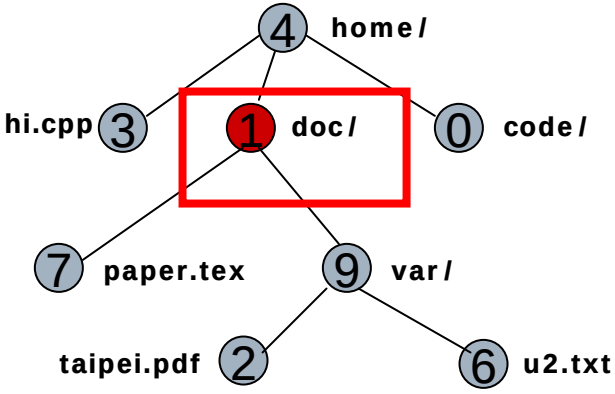
(9,["var",null,1,null,null,2])

s

s == hash(**proof**)?

name=="doc"?

Then: parent = 4



Does path "**home/doc/var/u2.txt**" exist?

s

GET(4)

(4,["home",null,null,null,null,3]) + **proof**

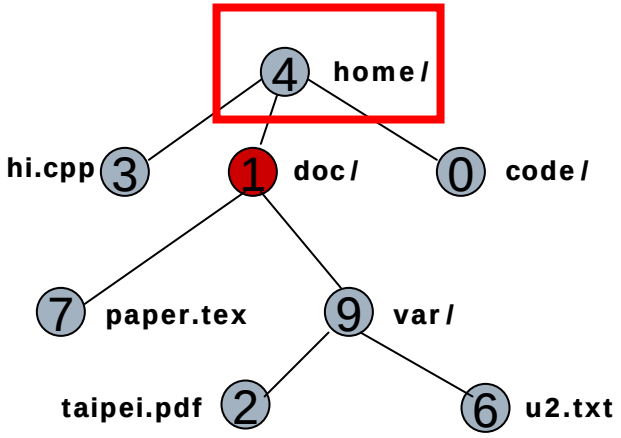
s == hash(**proof**)?

name=="home"?

Then: parent = null
and we are done!

(0,["code",null,null,null,1,null])
(1,["doc",null,4,0,3,7])
(2,["taipei.pdf",h(taipei.pdf),9,6,null,null])
(3,["hi.cpp",h(hi.cpp),4,1,null,null])
(4,["home",null,null,null,null,3])
(6,["u2.txt",h(u2.txt),9,null,2,null])
(7,["paper.tex",h(paper.tex),1,9,null,null])
(9,["var",null,1,null,null,2])

s



Create/read an authenticated FS

- Create: For each node v of the FS tree
  - Compute (key(v), I(v))
  - Use skip list insertion algorithm for (key(v),I(v))
- Let r be the root node of the FS tree
- Call READ(r)
- READ(v):
  - Send query **get**(key(v))
  - Receive proof for binding (key(v), I(v))
  - Authenticate I(v)
  - If **verifies**

    READ(key(child(v)));

    READ(key(sibling(v)));

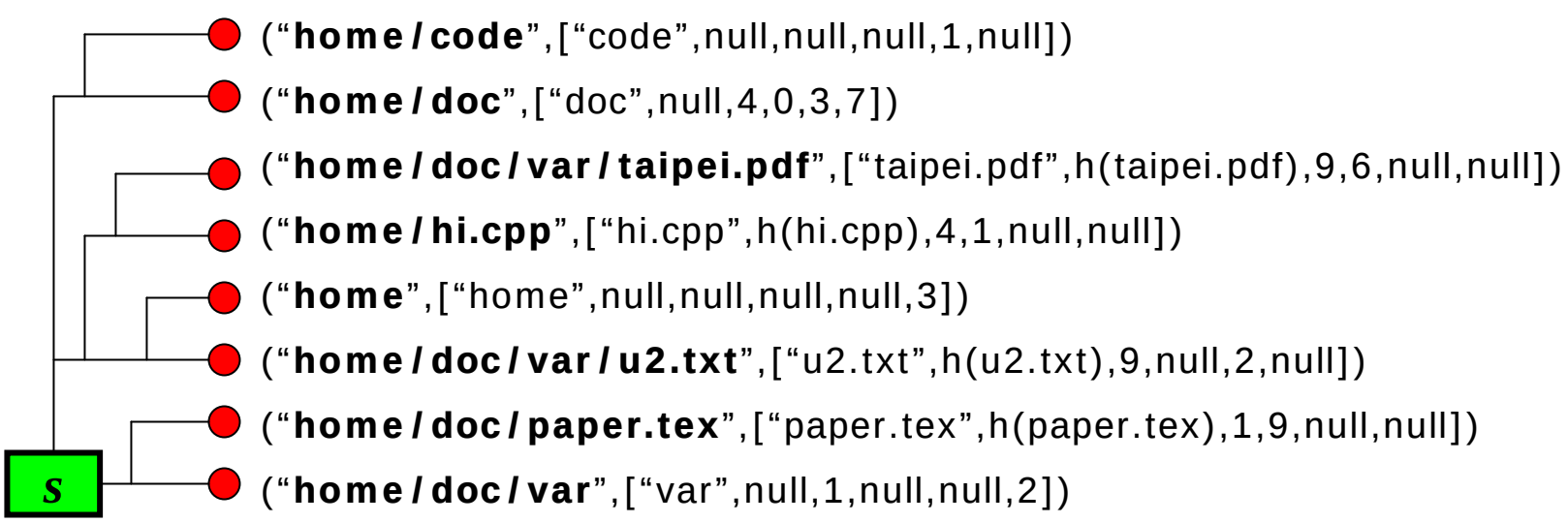
    else

    "INTEGRITY PROBLEM"

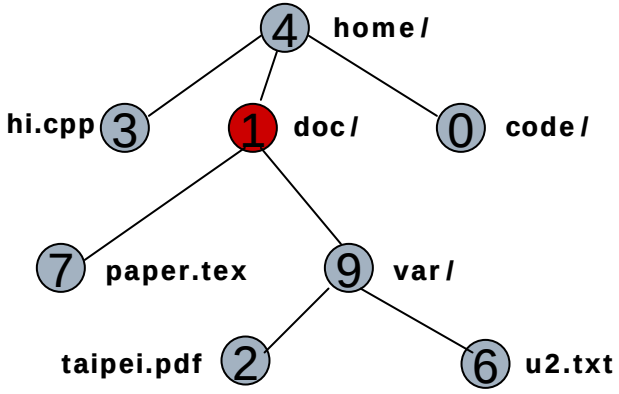
Time complexity - skip list

- P is a path of size k
- n is the size of the file system
- Authentication of P: $O(k \log n)$
- **cd**(P), **read**(P), **write**(P), **rm**(P), **mkdir**(P), **touch**(P): $O(k \log n)$
- **ls**(P): $O((k+l)\log n)$ (l = |returned list|)
- **rmdir**(P): $O((t+k)\log n)$
  - t = |removed directory|
- **move**(P,P'): $O((k+k')\log n)$

From skip lists to file systems (global information)



- path authentication: $O(k+\log n)$
- inefficient moves!



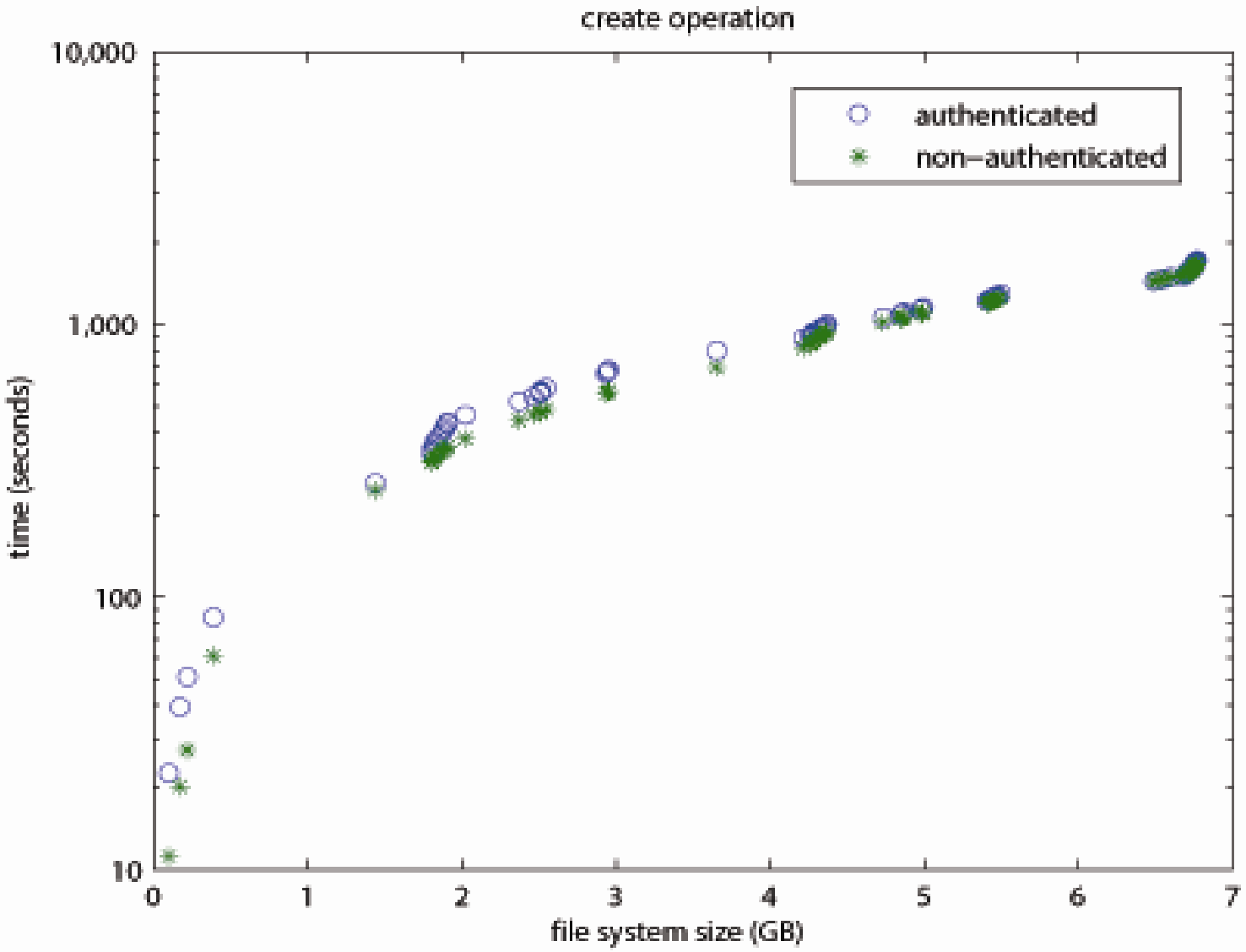
Authenticated dynamic trees

- Direct application of [CT-RSA 2003 Goodrich, Tamassia, Triandopoulos]
- Suppose we have any tree T of n nodes
- All nodes v have some property, say $l(v)$
- The property of a path P is defined as a concatenation of nodes properties (e.g., path name property)
- Let P be a path
- Authenticating path properties $O(k + \log n)$
- Authenticating updates: $O(k + \log n)$
- Better than $O(k \log n)$ and efficient mv/rmdir!
- Practical only for a depth >120 (Werneck and Tarjan, WEA 2007)

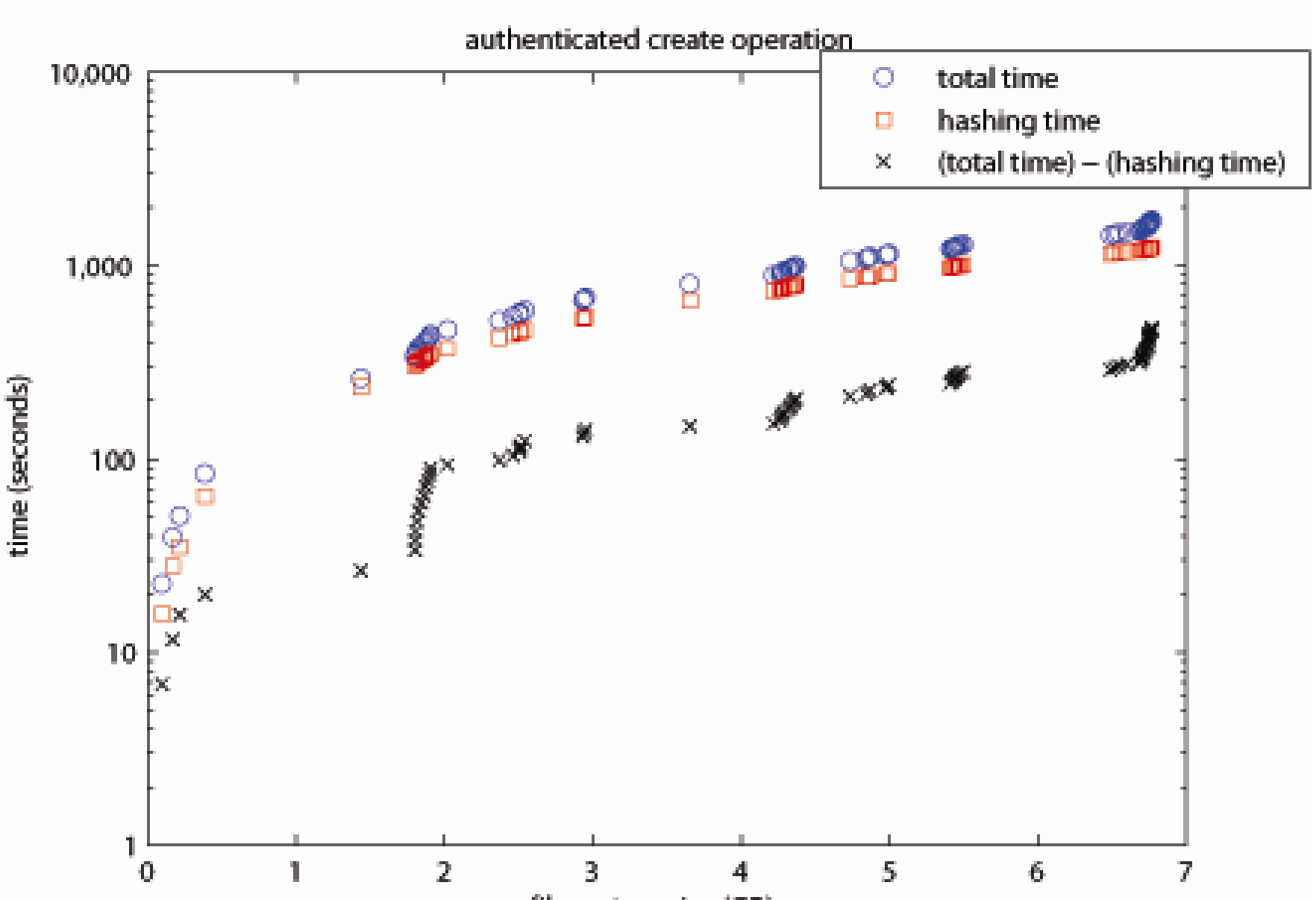
Theoretical Comparison

Operation	Skip lists (local)	Skip lists (global)	Dynamic trees
cd, read, write, rm, mkdir, touch	$k \log n$	$\log n + k$	$\log n + k$
ls	$(k+l) \log n$	$l(\log n + k)$	$k + l + \log n$
rmdir	$(k+t) \log n$	$t \log n + k$	$k + \log n$
mv	$(k+k') \log n$	$t \log n + k + k'$	$k + k' + \log n$

Experiments on a remote 7GB file system



How much does hashing cost?



Conclusions

- A scalable solution for authenticating outsourced file system
- Authentication of hierarchy
- Authentication of major FS operations
- Logarithmic costs
- Three different theoretical approaches
- A working prototype justifying theoretical findings