Zero-Interaction Authentication

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Major tertiary care center for Michigan
- FY 1999: 1.2M visits, $1B billable services

Results in large data volume and costs
- 5-8 pieces of paper/patient visit
- all records in physical charts without (official) copying

Obvious solution: electronic access to these records
- most patient records in a **clinical data repository**
- web-based front-end for easy access, CareWeb

CareWeb is not as useful as you might imagine
- requires aggressive authentication
- physicians are notoriously jealous of their time
- end-user perception drives acceptance: they don't!

Disconnected CareWeb

Experience with Coda suggested an obvious solution
- a laptop for every physician: **disconnected CareWeb**
- examine physician's schedule for upcoming day
- prefetch records for each scheduled patient

Demonstration for a number of UMHS staff members
- the physicians wanted it immediately
- the IT staff told us not to show it to any more physicians

Real costs if patient data is improperly revealed
- HIPAA: $250K fines for disclosure/misuse of data

Challenge:
- **protect** patient data
- **without inconveniencing** physicians

Solution: constant but invisible authentication

ZIA: **zero-interaction authentication**
- constantly ask user "are you there?"
- have something other than user answer

Watch as authentication token: "yes, I'm right here"
- worn by user for increased physical security
- enough computational power for small cryptographic tasks
- secure communication via **short-range** wireless network

Design goals:
- protect laptop data from physical possession attacks
- preserve performance and usability
  - give the user no reason to disable, work around

Outline

Threat model

Design
- how are files protected, shared?
- how do we improve performance?

Implementation

Evaluation
- what overhead does ZIA add?
- are optimizations useful?
- can ZIA be hidden from users?

Related work

Conclusion

Threat Model

Attacker can exploit physical possession
- use cached credentials
- console-based attacks
- physical modification attacks (remove disk, probe memory)

Attacker can exploit laptop-wireless link
- inspection, modification, insertion of messages

Things we don't consider
- network-based exploits (buffer overruns)
- jamming laptop-token link (DoS)
- replacing operating system
- untrustworthy users
- rubber hose cryptanalysis

Design guidelines

Protect file system data
- all data on disk encrypted
- ensure user is present for each decryption

Can't contact token on every decryption
- adds (short) latency to (many) operations

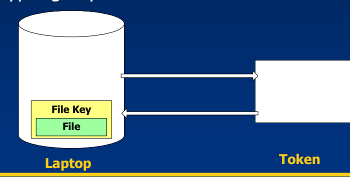
Take advantage of caching already used in file systems
- data on-disk: encrypted for safety
- data in cache: decrypted for performance
- token's keys required for decrypting files

Take advantage of fact that people move slowly
- only check "often enough" to notice user departure

Moving data from disk to cache

Tokens cannot decrypt file contents directly
- small, battery-powered: limited computation
- connected to laptop via wireless link
  - latency comparable to disk, bandwidth much less

Instead, store file encrypting key on disk, itself encrypted
- key encrypting key never leaves token



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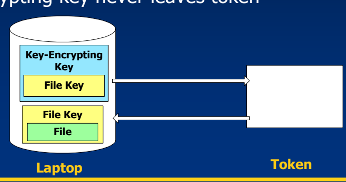

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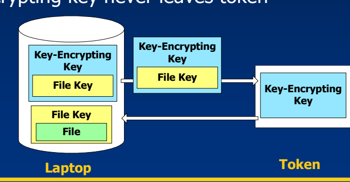

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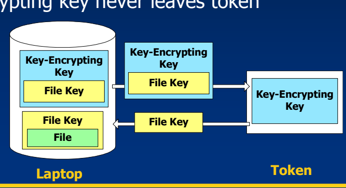

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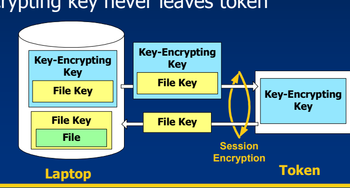


Key-encrypting keys are *capabilities*

File encrypted by some key, E

E is on disk, encrypted with another key, O
- O is known only to authentication token
- may also choose to escrow O as a matter of policy

Sharing accommodated by additional encrypted versions of E
- UNIX protection model: owner, group, and world
- E encrypted by owner key O, group key G
- each user's token holds their O, and all applicable Gs
- members of same group share copies of G

Can have per-machine world keys, too

Handle keys efficiently

Key acquisition time can be expensive
- network round trip + processing time
- many milliseconds
- can't add this to every disk operation!

Two mechanisms mitigate this problem
- overlap key acquisition with disk operations
- cache decrypted keys, exploiting locality

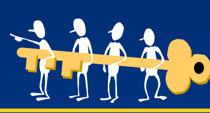
Neither mechanism helps with file creation
- is an asynchronous write: no overlap
- is a new file: no cached key
- observation: you don't need any **particular** key
  - prefetch a stash of "fresh" keys

Assign keys per directory

What is the right granularity for file keys?
- small grain limits damage of key exposure
- large grain increases effectiveness of caching

We chose **per-directory keys** to exploit access patterns
- files in same directory tend to be used together
- acquisition time amortized across a directory

Directory keys stored in the directory they encrypt



Maintain performance, retain correctness

Optimizations reduce laptop/token interactions
- but, still need to ask "are you there?" frequently!

Add periodic polling
- exchange encrypted nonces: challenge/response
- once per second, because people are slow

When user is away, protect file system data
- must be fast enough to foil theft

When user returns, restore machine to pre-departure state
- user should see no performance penalty on return

Make protection fast and invisible

Key question: what to do with cached data on departure?

One alternative: flush on departure, read on arrival
- flush is fast: write dirty pages, bzero cache
- recovery is slow: read entire file cache from disk

Instead, we encrypt on departure, decrypt on arrival
- protection is a bit slower, but fast enough
- **recovery is much faster**: no disk operations

This retains current file cache behavior
- unused file blocks can be flushed when idle
- encrypted file blocks are treated identically

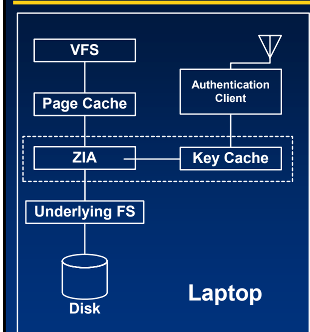
Implementation

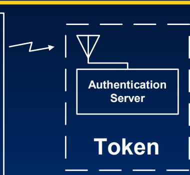
Implementation is split into two parts
- in-kernel file system support
- authentication system and token

In-kernel support (Linux)
- provides cryptographic I/O
- manages keys
- polls for token

Authentication system
- client running in user-space on the user's laptop
- server running on token (Linux or WinCE)
- communicate via a secure channel

Implementation





Implemented in-kernel as a stackable file system

Uses FiST toolkit (Columbia)

Rijndael used for encryption

Evaluation overview

Several important questions
- what overhead does ZIA impose?
- how long does it take to secure the cache?
- how long does it take to restore the cache?

Prototype System
- client system: IBM Thinkpad 570
- token: Compaq iPAQ 3650
- connected by 802.11 network in 1Mb/s mode

Evaluation: Andrew Benchmark

Determine file system overhead

Modified Andrew Benchmark
- copy and compile Apache source code
  - 7.4 MB source only
  - 9.7 MB source plus objects

Compare ZIA against three file systems
- Ext2fs: file system "at the bottom"
- Base: null stacking layer implemented in FiST
- Cryptfs: FiST's cryptographic file system (+Rijndael)

Modified Andrew Benchmark results

File System	Time, sec	Overhead (vs. Ext2fs)
Ext2fs	52.63 (0.30)	-
Base	52.76 (0.22)	0.24%
Cryptfs	57.52 (0.18)	**9.28%**
ZIA	57.54 (0.20)	**9.32%**

ZIA is indistinguishable from Cryptfs

Benefit of optimizations

Turn off prefetching, caching to see how useful they are

Ext2fs	52.63 (0.30)	-
ZIA	57.54 (0.20)	9.32%
No prefetching No caching	232.04 (3.40)	**340.86%**

optimizations are critical

Stress tests

Andrew benchmark obligatory, but not necessarily good
- often measures the speed of your compiler

Three benchmarks stress high-overhead operations
- 1) create many directories
- 2) scan those directories
- 3) bulk copy: 40MB Pine source

Creating directories

File System	Time, sec	Over Ext2fs
Ext2fs	9.67 (0.23)	-
Base	9.66 (0.13)	-0.15%
Cryptfs	9.88 (0.14)	2.17%
ZIA	10.25 (0.09)	**5.9%**

Fresh key prefetching minimizes overhead

Reading directories

File System	Time, sec	Over Ext2fs
Ext2fs	15.56 (1.25)	-
Base+	15.72 (1.16)	1.04%
Cryptfs	15.41 (1.07)	-0.94%
ZIA	29.76 (3.33)	**91.24%**

Directory reads expose full key acquisition costs

Copying large trees

File System	Time, sec	Over Ext2fs
Ext2fs	19.68 (0.28)	-
Base	31.05 (0.68)	57.78%
Cryptfs	42.81 (1.34)	**117.57%**
ZIA	43.56 (1.13)	**121.38%**

Bulk data costs dominated by cryptography and stacking overhead

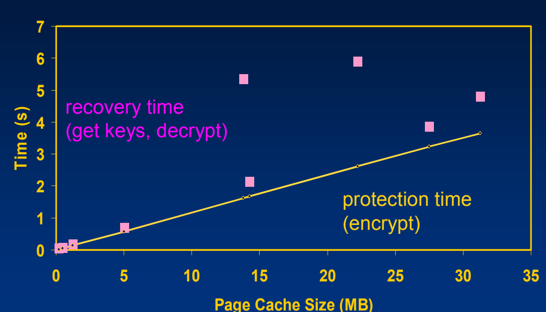
Time to secure/restore the file system

All data must be encrypted when user leaves

All data must be decrypted when user returns

Benchmark:
- copy various trees into ZIA
- disable token, measure time to safety
- enable token, measure time to recovery

Time to protect/recover the file system



Related work

Many examples of cryptographic file systems
- CFS (Matt Blaze), Cryptfs (Erez Zadok), EFS (Win2k)
- all suffer from the problem of "implied consent"
- once you log in, the file system can forevermore decrypt
- Win2k asks you to authenticate more frequently
  - inconvenient: anecdotally, it is often disabled

Can use a smart card to hold keys (Blaze) rather than in-kernel
- smart card left in the machine: still has "implied consent"

Some examples of hardware tokens for proximity detection
- Landwehr '97, Ensure Technologies
- all advisory; tokens are not capabilities
- laptop capable of acting, could be forced to

Next Steps (a.k.a. Mark's Thesis)

Underlying principle
- authentication is traditionally a persistent property
- what are the implications of making it transient?

Protect applications (brute force)
- treat VM images like files
- encrypt paging space (Provos)
- encrypt in-memory pages on departure, decrypt on return

Expose to applications
- API for transient authentication services
- security-conscious applications manage their own state

Conclusions

Your machine has the long-term authority to act as you

Zero-Interaction Authentication
- user retains long-term authority to decrypt
- laptop holds only transient authority
- defends against physical possession attacks

There is no reason to turn it off
- does not change user behavior
- does not noticeably impact performance

Protects and restores machine quickly
- entire buffer cache within six seconds