Plausibly Deniable Encryption Systems for Mobile Devices

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Final Exam

- Thursday, April 30 from 3:00pm-5:00pm in Canvas
- Will enable the exam at 2:55pm.
Mobile Devices are Turning to Mainstream Computing Devices

Number of smartphone users worldwide from 2014 to 2020 (in billions)

Number of tablet users worldwide from 2013 to 2021 (in billions)
Mobile Devices are Turning to Mainstream Computing Devices (cont.)

Number of connected wearable devices worldwide from 2016 to 2021 (in millions)
Mobile Devices Are Increasingly Used for Critical Applications

- Mobile devices are increasingly used to handle sensitive data
  - Online banking
  - Ecommerce
  - Cryptocurrency/stock trading
  - Naked photos
  - A human rights worker collects evidence of atrocities in a region of oppression
  - Etc.

- Security issues in mobile computing devices
  - Confidentiality
  - Integrity
  - Authentication
  - Access control
Coercive Attack against Confidentiality

• To protect confidentiality of sensitive data, we can simply encrypt them
  – AES
  – 3DES

• Conventional encryption is vulnerable to a coercive attack

An attacker forces the device’s owner to disclose the decryption key
Plausible Deniable Encryption (PDE)

- Plausible Deniable Encryption (PDE) [Canetti et al., CRYPTO ’97]: a crypto primitive designed for mitigating coercive attacks
  - Disclose the decoy key
  - Keep the true key secret
Issues: the size of ciphertext is increased. Deniability is easily compromised.
Implementing PDE in Systems - Hidden Volume

- Hidden volume [TRUECRYPT ’04] realizes the concept of PDE in systems
  - Only the decoy key will be disclosed
  - The encrypted hidden volume cannot be differentiated from the random noise
The Challenges: Over-writing Issues

• The data written to the public volume may **over-write** the data in the hidden volume
  – The hidden volume is part of the public volume
The Challenges: Over-writing Issues (cont.)

- File systems really matter for over-write issues
  - FAT allocates blocks sequentially
  - EXT4 does not allocate blocks sequentially

It is challenging to allow any file systems to be deployed while mitigating the over-write issues
To realize file system friendly design, a new layer is introduced to decouple the file system and the underlying PDE system

1. Provide virtual volumes to file systems
2. Any block-based file system can be built on a virtual volume
3. Non-sequential allocation on the virtual volume will be converted to sequential allocation on the underlying layer

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Evaluation Highlights

- Implemented a prototype of our solution on LG Nexus 4

Throughput (MB/s) from AndroBench
Deniability Compromise in The Lower Layer?

Existing deniable storage systems (e.g., MobiPluto)

Apps/Android framework

OS/File system

Flash storage (eMMC card/SD card)

deniability compromise
NAND Flash Memory

- Flash memory
  - NAND flash (broadly used for mass-storage devices)
  - NOR flash (used for storing program code that rarely needs to be updated, e.g., a computer’s BOIS)

- NAND flash organization
  - Block
  - Page

![Diagram of NAND Flash Memory organization with blocks and pages.](image)
Special Characteristics of Flash Memory

- **Update unfriendly**
  - Over-writing a page requires first erasing the entire block
  - Write is performed in pages (e.g., 4KB), but erase is performed in blocks (e.g., 128KB)
    - Over-write may cause significant write amplification
    - Usually prefer out-of-place update instead of in-place update
Support a finite number of program-erase (P/E) cycles

- Each flash block can only be programmed/erased for a limited number of times (e.g., 10K)
- Data should be placed evenly across flash (wear leveling)
How to Manage NAND Flash

• Flash-specific file systems, which can handle the special characteristics of NDND flash
  – YAFFS/YAFFS2, UBIFS, F2FS, JFFS/JFFS2

• Flash translation layer (FTL) – a flash firmware embedded into the flash storage device, which can handle the special characteristics of NAND flash and emulate the flash storage as a regular block device (most popular)
  – SSD
  – USB
  – SD / miniSD/MicroSD
  – MMC cards
Flash Translation Layer (FTL)

FTL usually provides the following functionality:
✓ Address translation
✓ Garbage collection (GC)
✓ Wear leveling (WL)
✓ Bad block management
Most of the existing PDE systems deploy hidden volume on top of the block device

- Mobiflage [Skillen et al., NDSS ’13]
- MobiHydra [Yu et al., ISC ’14]
- MobiPluto [Chang et al., ACSAC ’15]
- MobiCeal [Chang et al., DSN ’18]
Deniability May be Compromised When Deploying Hidden Volume on The Block Layer

- Apps/Android framework
- OS/File system
- flash translation layer (FTL)
- NAND flash
- erasure block
- page

Block-based PDE systems

Attacker’s view

deniability compromise

Flash storage (eMMC card/SD card)
Compromise of Existing PDEs Built on top of the block device (1)

A flash block partially used by the hidden volume

Cannot be decrypted

A page

random
random
random
random
random

Ciphertext
Ciphertext
All “1”
All “1”
All “1”

erase

A block

Compromise of Existing PDEs Built on top of the block device (1)
Compromise of Existing PDEs Built on top of the block device (2)

Special flash memory operations like wear leveling and garbage collection on the hidden volume will create duplicate randomness

Block i and block j have duplicate randomness

Special flash memory operations like wear leveling and garbage collection on the hidden volume will create duplicate randomness

Refer to our paper published in CCS ’17 for more compromises
Fundamental Reasons for Compromises of The Existing Block-based PDE Systems

• Built on top of block device (outside the black box of flash memory), and cannot manage the internal flash memory

• Unexpected "traces" of hidden sensitive data could be created in the flash memory which is out of the control of the block-based PDE
Existing PDE Systems for Mobile Devices (cont.)

• The sole PDE system built into the flash memory is DEFY [Peters et al., NDSS ’15]
  • Strongly rely on special properties of the flash file system YAFFS (hence not applicable to FTL, which is a dominant flash architecture)
  • Suffering from deniability compromise since it simply disables garbage collection (insecure)
Our FTL-based PDE System [CCS ’17]

Key insight 1: move the public/hidden volume design down to the flash translation layer (FTL).

Our FTL-based PDE System (cont.)

Key insight 2: to mitigate the over-write issue:

1) The public volume will allocate blocks from the head of the free block pool; active garbage collection will be performed to fill the head of the free block pool.

2) The hidden volume will allocate blocks from the tail of the truly free blocks; active garbage collection will be performed to fill the tail of the truly free blocks.
Acknowledgments

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• Don’t forget to send your grade for today’s presenters