Data Security in Mobile Computing Devices

A Guest Lecture for CS 4491/7990 Deep Learning for Cybersecurity (Kennesaw State University)

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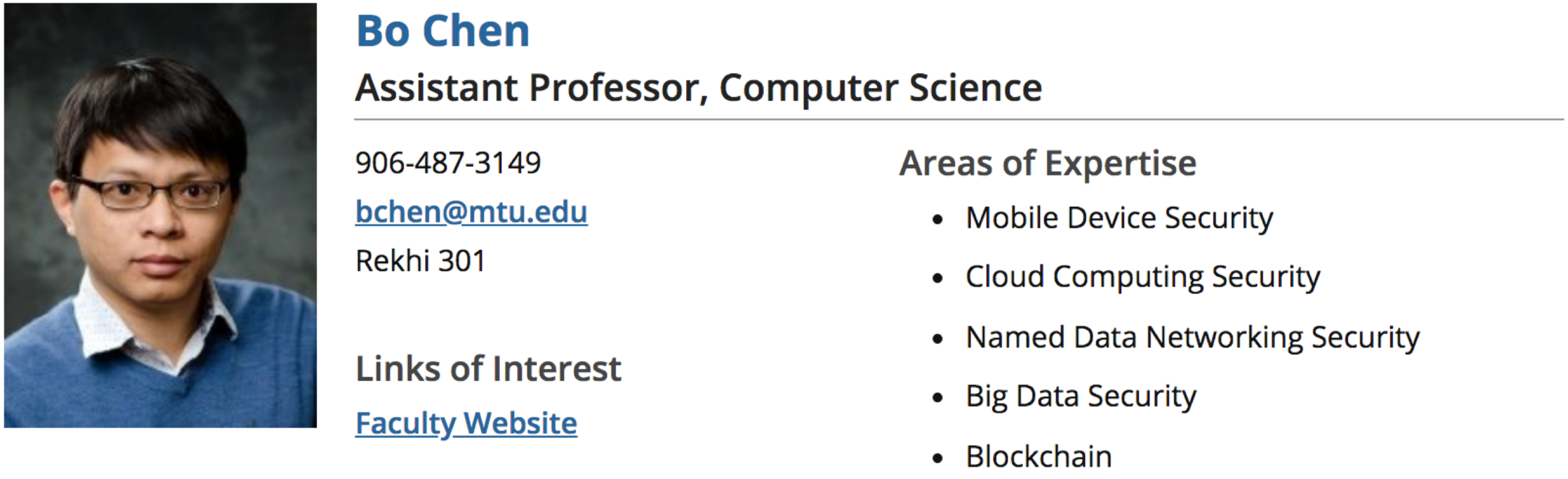
About Me

- Assistant Professor in Department of Computer Science



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Links of Interest

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Areas of Expertise

- Mobile Device Security
- Cloud Computing Security
- Named Data Networking Security
- Big Data Security
- Blockchain

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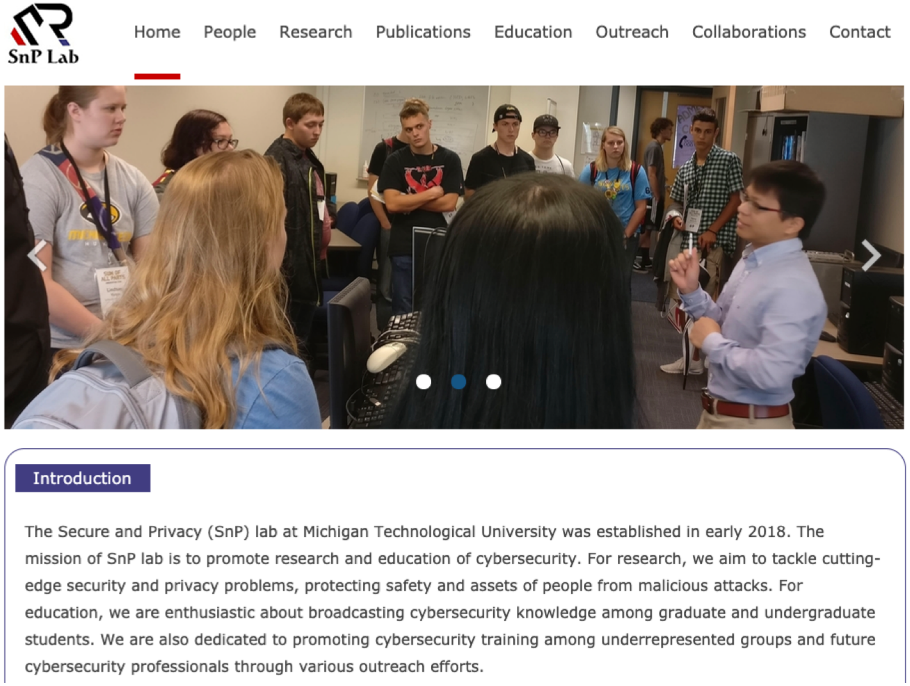
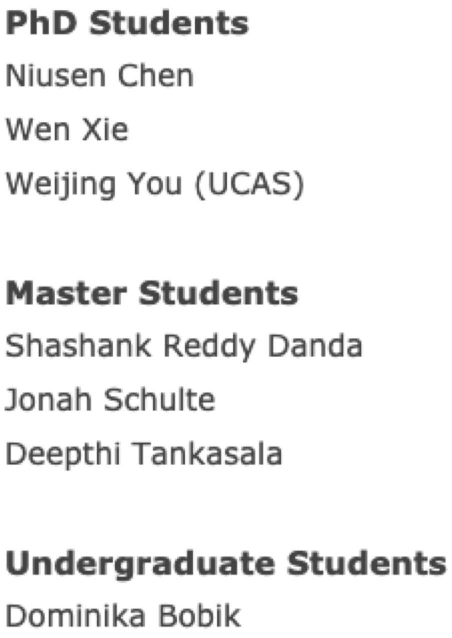
About MTU Security and Privacy (SnP) Lab



Introduction

The Secure and Privacy (SnP) lab at Michigan Technological University was established in early 2018. The mission of SnP lab is to promote research and education of cybersecurity. For research, we aim to tackle cutting-edge security and privacy problems, protecting safety and assets of people from malicious attacks. For education, we are enthusiastic about broadcasting cybersecurity knowledge among graduate and undergraduate students. We are also dedicated to promoting cybersecurity training among underrepresented groups and future cybersecurity professionals through various outreach efforts.



PhD Students

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Jonah Schulte

Deepthi Tankasala

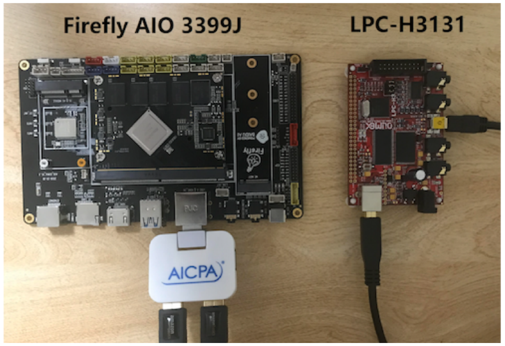
Undergraduate Students

Dominika Bobik

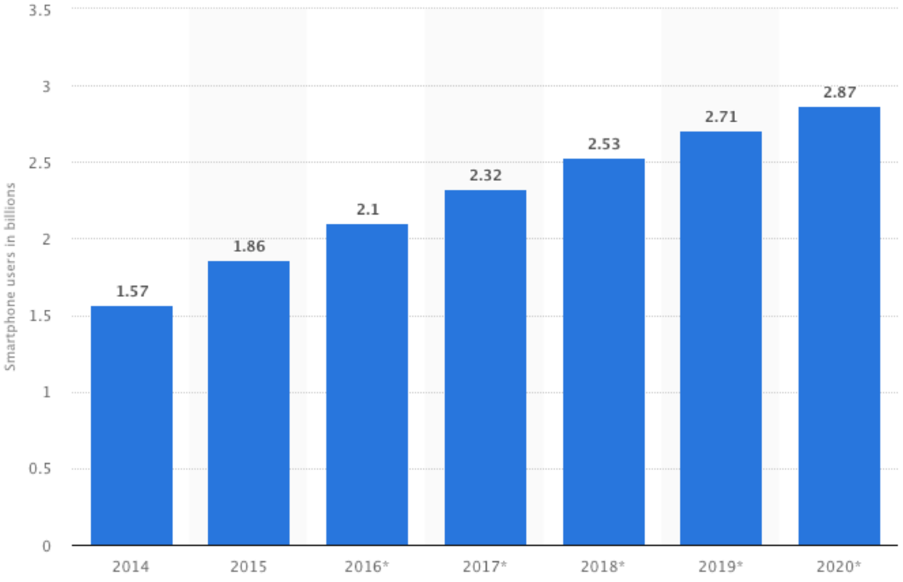
https://snp.cs.mtu.edu

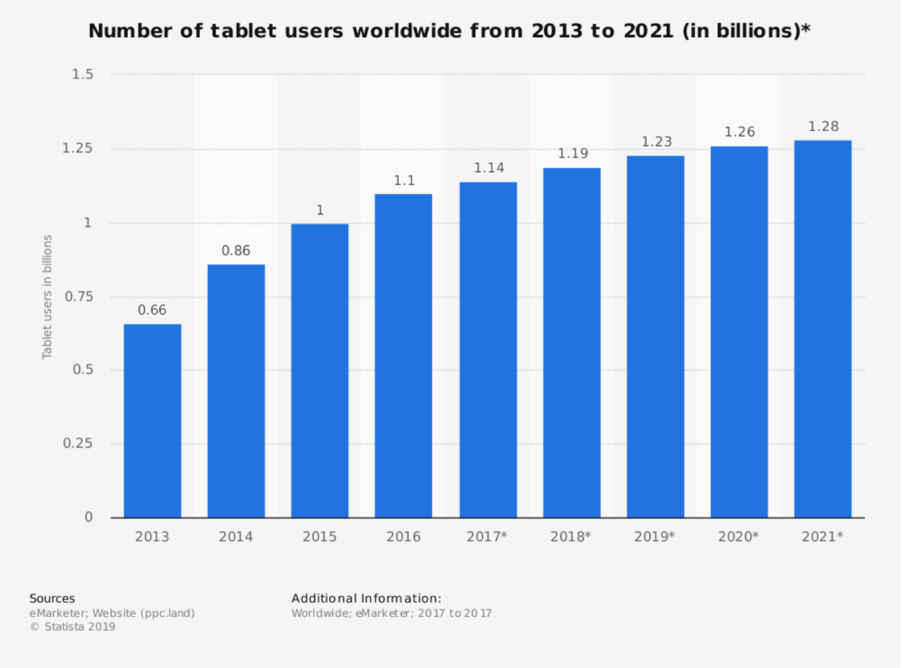
About Security and Privacy (SnP) Lab

- Projects are currently funded by national science foundation, national security agency, etc.
  - Protecting sensitive data in mobile devices, IoT devices
  - Protecting critical data/ infrastructures outsourced to public clouds
  - Blockchain and information centric networking
  - Leveraging mobile devices for COVID-19 mitigation (recently)



Mobile Devices are Turning to Mainstream Computing Devices



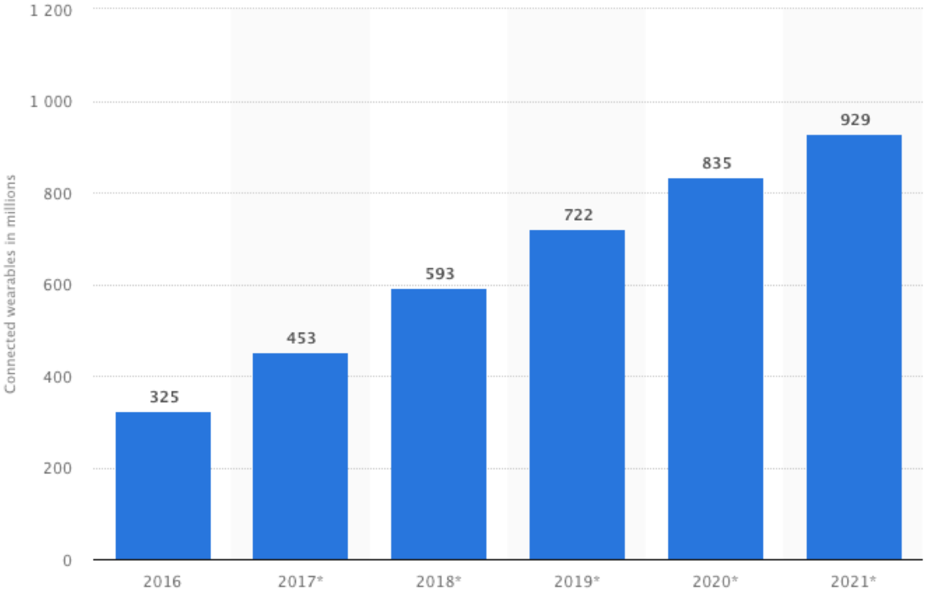


Number of smartphone users worldwide from 2014 to 2020 (in billions)

Number of tablet users worldwide from 2013 to 202

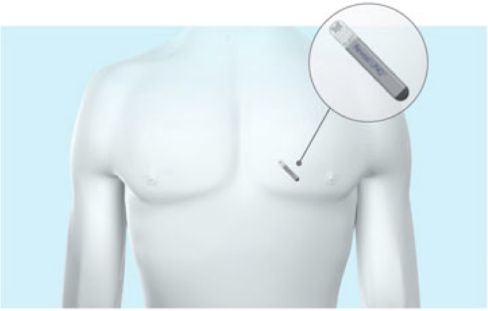
(in billions)

Mobile Devices are Turning to Mainstream Computing Devices (cont.)



Number of connected wearable devices worldwide from 2016 to 2021 (in millions)

Mobile Devices are Turning to Mainstream Computing Devices (cont.)



Mobile Computing 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.

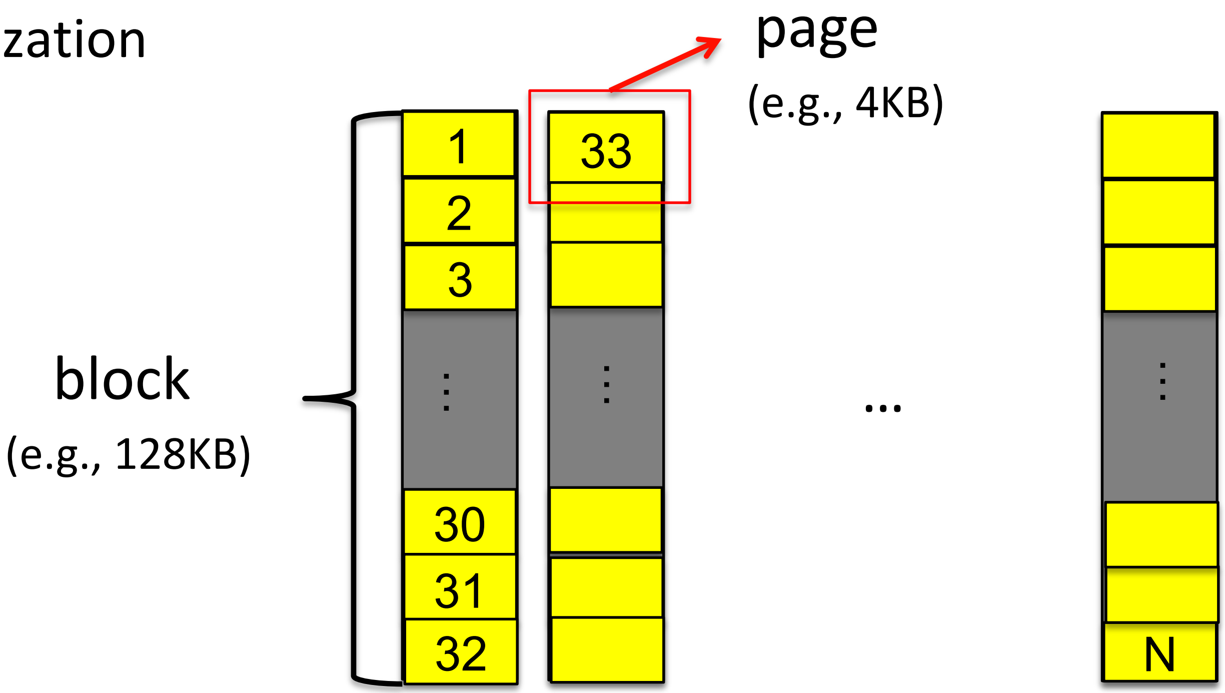
- Security issues in mobile computing devices
  - Confidentiality (C)
  - Integrity (I)
  - Access control (A)
  - Authentication
  - Etc..

Background on Storage Systems of Mobile Computing Devices

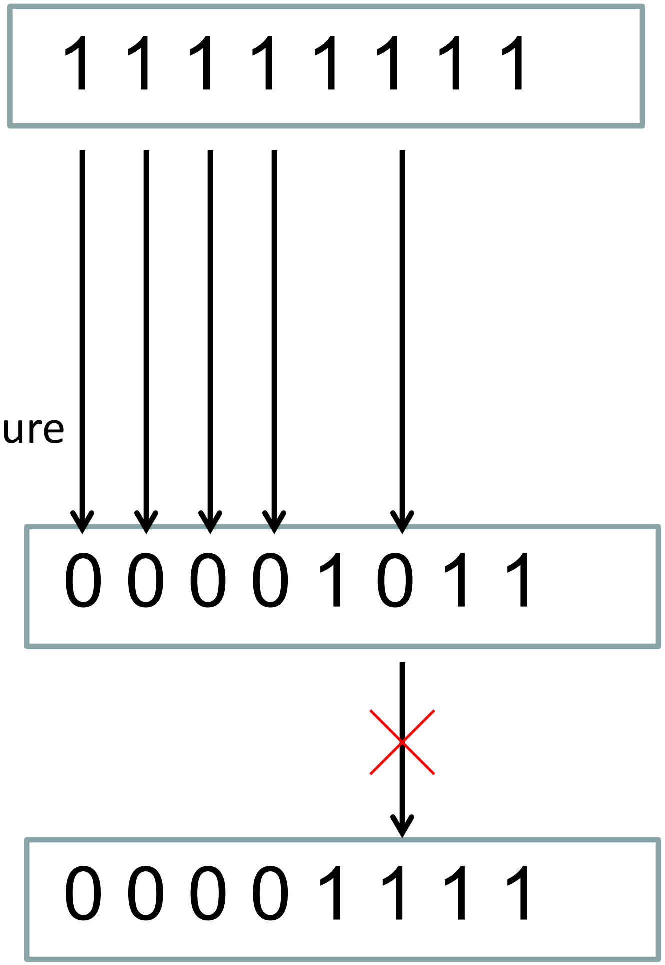
NAND Flash Memory

- 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



Flash Memory Programming



All ‘1’ initially:

1 1 1 1 1 1 1 1

Write 0x0b:

Rule:

1) 1 can be programed to 0

2) 0 cannot be programed to 1 except performing an erasure

0 0 0 0 1 0 1 1

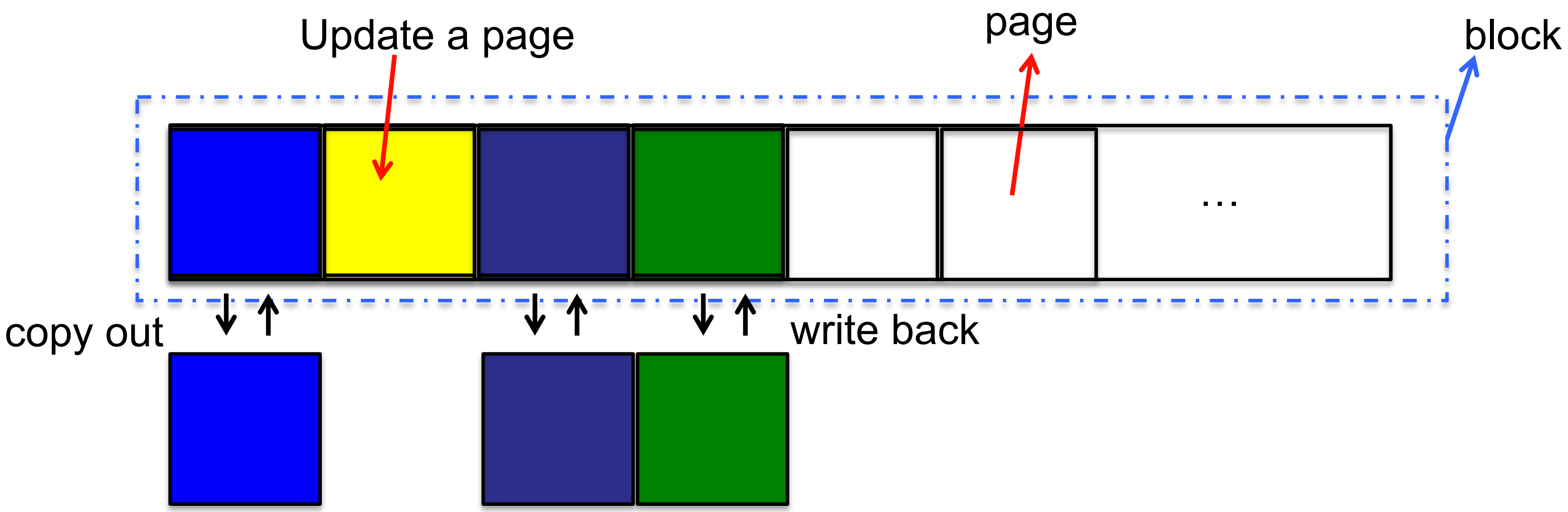
Write 0x0f?

0 0 0 0 1 1 1 1

Need to erase to all ‘1’ first

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

Special Characteristics of Flash Memory (cont.)

- 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)

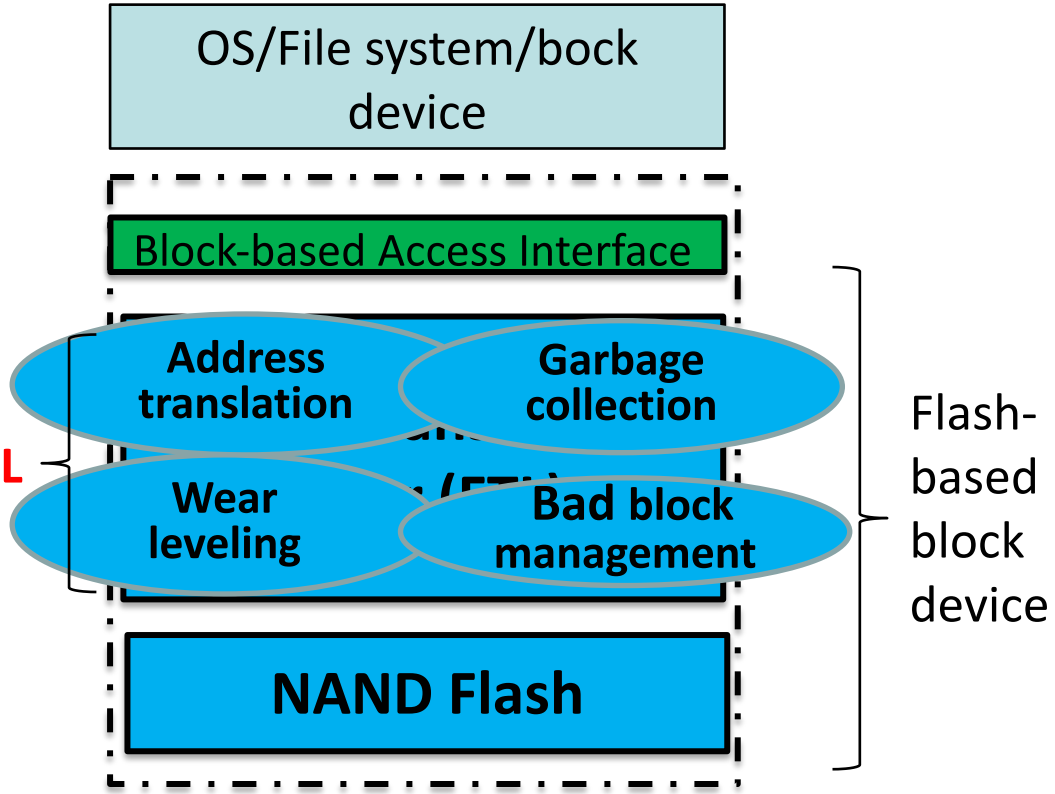
How to Manage NAND Flash

- 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
  - UFS

Flash Translation Layer (FTL)

FTL usually provides the following functionality:

- ✓ Address translation
- ✓ Garbage collection (GC)
- ✓ Wear leveling (WL)
- ✓ Bad block management



Plausibly Deniable Encryption (PDE) Systems for Mobile Devices

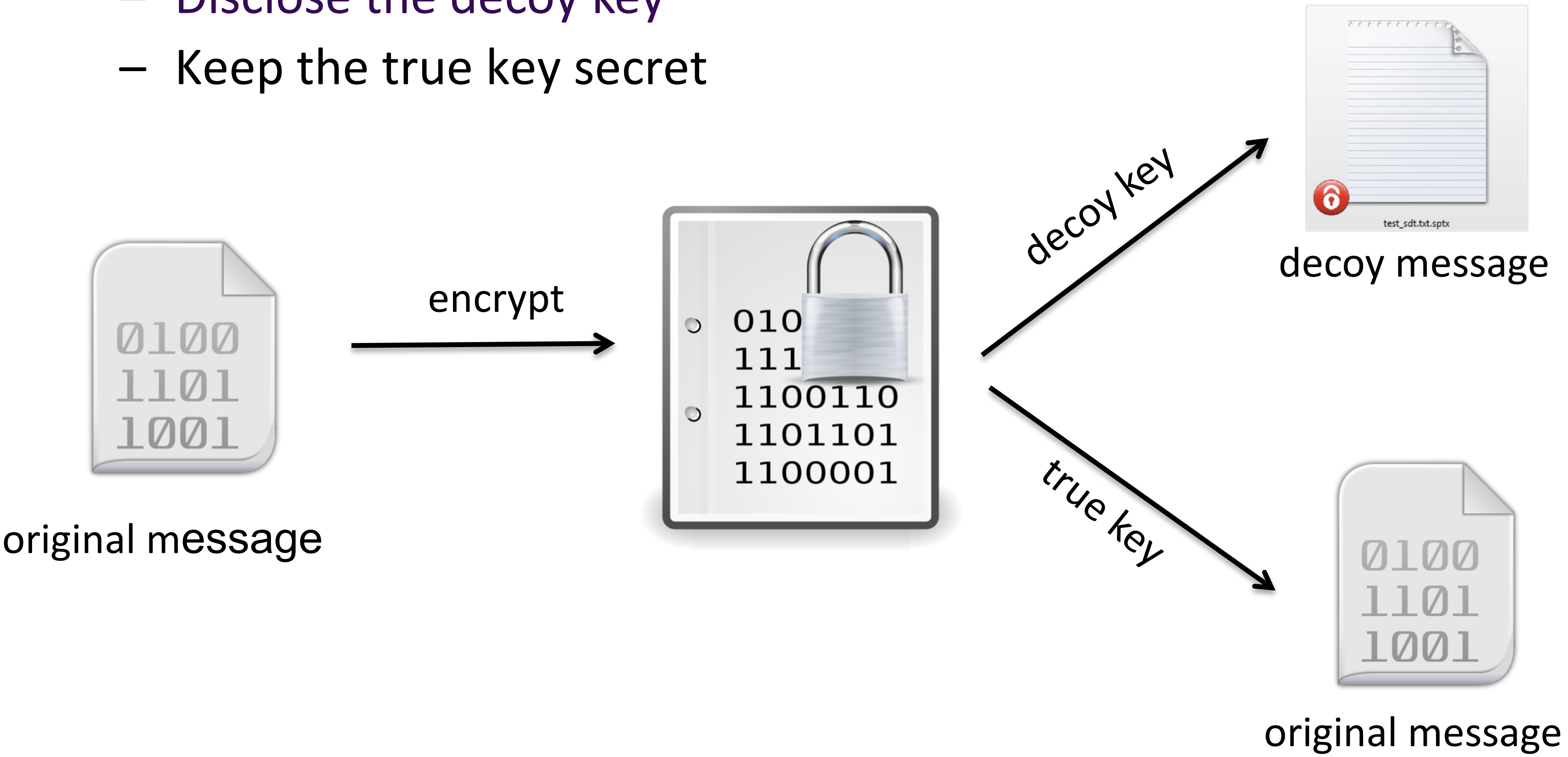
Coercive Attack against Confidentiality

- To protect confidentiality of sensitive data, we can simply encrypt them
  - AES/3DES
  - Full disk encryption (FDE): TrueCrypt, BitLocker, FileVault, etc
- Conventional encryption is vulnerable to a coercive attack

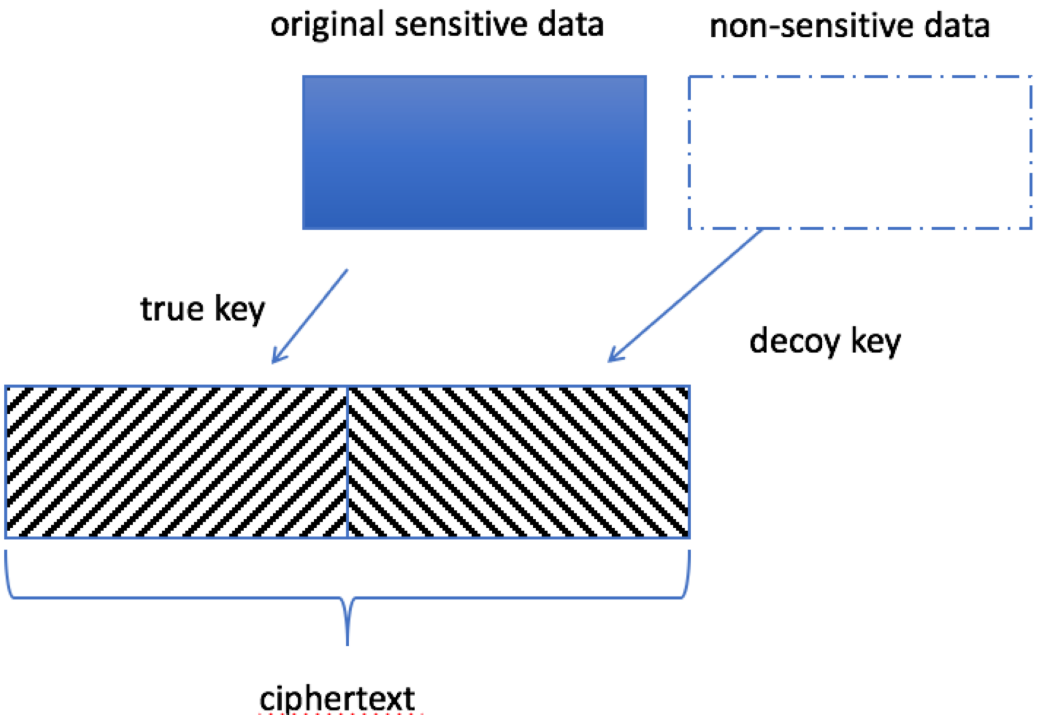
An attacker forces the device's owner to disclose the decryption key

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



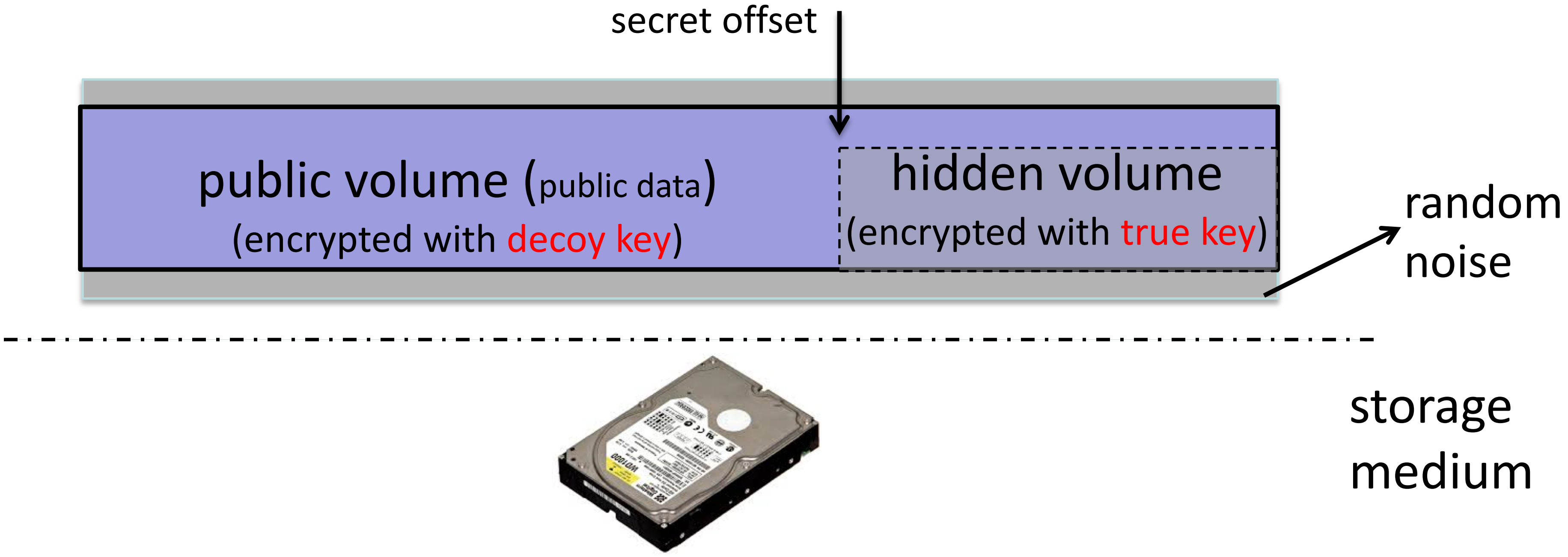
Instantiating PDE (Plausibly Deniable Encryption) in Cryptography



- 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



secret offset

public volume (public data)

(encrypted with decoy key)

hidden volume

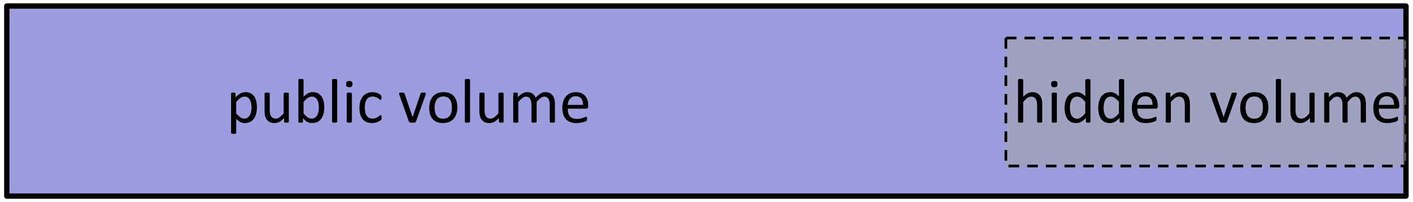
(encrypted with true key)

random noise

storage medium

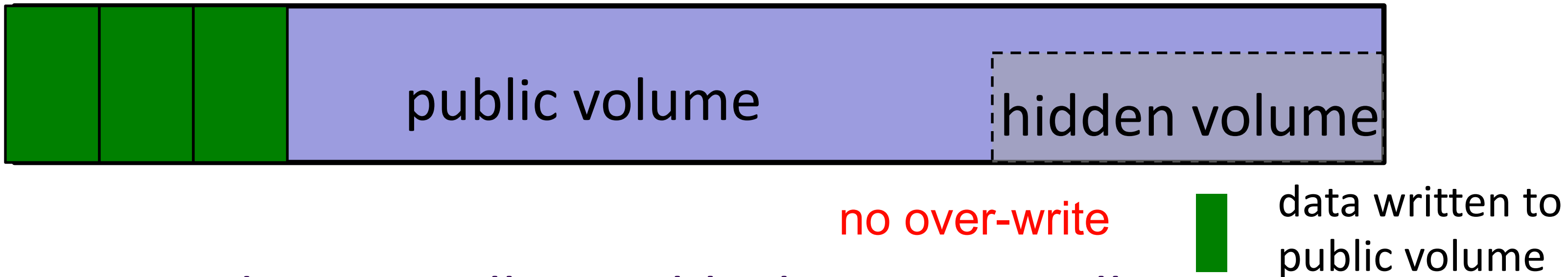
The Challenges: Over-writing Issues

- 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

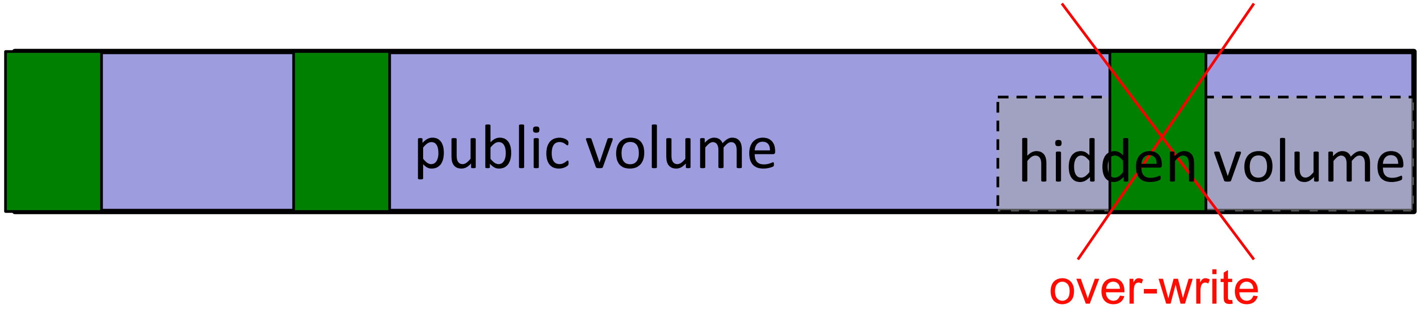


The Challenges: Over-writing Issues (cont.)

- File systems really matter for over-write issues
  - FAT allocates blocks sequentially



  - EXT4 does not allocate blocks sequentially

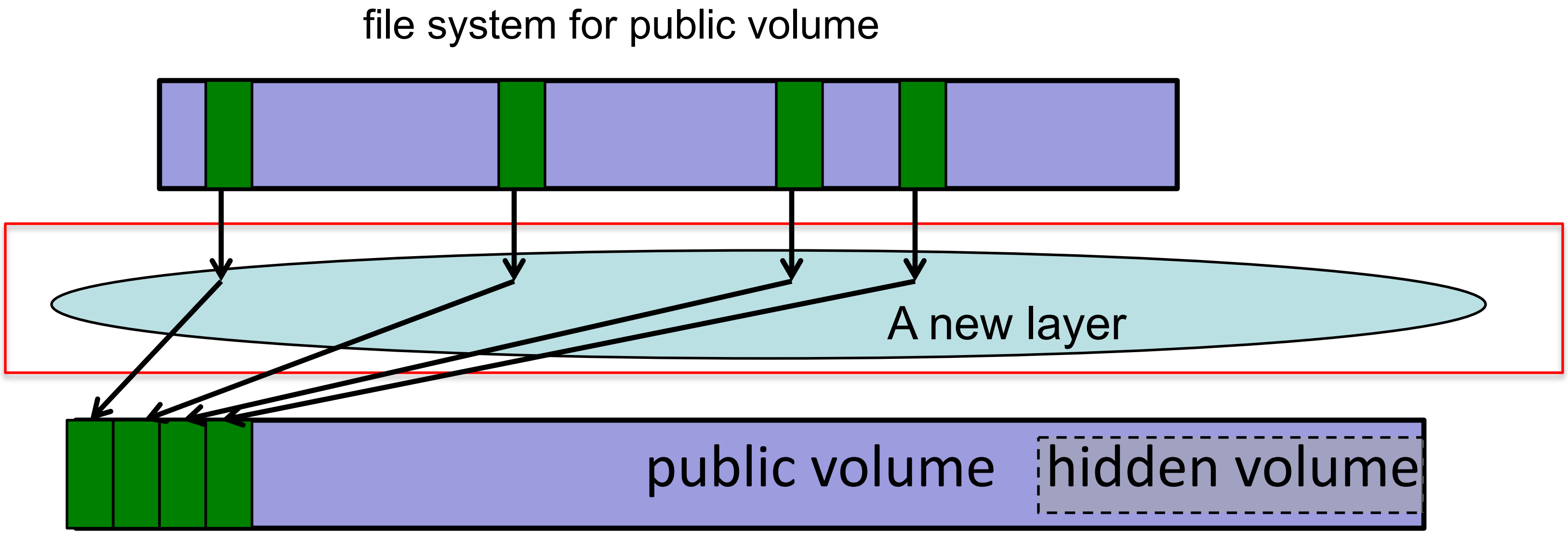


It is challenging to allow any file systems to be deployed while mitigating the over-write issues

Our Mobile PDE System [ACSAC ’15]

Key Insights: To realize file system friendly design, a new layer is introduced to decouple the file system and the underlying PDE system

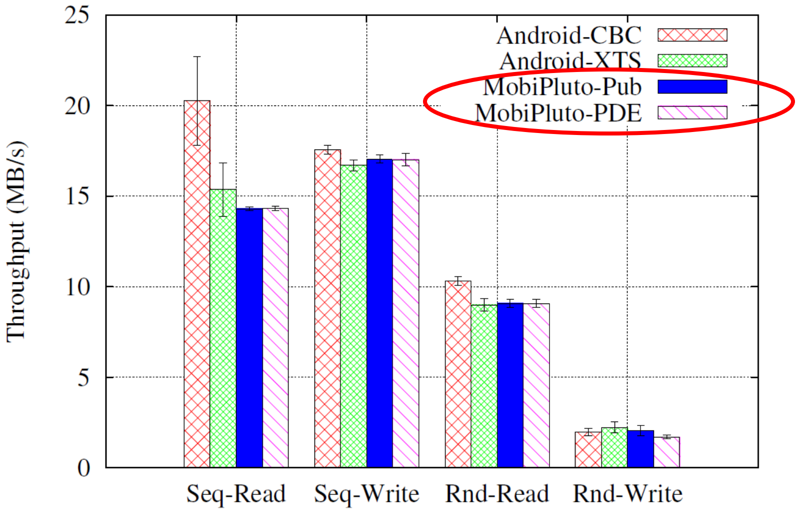
1. Provide virtual volumes to file systems
2. Any block-based file system can be built on a virtual volume
3. Non-sequential allocation on the virtual volume will be converted to sequential allocation on the underlying layer



Bing Chang, Zhan Wang, Bo Chen, and Fengwei Zhang. MobiPluto: File System Friendly Deniable Storage for Mobile Devices. 2015 Annual Computer Security Applications Conference (ACSAC '15), Los Angeles, California, USA, December 2015 (Acceptance rate: 24.4%)

Evaluation Highlights

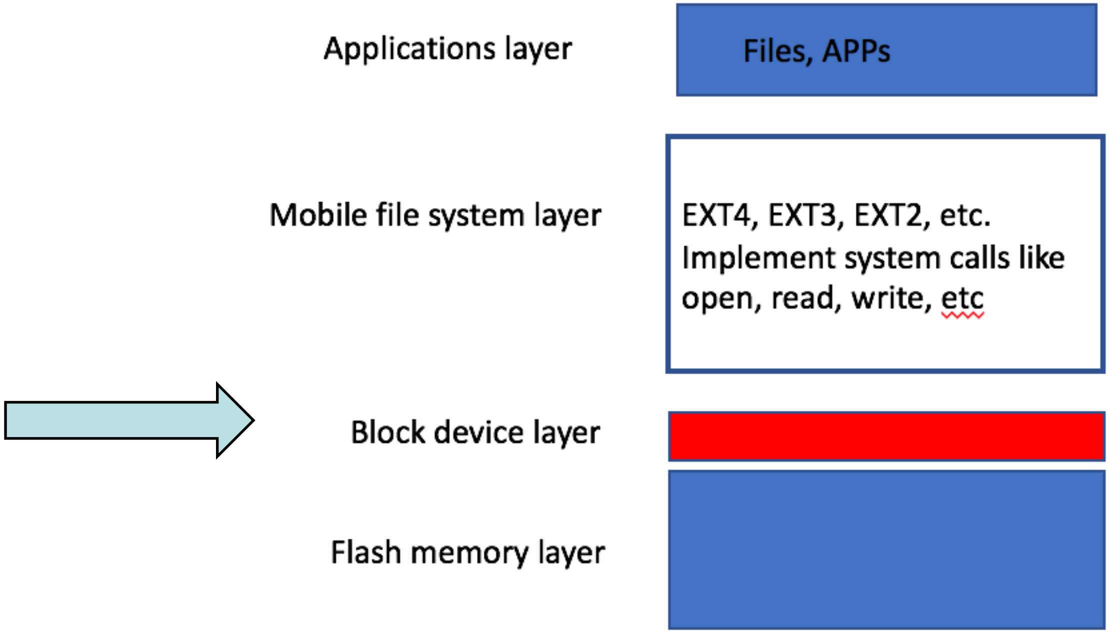
- Implemented a prototype of our solution on LG Nexus 4



Throughput (MB/s) from AndroBench

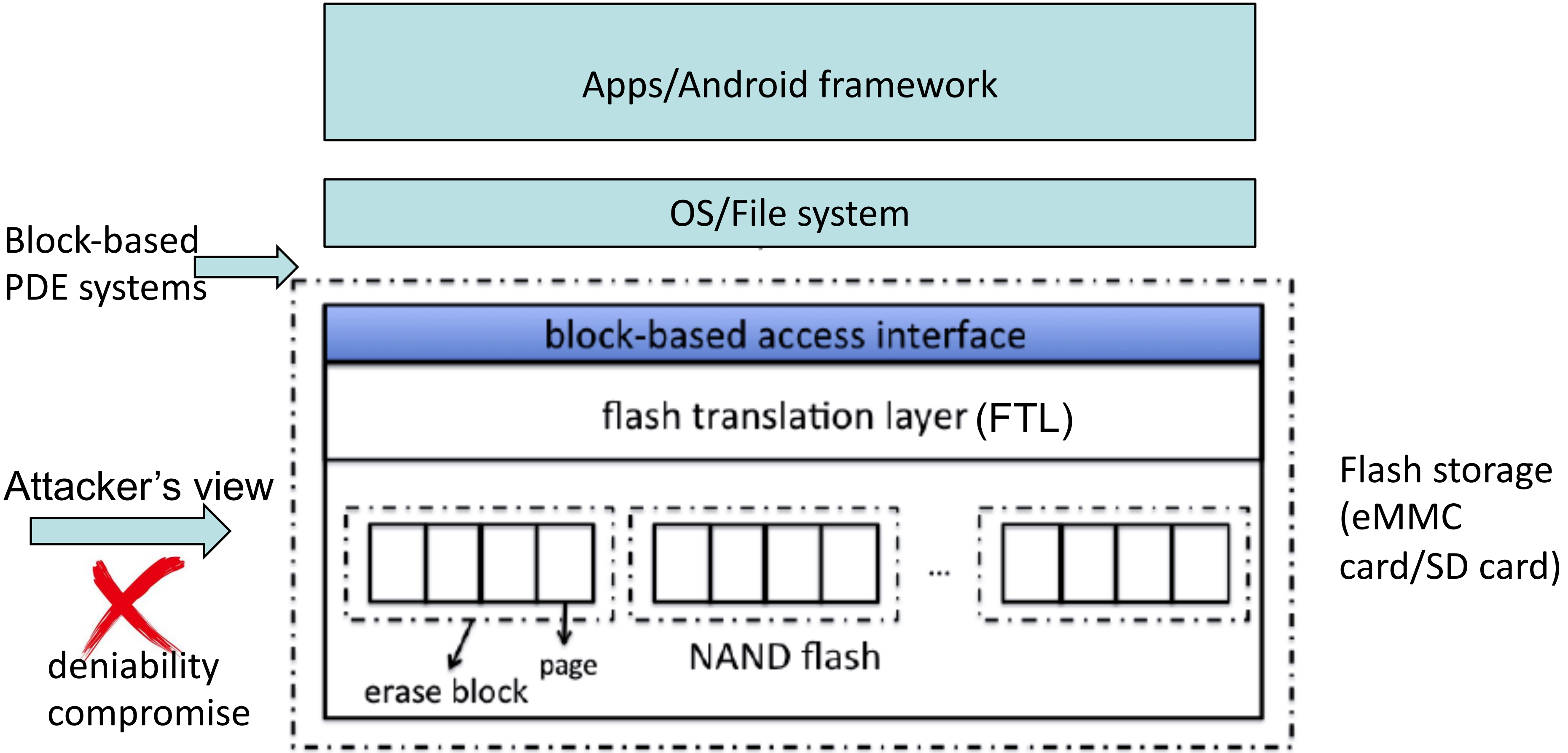
Existing PDE Systems for Mobile Devices

- Most of the existing PDE systems deploy hidden volume on top of the block device
  - Mobiflage [Skillen et al., NDSS ’13]
  - MobiPluto (our work) [Chang et al., ACSAC ’15]
  - MobiCeal (our work) [Chang et al., DSN ’18]



The architecture of mobile storage

Deniability May be Compromised When The Attacker Can Have Access to Flash Memory



Apps/Android framework

OS/File system

Block-based PDE systems

block-based access interface

flash translation layer (FTL)

Attacker’s view

deniability compromise

erase block

page

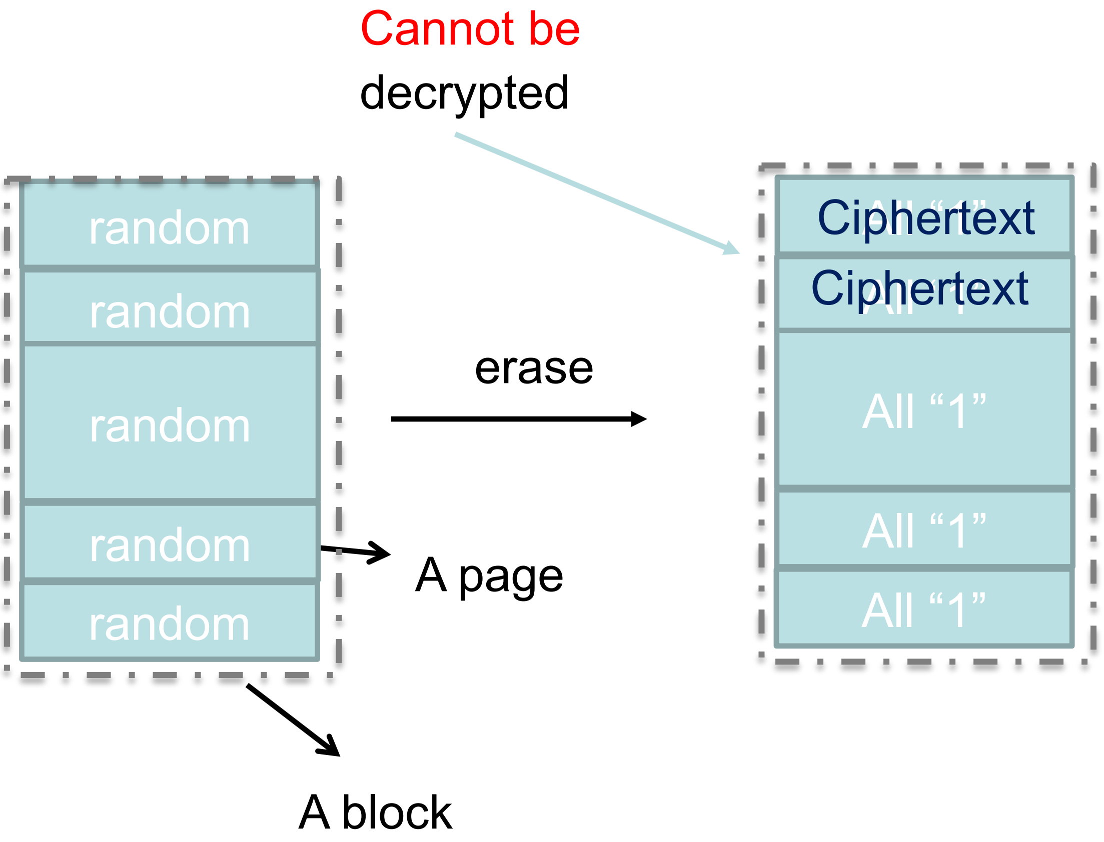
NAND flash

...

Flash storage (eMMC card/SD card)

Compromise of Existing PDEs Built on top of the block device: Example 1

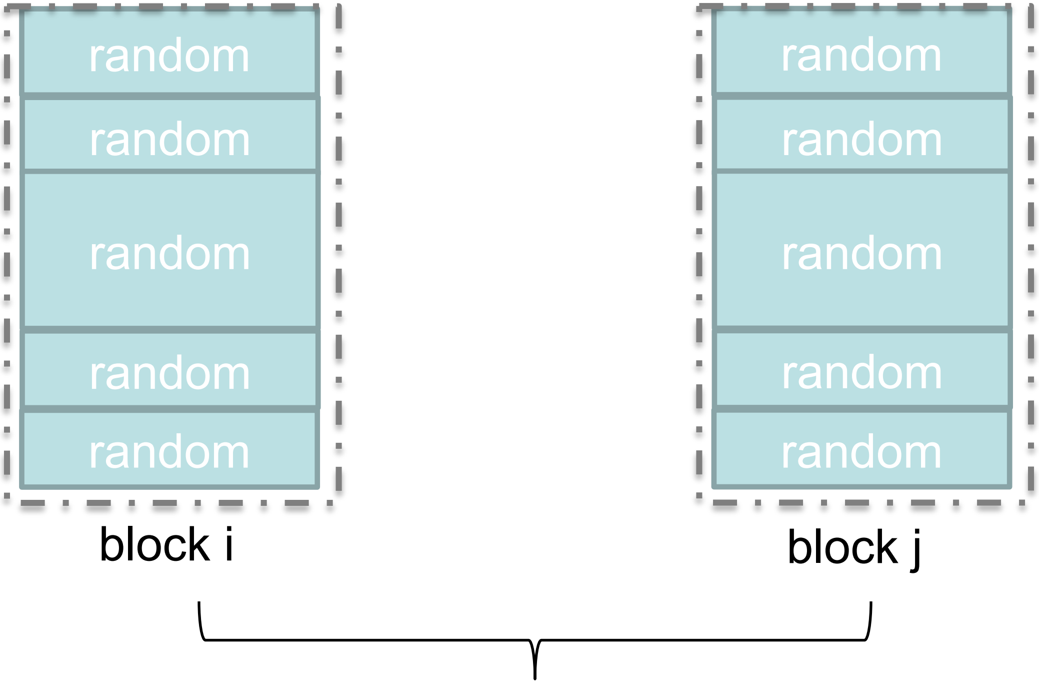
When the attacker can have access to the flash memory



A flash block partially used by the hidden volume

Compromise of Existing PDEs Built on top of the block device: Example 2

When the attacker can have access to the flash memory



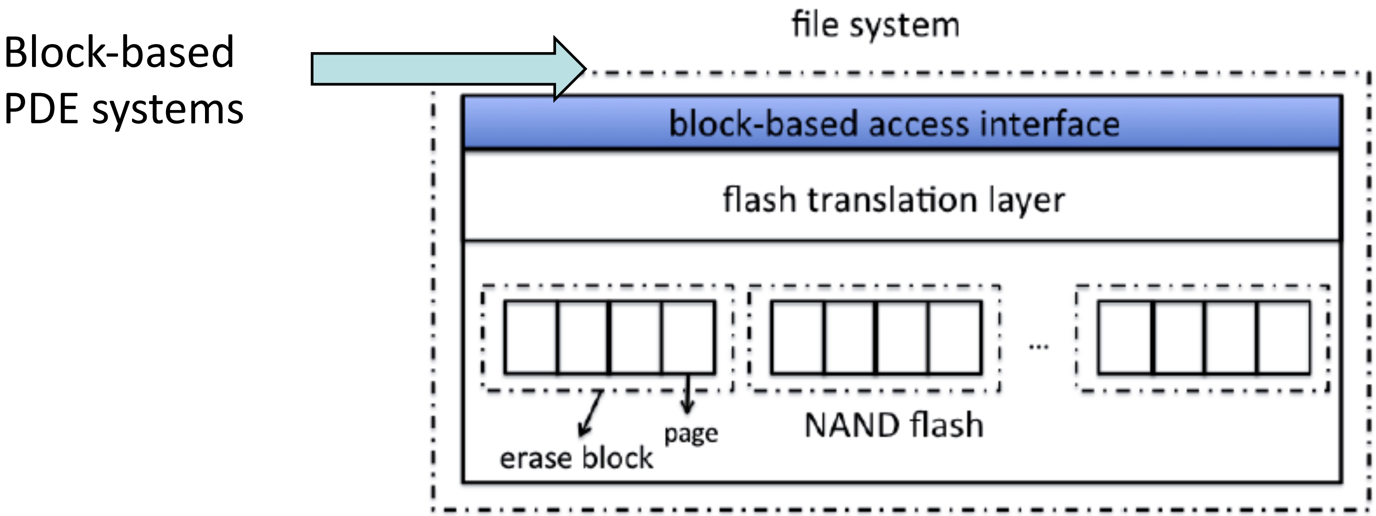
block i and block j have duplicate randomness

Special flash memory operations like wear leveling and garbage collection in the hidden volume will produce duplicate blocks

Refer to our paper published in CCS '17 for more compromises

Fundamental Reasons for Compromises of The Existing Block-based PDE Systems

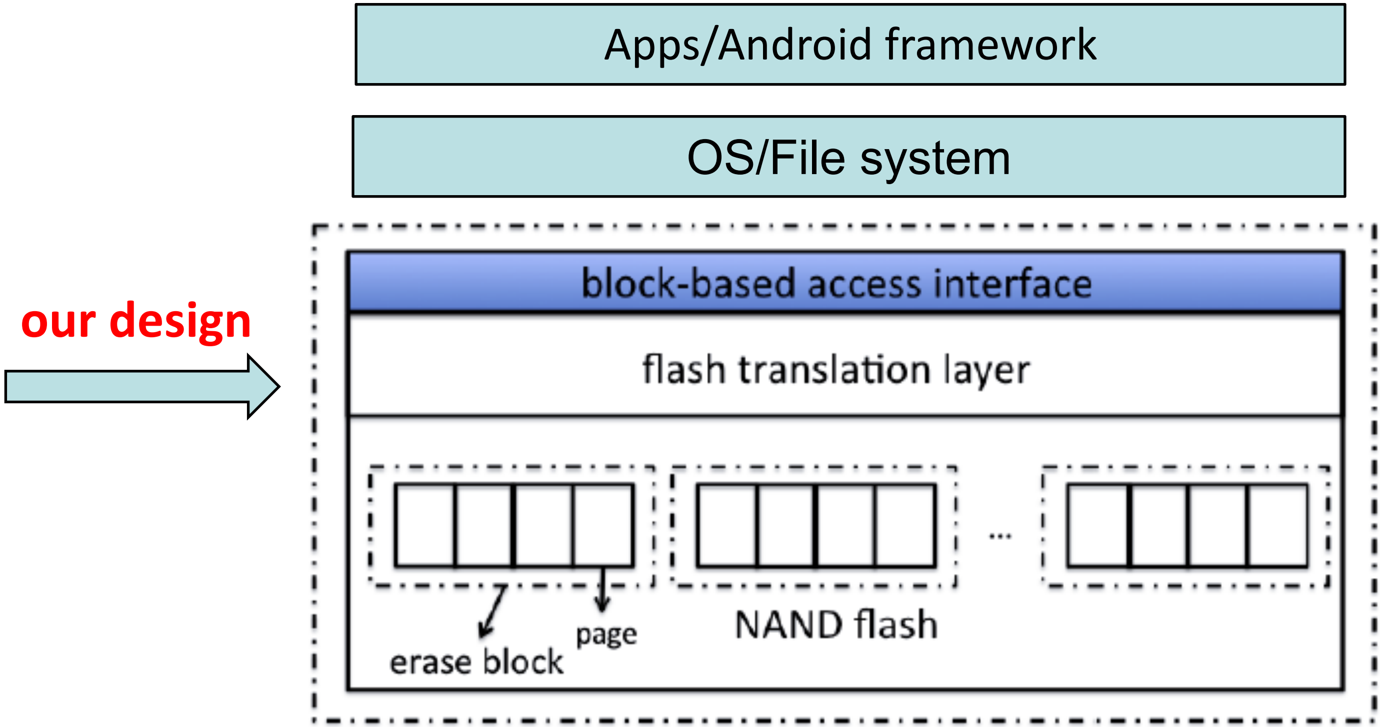
- Built on top of block device (outside the black box of flash memory), and cannot manage the internal flash memory
- Unexpected ``traces'' of hidden sensitive data could be created in the flash memory which is out of the control of the block-based PDE



Block-based PDE systems

Our FTL-based PDE System [CCS ’17]

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

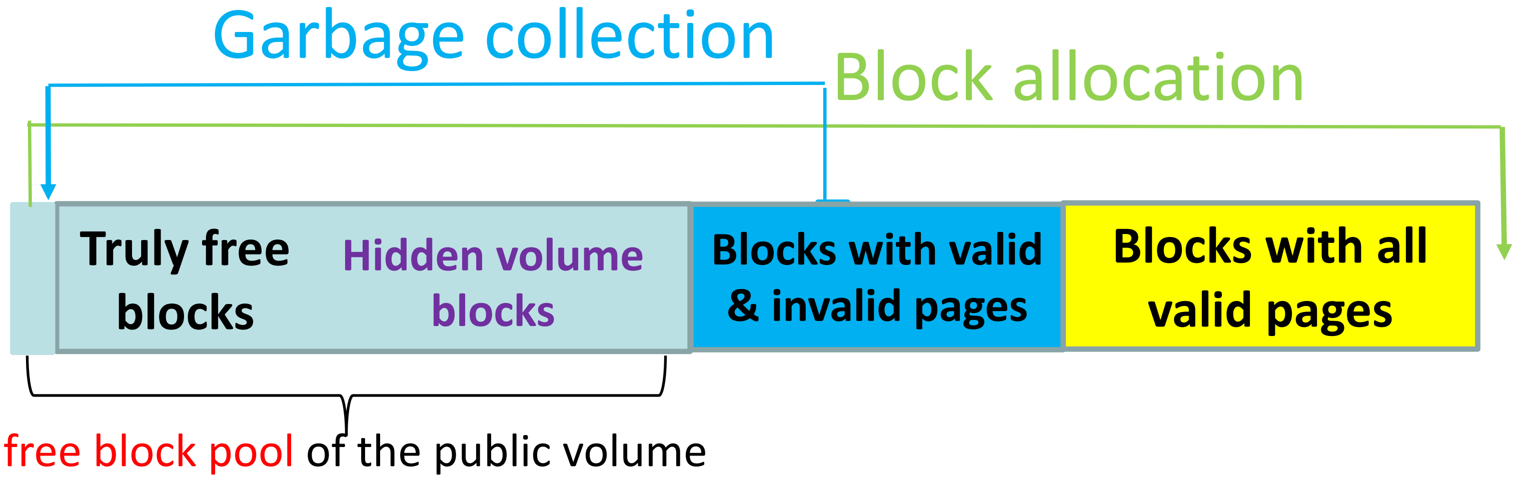


Shijie Jia, Luning Xia**, Bo Chen**, and Peng Liu. DEFTL: Implementing Plausibly Deniable Encryption in Flash Translation Layer. 2017 ACM Conference on Computer and Communications Security (CCS '17), Dallas, Texas, USA, Oct 30 - Nov 3, 2017 (Acceptance rate: 18%)

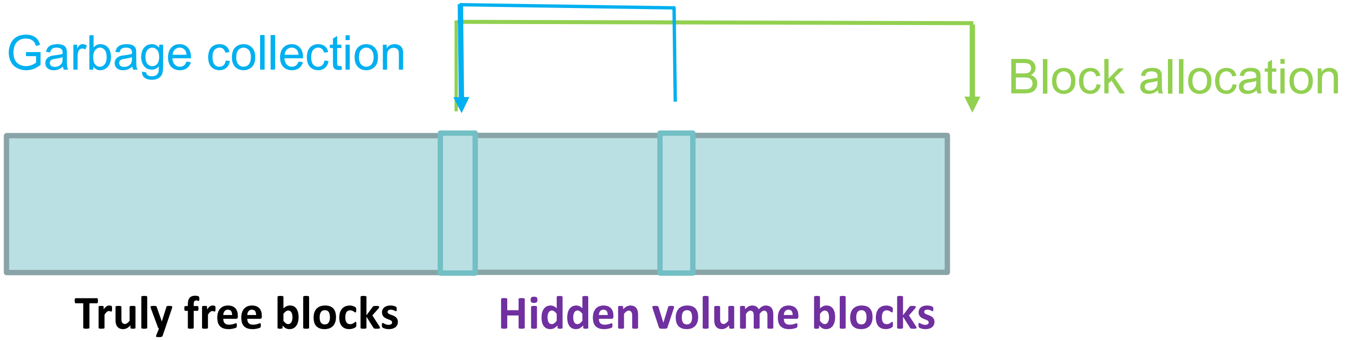
Our FTL-based PDE System (cont.)

Key insight 2: to mitigate the over-write issue, the hidden volume and the public volume should avoid sharing blocks:

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.


Garbage collection
Block allocation
Truly free blocks
Hidden volume blocks
Blocks with valid & invalid pages
Blocks with all valid pages
free block pool of the public volume

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.



Enabling Data Recovery in Mobile Devices from Malicious Attacks

Ransomware

- A piece of special malware that infects a computer and restricts access to the computer and/or its files
  - A ransom needs to be paid in order for the restriction to be removed

Growth in Ransomware Variants Since December 2015

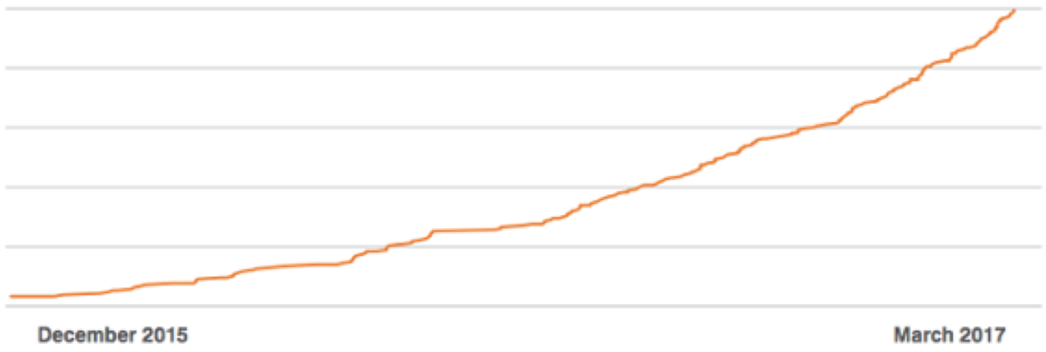
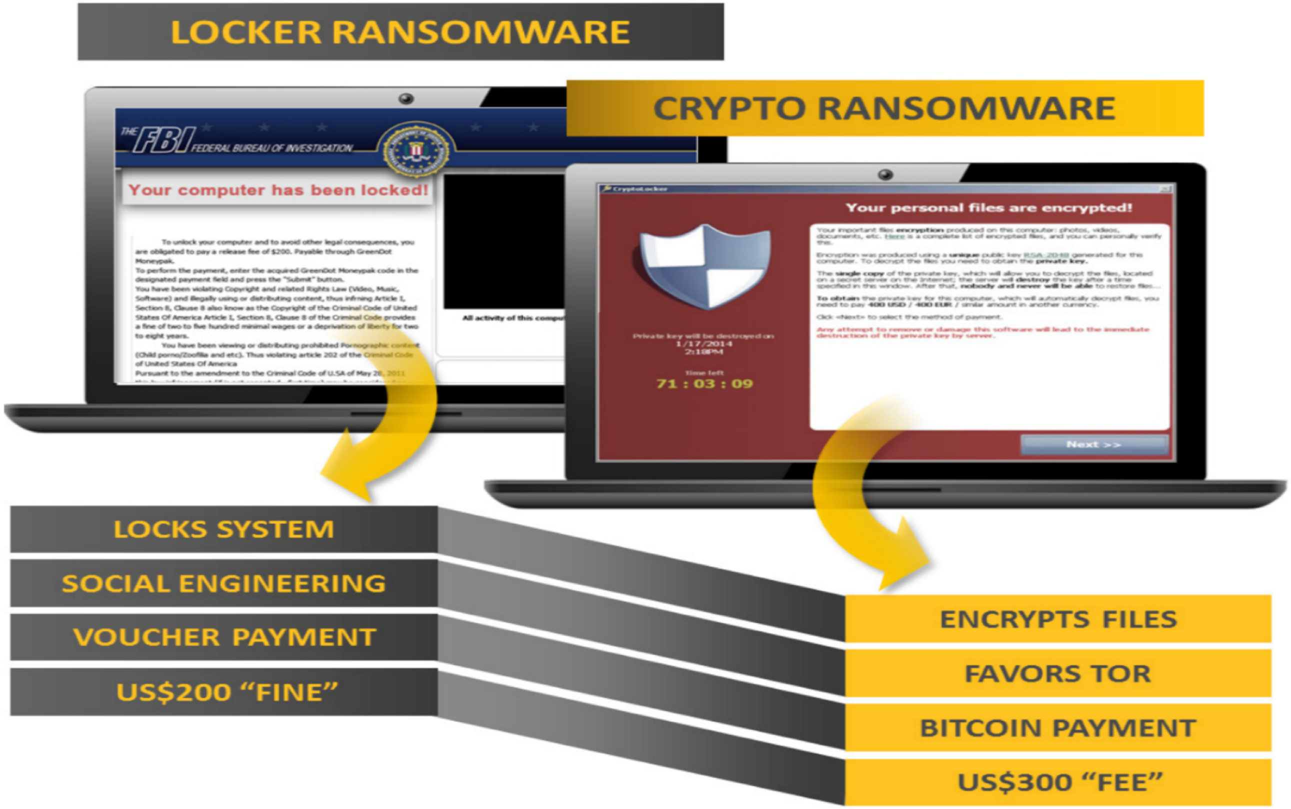


Figure 6: Indexed growth in total number of observed ransomware strains, December 2015-March 2017

Source: *Proofpoint Q1 2017 Quarterly Threat Report*

Main Types of Ransomware

- Locker ransomware
- Crypto-ransomware



THE FBI FEDERAL BUREAU OF INVESTIGATION

Your computer has been locked!

To unlock your computer and to avoid other legal consequences, you are obligated to pay a release fee of $200. Payable through GreenDot Moneypak.

To perform the payment, enter the acquired GreenDot Moneypak code in the designated payment field and press the "Submit" button.

You have been violating Copyright and related Rights Law (Video, Music, Software) and illegally using or distributing content, thus infrning Article 1, Section 8, Clause 8 also know as the Copyright of the Criminal Code of United States Of America Article 1, Section 8, Clause 8 of the Criminal Code provides a fine of two to five hundred minimal wages or a deprivation of liberty for two to eight years.

You have been viewing or distributing prohibited Pornographic content (Child porno/Zoofilia and etc). Thus violating article 202 of the Criminal Code of United States Of America

Pursuant to the amendment to the Criminal Code of U.SA of May 28, 2011

All activity of this compu

CryptoLocker

Your personal files are encrypted!

Your important files **encryption** produced on this computer: photos, videos, documents, etc. Here is a complete list of encrypted files, and you can personally verify this.

Encryption was produced using a **unique** public key RSA-2048 generated for this computer. To decrypt the files you need to obtain the **private key.**

The **single copy** of the private key, which will allow you to decrypt the files, located on a secret server on the Internet; the server will **destroy** the key after a time specified in this window. After that, **nobody and never will be able** to restore files...

To obtain the private key for this computer, which will automatically decrypt files, you need to pay **400 USD / 400 EUR** / similar amount in another currency.

Click <Next> to select the method of payment.

Any attempt to remove or damage this software will lead to the immediate destruction of the private key by server.

Private key will be destroyed on
1/17/2014
2:18PM

Time left
71 : 03 : 09

How to Combat Locker Ransomware?

- Observation: only the system is locked by the ransomware, but the data are stored intact
- Unplug the storage medium (e.g., SSD drives, microSD cards), plug the storage medium to a new computing device, and copy out the data
- Plug the storage device back to the device which has been locked, and re-install/initialize the system, then copy the data back

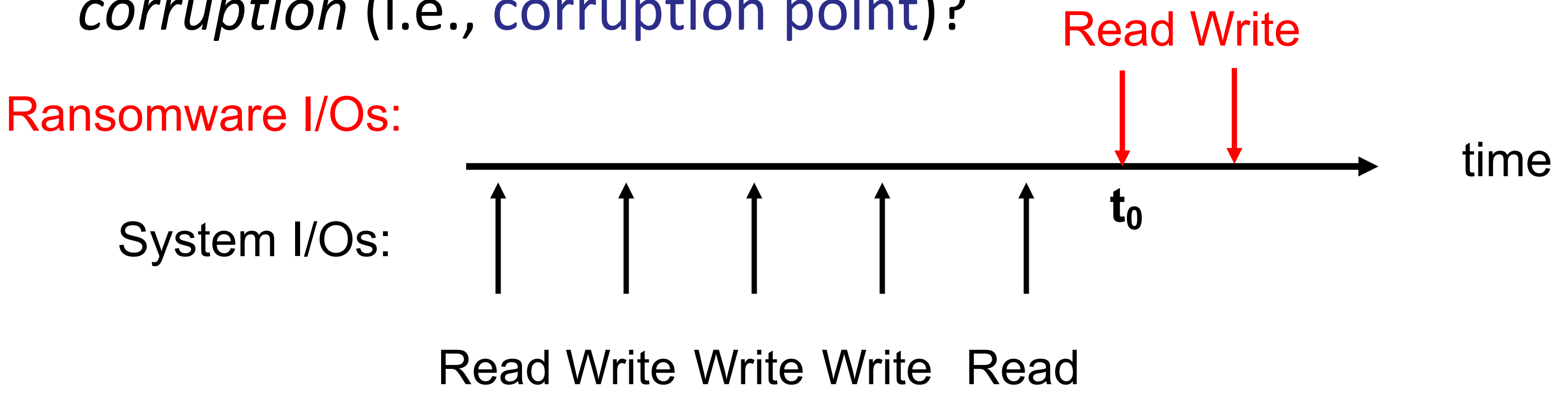
Crypto-ransomware Defense

- Crypto-ransomware behaviors:
  - Encrypt the victim data, and delete the original data
    - In systems, the delete operation is implemented by overwriting the data with garbage data
  - Or encrypt the victim data, and use the ciphertext to overwrite the original data
- Data recovery from crypto-ransomware attacks
  - Option 1: obtain the decryption key
    - Pay the ransom: money loss; cannot guarantee the key can work after paying the ransom
    - Extract the key locally: may work if the ransomware uses symmetric encryption, but no guarantee the key can be extracted
  - Option 2: data recovery from backups
    - More reliable

A Challenging Issue When Restoring Victim Data from Backups

- After a computing device is hacked by ransomware, the victim data will be recovered by backups

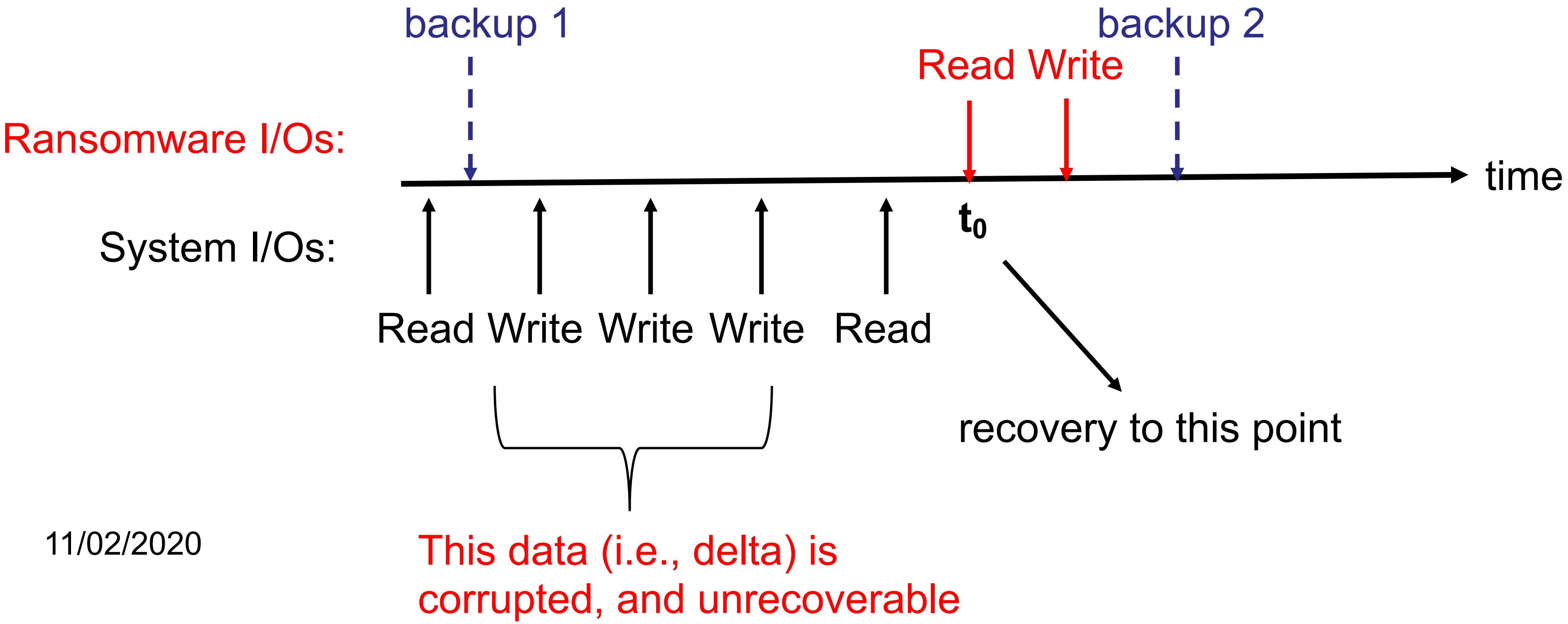
- A challenging issue is how to *ensure data stored in the victim device is recoverable to the exact point right before the corruption* (i.e., corruption point)?



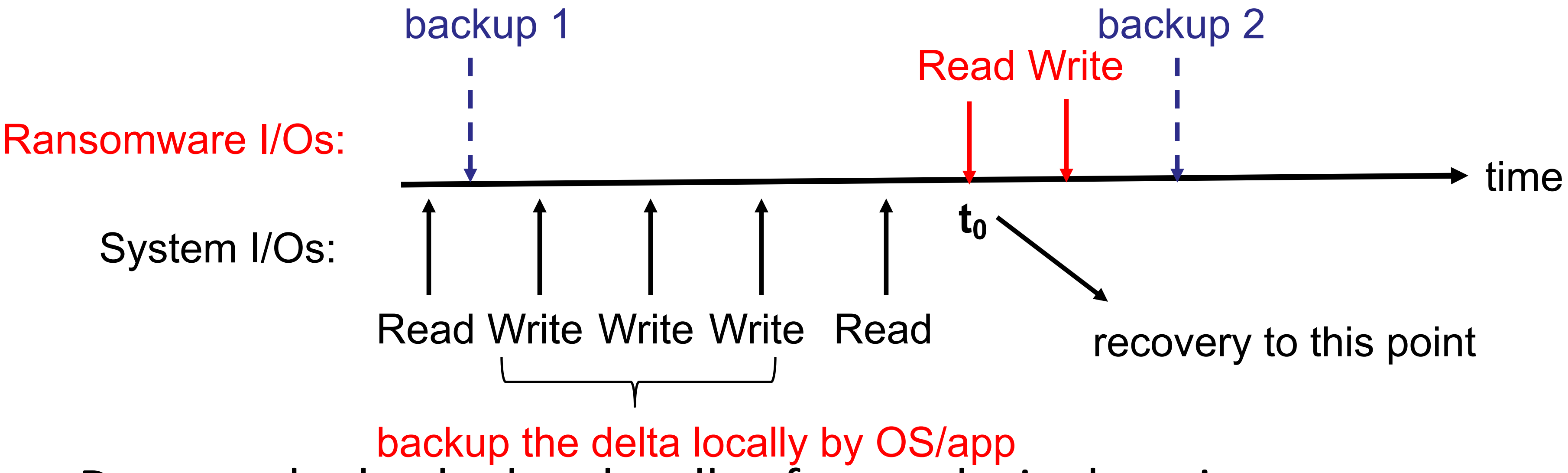
t_0 - corruption point

Why Remote Backups Cannot Recover Data at The Corruption Point?

- Each backup operation usually happens periodically (e.g., daily, hourly) rather than continuously
  - No enough battery
  - Internet is not necessarily available any time
  - There is no guarantee that the data at the corruption point have been backed up remotely

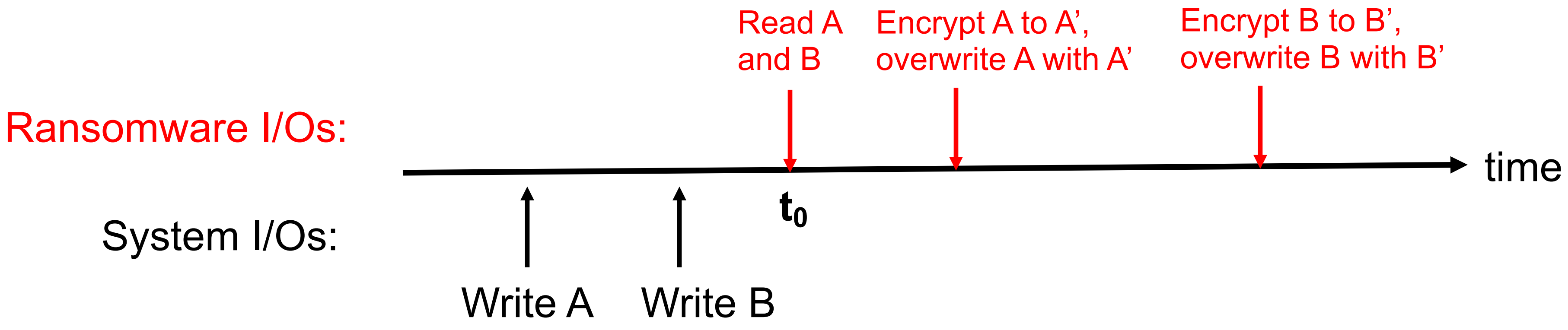


What about Backing Up Delta by OS/Apps Locally?



- Data can be backed up locally after each single write
- This could be problematic:
  - Creating backups after each single write incurs a large overhead
  - The ransomware may compromise the entire OS and all the local backups created at the upper layers may be corrupted and cannot used for data recovery

Our Observation



Ransomware I/Os:

Read A and B

Encrypt A to A’, overwrite A with A’

Encrypt B to B’, overwrite B with B’

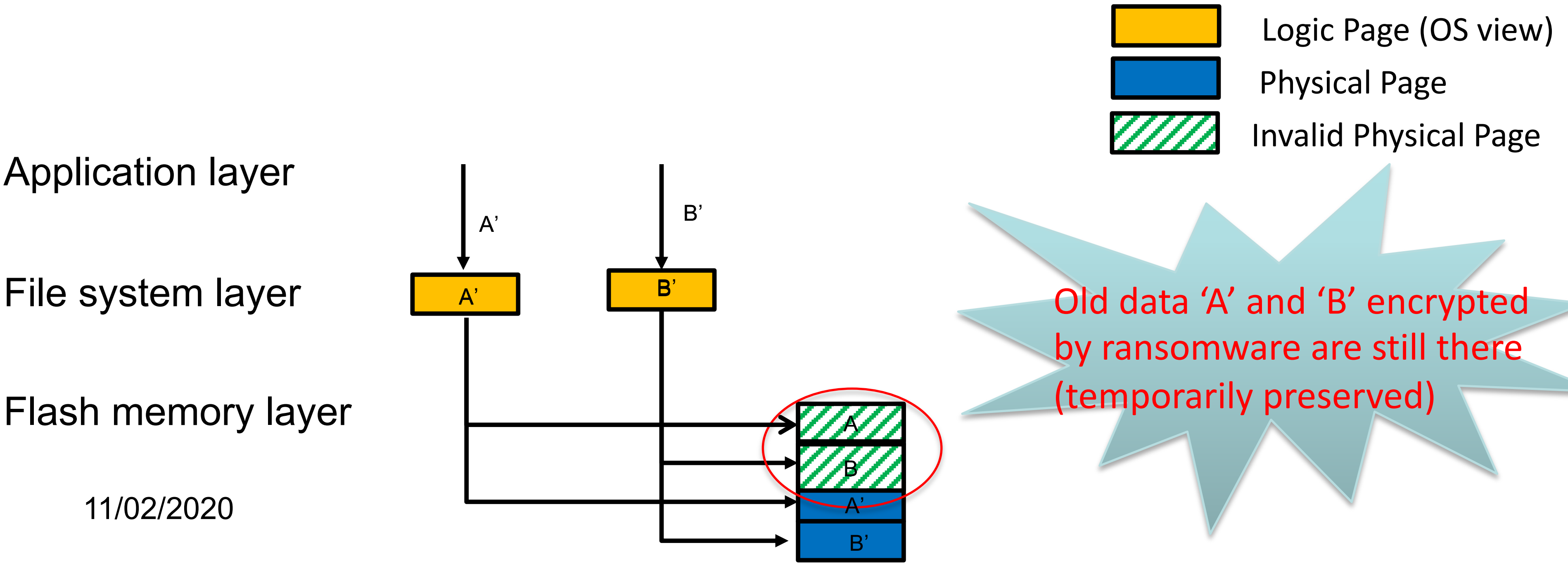
time

t_0

System I/Os:

Write A

Write B



▆ Logic Page (OS view)

▆ Physical Page

▨ Invalid Physical Page

Application layer

File system layer

Flash memory layer

Old data ‘A’ and ‘B’ encrypted by ransomware are still there (temporarily preserved)

Our Solution

- A ransomware detection tool is integrated into the flash translation layer
- Each time if no ransomware is detected, a backup is created and stored in the remote server
- Each time if the ransomware is detected, we will restore the data at the corruption point by:
  - Retrieve the latest version of the data from the remote server
  - Extract the delta from the flash memory (the delta will be preserved in the flash memory due to out-of-place update)
  - Apply delta to the latest data version

A Few Additional Questions

- How can we ensure that the temporarily preserved delta will not be reclaimed by garbage collection?
  - Garbage collection in the flash memory storage may reclaim space occupied by invalid data, leading to deletion of the temporarily preserved old data
  - Our solutions:
    - Completely disable garbage collection
    - a phase garbage collection strategy: The garbage collection runs regularly if no ransomware is detected; the garbage collection will be temporarily disable if any ransomware is detected

Le Guan, Shijie Jia, **Bo Chen**, Fengwei Zhang, Bo Luo, Jingqiang Lin, Peng Liu, Xinyu Xing, and Luning Xia. Supporting Transparent Snapshot for Bare-metal Malware Analysis on Mobile Devices. 2017 Annual Computer Security Applications Conference (ACSAC '17), Orlando, Florida, USA, December 2017 (Acceptance rate: 19.7%)

Peiying Wang, Shijie Jia, **Bo Chen**, Luning Xia and Peng Liu. MimosaFTL: Adding Secure and Practical Ransomware Defense Strategy to Flash Translation Layer. The Ninth ACM Conference on Data and Application Security and Privacy (CODASPY '19), Dallas, TX, USA, March 2019 (Acceptance rate: 23.5%)

Acknowledgments

- The presented research has been supported by US National Science Foundation under grant number 1928349-CNS and 1938130-CNS
- Our cybersecurity education has been supported by a few Gencyber grants from NSA and NSF (co-funded)

Q &A