Protecting Suspended Devices from Memory Attacks

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Outline

Introduction

Protection of Linux Systems

Protection of other OSs

Performance and Security

Conclusion

Introduction
Motivation

Problem: Common systems keep main memory in plaintext

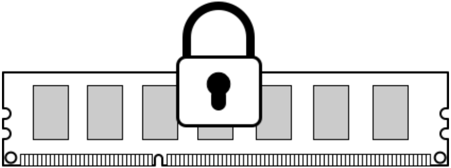
- Makes devices left unattended especially susceptible to memory attacks
- Physical attackers can retrieve main memory via JTAG, DMA, Coldboot

Valuable targets: FDE key and sensitive process memory (passwords, classified information, ...)

Goal: Protect sensitive data on stolen/unattended x86 devices from disclosure

Introduction
Contributions

Idea: Encrypt the RAM possibly containing sensitive data on suspension and decrypt on resumption



Contributions:

- Generic design of a lightweight RAM encryption kernel mechanism
- Prototype for current Linux kernel versions
- Integration into a hypervisor to transparently protect other OSs
- Performance and security evaluation

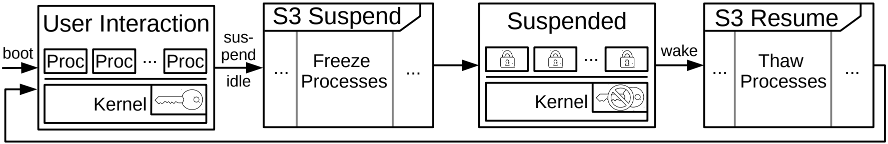
Introduction
Previous Work

- **Hardware based approaches:** XOM, Aegis, processor extensions, ...
  - Hardware extensions typically not available on consumer devices
  - Processor extensions only serve as a building block for memory protection (re-design software)
- **Key hiding:** TRESOR, Copker, ...
  - Move keys to CPU/GPU registers or caches
  - Protect specific assets only
- **Software-based approaches:** Hypercrypt, RamCrypt, Hypnoguard, ...
  - Smaller coverage leaving possibly sensitive segments uncovered
  - Sliding windows with undefined unencrypted memory
  - Adversely affect performance with runtime encryption
  - Some on ARM, some rely on specific (legacy) hardware characteristics

Protection of Linux Systems
Design Goals

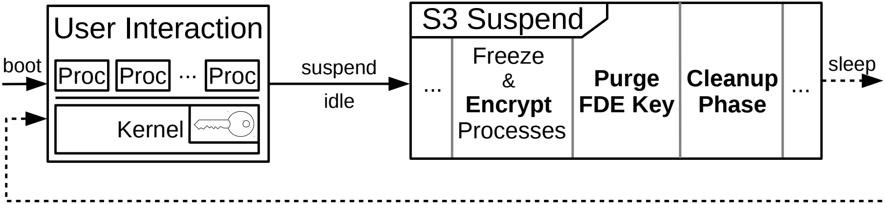
- **Lightweightness:** No configuration, ease of integration
- **Usability:** No implications on workflow, common authentication
- **Hardware Independence:** No dependencies, simple portability
- **Performance:** No lengthy resumption, seamless suspend and wakeup cycles
- **Coverage:** No confidential data left unencrypted

Protection of Linux Systems
Overview and Observations



- **Wake state:** Sensitive data in kernel and userspace while system in use
- **Desired Suspend State:** Encrypted process memory and no sensitive contents in kernel memory
- **Observations:**
  - Common systems use FDE with LUKS for storage protection
  - Processes are frozen on suspend and thawed on wakeup

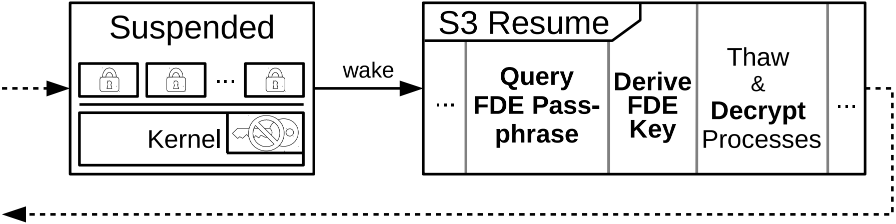
Protection of Linux Systems
Redesign of the Suspension



- Use the FDE key to encrypt confidential data in RAM
- Every freezing task encrypts its memory regions in parallel
- Remove FDE key and other sensitive kernel data

Protection of Linux Systems

Redesign of the Resumption

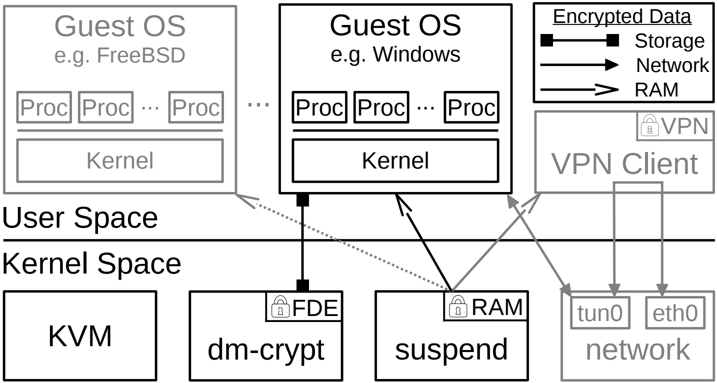


- Query passphrase from user
- Restore FDE key based on LUKS header (key derivation)
- Re-supply key to storage encryption
- Decrypt process memory before thawing processes

Protection of Linux Systems
Implementation

- **En-/decryption:**
  - Shared kernel structures (virtual memory regions) between threads
    $\longrightarrow$ Only last task of a process encrypts (same one decrypts)
  - Shared physical pages between processes
    $\longrightarrow$ Mark pages as encrypted (page flags) and reset flags on decryption
  - Use AES in CTR mode. Physical page addresses provide unique IVs for all blocks
  - Excluded: special segments (memory-mapped IO, DMA memory), shared library code segments
- **Cleanup Phase:** zero FDE key, utilized cipher structures, kernel stack regions, freed pages (list in page allocator)
- **Passphrase Query:** simple query in kernel
  $\longrightarrow$ fully operational kernel to reuse drivers and interact with devices

Protection of other OSs



- Use the mechanism in a hypervisor, which only appears to user on boot and resume
- Protects the full guest OS's memory
- Transparent VPN network traffic routing

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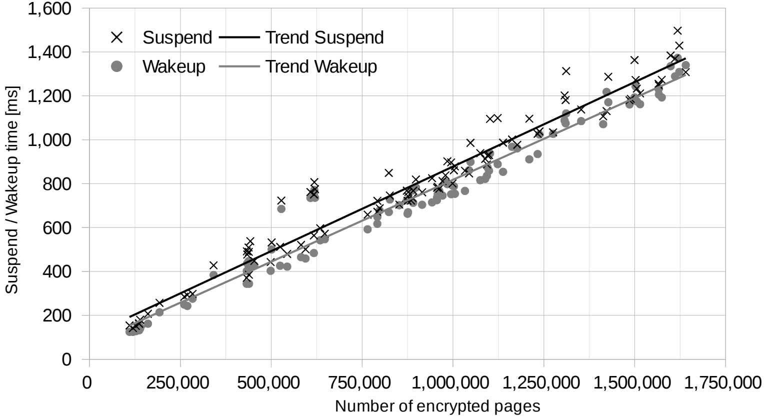
Performance and Security
Performance Measurements



- Measured with AES256-CTR on a dual-core 12GB notebook (2.6 GHz)
- Linear growth, decryption slightly faster

Performance and Security
Performance Measurements

Measurement	Minimum	Maximum	Average
Processes	83	127	**105**
VMAs Encrypted	11,899	28,245	**20,379**
VMAs Total	15,241	35,050	**25,548**
Pages Encrypted	110,148	**1,640,439**	898,384
Suspend Time [ms]	142	**1,497**	807
Wakeup Time [ms]	125	**1,373**	745
Enc. Speed [MB/s]	2,860	5,106	**4,453**
Dec. Speed [MB/s]	3,081	5,387	**4,824**

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Performance and Security
Security

- **Persistent memory:**
  - Requires decryption of LUKS header
  - Can be brute-forced (PBKDF2 derivation)
  - Depends on complexity of FDE passphrase
  - TPM or SE can be easily integrated (e.g., TPM-LUKS)
- **Process memory:**
  - All confidential VMAs encrypted
  - Efforts coincide with the decryption of persistent memory
- **Kernel memory:** removed FDE key, cleaned memory
  → complete cleanup for productive devices required (e.g., IPSec key)
- **Freed memory:** zero'd out

Conclusion

- Devices are protected from memory disclosure once suspended
- Fulfilled design goals:
  - ✓ **Lightweightness:** Comes as an easy to deploy kernel patch
  - ✓ **Usability:** Requires FDE passphrase for authentication only and allows to disable screen lock
  - ✓ **Hardware Independence:** Works straightforward on Linux systems
  - ✓ **Performance:** On a common device, wakeup delay of less than 1.4 seconds
  - ✓ **Completeness:** Encrypts, resp. purges, all sensitive data

Conclusion
Thank you for your attention!

Questions, Answers, Discussion, ...

Conclusion
Comparison with Hypnoguard

Hypnoguard (presented at CCS 2016):

- RAM encryption on suspend/wakeup cycles using a TPM and Intel TXT
- Hook into stages where kernel is inactive
- Encrypts (almost) all RAM in one chunk including kernel memory
- Missing support of the OS and drivers:
  - Complicates portability (displays, keyboards)
  - Makes implementation of hardware-specific drivers and crypto routines necessary

Contact Information

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