TUX : Trust Update on Linux Kernel

Suhho Lee
Mobile OS Lab, Dankook university
suhho1993@gmail.com

--

Hyunik Kim, and Seehwan Yoo
{eternity13, seehwan.yoo}@dankook.ac.kr
Index

• Intro
• Background
• Threat Model
• Goals
• TUX : Trusted Update on Linux Kernel
• Experiments
• Discussion
• Conclusion
Security vulnerabilities are prevalent.

- Tons of CVEs
- Meltdown & Spectre

Lots of security updates!

Less attention was given to the changing integrity after the updates are conducted.
Intro

Maintain Integrity

Verifying the system by checking whether there are any malicious modification.

VS

Security Update

countermeasure vulnerabilities by modifying the system.
Can modern solutions distinguish between updates and malicious modifications?

Is the integrity being managed according to the updates?
Intel’s Measured / Verified boot technology

tboot

- Grub bootloader module
- Measure and verify integrity using DRTM

Launch control policy (LCP)

- Known good integrity values for certain booting stages
- Used to verify the integrity of the booting
- Also needs to be updated when the system is updated

Does not measure/verify Grub environment (e.g., Grub commands)
Intel’s remote attestation solution
Validate TPM measurements from the remote server

Known-good values
• Stored in the Open CIT server
• Imported from the local systems

Local updates are not transparent
• Open CIT cannot monitor updates conducted from the local systems
• If local system is updated, remote attestation fails
**UEFI secure boot**

**UEFI BIOS’s Verified boot component**
- Verify integrity using the key stored in the firmware DB
- Booting components must be digitally signed

**Updating is easy for Secure boot**
- Sign updated binary and deploy
- Receive update and install

**Not suitable for Linux environment**
- Does not approve Grub bootloader
- Cannot verify Grub commands

**No TPM measurements**
Subverting Open CIT

- Occurs because the local updates are not transparent to the Open CIT
- Assumption: Attacker can update OS and perform measured boot
Circumventing verified boot

- Rootkit
  - Breaking Hardware-Enforced Security with Hypervisors (Black hat USA 2016)
- Attacker can modify Grub commands even though the Secure boot is on
- TXT and Secureboot lack of Grub command verification
Goals!

To maintain integrity properly...

1. Remote attestation must manage local updates transparently.
2. Maintain whitelist according to conducted updates and perform remote attestation using the up-to-date whitelist.
3. Perform thorough measured / verified booting including Grub.
TUX!

TUX Code can be found at…
https://github.com/suhho1993/TUX.git
Provide TEE for integrity measurement
Tamper-proof device
Practically used in measured boot
Platform Configuration Registers (PCRs)
  - TPM measures integrity using extend operation.
    - $PCR_{new} = Hash(PCR_{old} \oplus Hash(Data))$
    - Form Chain-of-Trust to verify the system configuration
    - Measure entire booting process with extend operation
Shim and Grub

Shim

• 1stage bootloader to support UEFI secure boot
• Can be verified by the UEFI secure boot
  • Signed with MS’s firmware key
• Shim verifies and execute Grub
• Verification using firmware keys
  • Shim_lock verification

Grub

• CoreOS and other GRUBs support measured boot using TPM v2.0
Assumptions

TUX server is the maintainer/administrator of the updates.

TUX only verifies integrity of the Linux Booting process.

TUX server is trusted and safe.

TUX owner holds manifest of specific booting process of each managed machine.

All managed machines hold TUX owner’s public key.
TUX Architecture

TUX server (Attestation server)

Integrity manager

Whitelist Updater

Measurement Configuration

PCR-signed kernel generator

Private key

New Whitelist

Valid binaries (Kernel, Grub, Shim, etc.)

Open CIT DB

Trusted Repository

PCR-signed kernel

TS-Boot

Managed Machine1

Unverified, halt

Verified, boot

Managed Machine2

Verified, boot

Managed Machine3

PCR-signed kernel

TS-Boot

PCR-signed kernel

TS-Boot

PCR-signed kernel

TS-Boot
Integrity Manager

Integrity management / kernel update component
• Located at the Open CIT server
• Consists of Trusted repository, Whitelist updater, PCR-signed Kernel generator

Trusted repository
• Update repository
• Stores kernel binaries and manifests for the update
• Provide binaries to generate new whitelist.

Whitelist updater
• Calculate new integrity value and update the whitelist
• Calculate t-PCR

PCR-signed kernel generator
• Generate PCR-signed kernel
Kernel update using TUX

1) Update notify
2) Update request
3) Calculate and Update new whitelist value
4) Generate PCR-signed Kernel
5) Deploy kernel
6) Install
7) Remote Attestation
Remote attestation with TUX

With Integrity Manager, TUX...

- Manage local updates transparently (Goal 1)
- Prevent remote attestation failure after updates
- Perform remote attestation with updated whitelist (Goal 2)
t-PCR
  • Calculated known-good value by extending entire booting process

PCR-signed Kernel
  • Use t-PCR value to sign the kernel binary instead of digested hash
  • Signed with TUX owner’s private key
  • Used to verify integrity during the booting
Trusted Secure boot (TS-Boot)

Combination of UEFI secure boot, Shim, and CoreOS Grub

- Perform robust measured/verified boot

Linux friendly

Binary verification using the firmware key

- Shim_lock verification

Thorough measurement / verification of the booting process

- Including Grub commands and modules
- PCR-verification
PCR-Verification

- Verifies the integrity of the entire booting process on runtime
- Extend measurement of every booting process using the PCR12
- Execute kernel using linuxefi function
  - Pass the kernel to Shim using shim_lock_verification
- Compare PCR12 with t-PCR stored in the kernel signature
- Any changes can be detected
Trusted Secure Boot (TS-Boot)

With TS-Boot, TUX...

Measure / verify the integrity of the entire booting process including Grub command and modules (Goal 3)
### Experiment

- **TPM measurement**

<table>
<thead>
<tr>
<th>Bank/Algorithm: TPM ALG SHA256(0x000b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCR_00: 05 48 02 7e c</td>
</tr>
<tr>
<td>PCR_01: f1 67 99 3b a</td>
</tr>
<tr>
<td>PCR_02: 3d 45 8c fe 5</td>
</tr>
<tr>
<td>PCR_03: 3d 45 8c fe</td>
</tr>
<tr>
<td>PCR_04: f5 f3 f8 1f 6b 5</td>
</tr>
<tr>
<td>PCR_05: de 89 35 69 c PCR_05: de 89 35 69 c</td>
</tr>
<tr>
<td>PCR_06: 3d 45 8c fe 5 PCR_06: 3d 45 8c fe 5</td>
</tr>
<tr>
<td>PCR_07: 25 c0 b3 ce 4 PCR_07: 25 c0 b3 ce 4</td>
</tr>
<tr>
<td>PCR_08: 63 81 11 5c d PCR_08: f4 1e 86 df</td>
</tr>
<tr>
<td>PCR_09: e2 fa 1b a3 f PCR_09: e2 fa 1b a3 f</td>
</tr>
<tr>
<td>PCR_10: 0b 74 50 53 8 PCR_10: 0b 74 50 53 8</td>
</tr>
<tr>
<td>PCR_11: 53 45 a7 13 8 PCR_11: 79 bd 24 78 8</td>
</tr>
<tr>
<td>PCR_12: 92 5a 80 6e c PCR_12: 31 68 59 c3 e</td>
</tr>
</tbody>
</table>

**Note:** The table contains TPM measurement data for different scenarios, indicating the specific values for each scenario.
## TPM measurements

<table>
<thead>
<tr>
<th>PCR #</th>
<th>Content</th>
<th>Measurement Host</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCR 0-7</td>
<td>BIOS and hardware configurations.</td>
<td>UEFI secure boot</td>
</tr>
<tr>
<td>PCR 8</td>
<td>Executed Grub commands.</td>
<td>Trusted Grub</td>
</tr>
<tr>
<td>PCR 9</td>
<td>Executed Modules from Trusted Grub.</td>
<td>Trusted Grub</td>
</tr>
<tr>
<td>PCR 10</td>
<td>Trusted Grub binary.</td>
<td>Shim</td>
</tr>
<tr>
<td>PCR 11</td>
<td>Kernel and initrd</td>
<td>Shim</td>
</tr>
</tbody>
</table>
Experiment

- PCR-verification
Experiment

- whitelist update
Registered in Open CIT with Kernel version vmlinux-4.4.0-62
Discussion

Roll-back and multiple kernel support

- Roll-back attack can be detected!

TUX owner’s Key is Safe

- Open CIT server is safe / Firmware is safe

TUX may be applicable to environment other than desktop or server

SRTM or DRTM?
Conclusion

Integrity changes when update is conducted, and thus, it should be properly managed along with updates.

TUX...

- Extends Open CIT to transparently manage local updates
- Remote attestation with up-to-date whitelist
- Thorough integrity measurement, including Grub commands and modules
- Robust integrity verification with PCR-verification
Thank you.

Any Questions?