

Authenticated and Encrypted Storage on Embedded Linux

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Linux Storage Stack

userspace processes

filesystems & VFS

device mapper

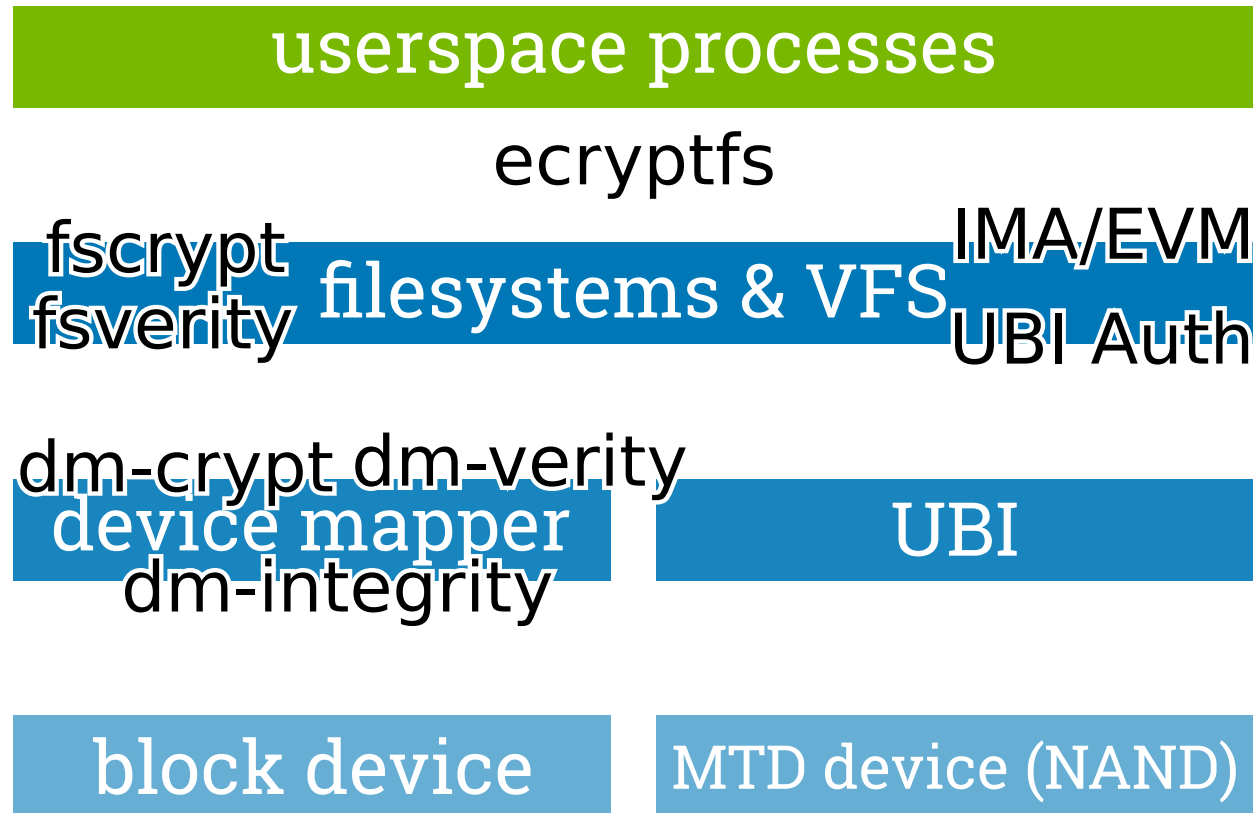
UBI

block device

MTD device (NAND)



Transparent Authentication and Encryption



Crypto?



<https://www.instructables.com/id/Laser-Cut-Cryptex/>

Quick Crypto Refresher

Hash: one-way function, fixed output size (SHA*)

HMAC: data authentication using hash and shared secret

Signature: data authentication using public key cryptography (keys & certificates, RSA & ECDSA)

Unauthenticated encryption: attacker can't read private data, but could modify it (AES-CBC, AES-XTS, ...)

Authenticated encryption: attacker can't read private data and modification is detected (AEAD: AES GCM, AEGIS)



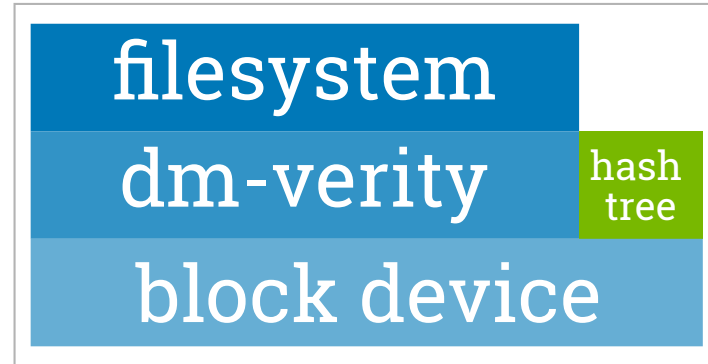
Overview

- Building Blocks
 - authentication
 - encryption
 - authenticated encryption
- General Considerations

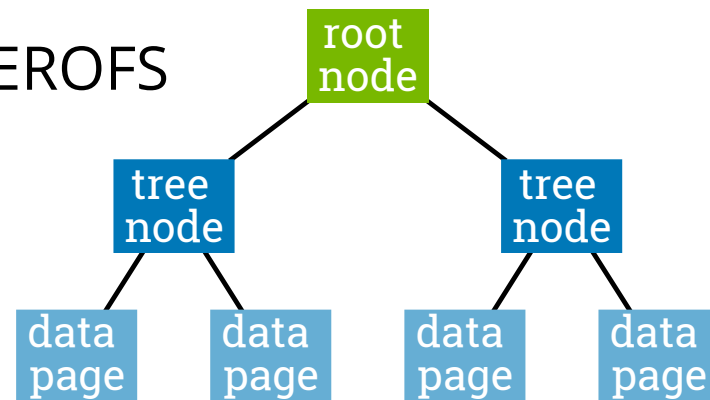


dm-verity (since 2012, v3.4)

- authentication via hash tree: **read-only**
- used by Chrome OS & Android for rootfs
- root hash provided out-of-band (kernel cmdline) or via signature in super block (since v5.4)
- can be created and configured via veritysetup (LUKS2)
- combine with ext4, SquashFS or EROFS



⇒ best choice for RO data



dm-integrity (since 2017, v4.12)

- emulates integrity data on normal block devices
- one meta-data block per n data blocks, interleaved
- performance overhead (data written twice due to journaling)
- can provide simple check-sums without encryption (CRC32/SHA256/-HMAC)
- usually configured via integritysetup (LUKS2)



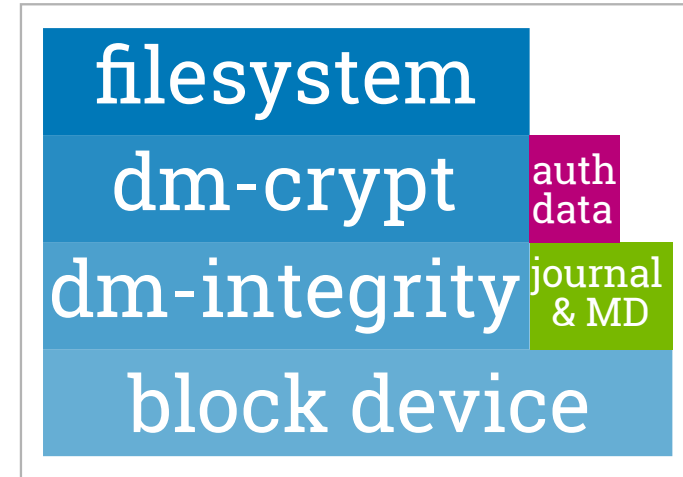
dm-crypt

- sector-based encryption of block devices
 - supports multiple algorithms and modes
 - usually configured using cryptsetup (LUKS2)
 - experimental online reencryption
 - does **not** authenticate, because that would need additional space (uses “length-preserving encryption”)
- ⇒ best choice on RW block devices (if auth is not critical)



dm-crypt with authentication

- needs dm-integrity or block device with T10/DIF
- can also use a random initialization vector (IV)
- uses AEAD cipher modes:
 - AES256-GCM-random, AEAD (12B IV, 16B auth tag)
 - **AEGIS128-random**, AEAD (16B IV, 16B auth tag)
 - ChaCha20-random, integrity Poly1305 (16B IV, 32B auth tag)
- only authenticates individual sectors, replay is possible



⇒ best choice on RW block devices for authenticated encryption



fsverity (since 2019, v5.4)

- “dm-verity for files”: efficient authentication of (large) read-only files via a hash tree
- root hash provided out-of-band
- integrated into ext4
- could be integrated with IMA/EVM to improve performance

⇒ Android will likely be the main user (for .apk authentication)



fsencrypt

- initially ext4-only (2015), then F2FS, generalized in (2016, v4.6), UBIFS support (2017, v4.10)
- file-based encryption, supports different keys for multiple users
- files can be removed without key
- no authentication

⇒ alternative to dm-crypt for multi-user systems (like Android)



UBIFS Authentication (since 2018, v4.20)

- UBIFS is copy-on-write (because flash): a “wandering tree”
- Hashes added to tree nodes
- root hash (in superblock) authenticated via HMAC or signature for image deployment (since v5.3)
- is the only FS which authenticates full data and metadata

⇒ best choice for raw NAND/MTD devices



ecryptfs (since 2006, v2.6.19)

- stacked file system (problems)
- default home directory encryption method for Ubuntu beginning with 9.04, now deprecated, maintenance unclear
- no authentication, GCM patches posted, but not merged
- encrypts data and filenames

⇒ superseded by fscrypt



IMA/EVM (since 2009/2011, v2.6.30/v3.2)

- initially developed for usage with TPMs, Verified Boot and Remote Attestation
- uses extended attributes
- EVM appraisal can protect locally against offline file data modification, but currently not against directory modification (`cp /bin/sh /sbin/init`)

⇒ IMA for remote attestation, EVM is problematic for local auth.

See Luke Hinds' talk on the Keylime remote attestation tool (on monday): <https://sched.co/TLCY>



Master Key Storage

How can we protect the key that protects the data?

- embedded: no user to enter a password
- Many SoCs have HW that can “wrap” (encrypt) keys with a fixed per-device key (only useful with secure boot)
- Other options: OP-TEE or TPM

See Gilad Ben Yossef's talk on hardware protected keys (earlier today): <https://sched.co/TLJE>



Recovery: Split RO and RW?

Authenticated, writable storage can only detect offline attacks!

- no difference between intentional and malicious modification (possibly caused by root-level intrusion)

⇒ signed root file system allows recovery via reboot

⇒ read-only recovery system allows factory reset



Field Return Mode

How can we analyze problems on returned hardware?

⇒ implement authenticated method to:

- erase keys for private data
- disable verified boot / authentication



Recommendations

- dm-crypt (maybe with dm-integrity) for RW block device
- dm-verity for RO data
- UBIFS authentication for NAND
- verified boot and key wrapping for master key protection
- HW acceleration for ciphers

⇒ avoid complexity, select only the necessary components



Thanks!

Questions?



Further Reading

dm-verity: <https://gitlab.com/cryptsetup/cryptsetup/wikis/DMVerity>

dm-integrity: <https://gitlab.com/cryptsetup/cryptsetup/wikis/DmIntegrity>

dm-crypt on dm-integrity: <https://arxiv.org/abs/1807.00309>

fscrypt: <https://www.kernel.org/doc/html/latest/filesystems/fscrypt.html>

fsverity: <https://www.kernel.org/doc/html/latest/filesystems/fsverity.html>

ubifs auth: <https://www.kernel.org/doc/html/latest/filesystems/ubifs-authentication.html>

