Android Platform Security

ACN / Mobile Security 2020

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Outline

- Low-level System Security
  - Verified Boot & dm-verity
- Encryption System
  - Full Disk Encryption
  - File-based Encryption
- Android OS Security
  - Architecture & Sandbox
  - SELinux

275 million Android phones imperiled by new code-execution exploit

Unpatched "Stagefright" vulnerability gives attackers a road map to hijack phones.

DAN GOODIN - 3/18/2016, 9:26 PM

Primary
Hanan Beer
Check out these cute kittens!
Gmail Team
Stay more organized
Gmail Team
The best of Gmail, wherever
Drive-by email attack, go kittens!

Source: https://goo.gl/9fgYSc

What?

Bugs in Android's `libstagefright` and `libutils`

How?

- Attacker embeds shellcode in harmless multimedia file
- Message is downloaded (e.g. via MMS)
- Exploit is executed

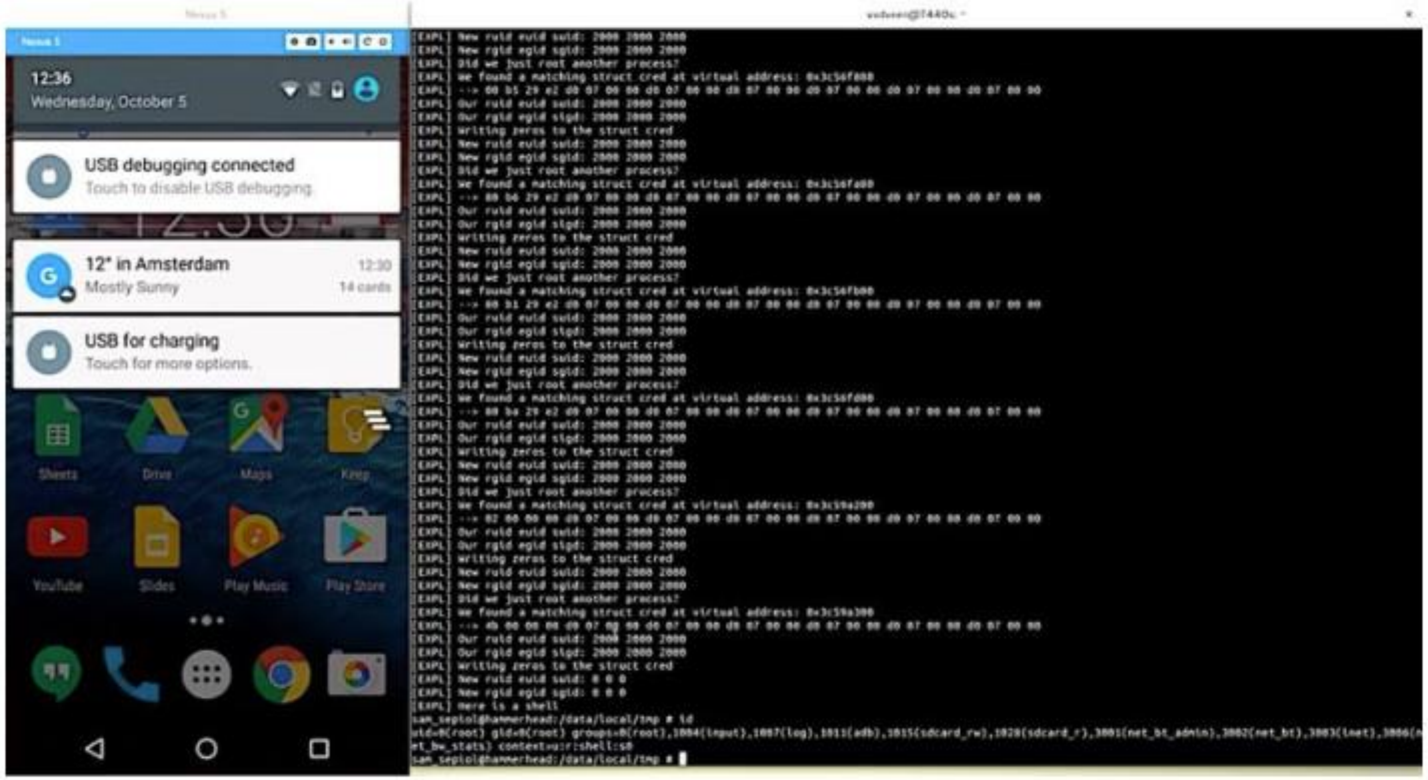
Result

- Attacker can execute any code on remote device

Using Rowhammer bitflips to root Android phones is now a thing

Permission-less apps take only seconds to root phones from LG, Samsung and Motorola.

DAN GOODIN - 10/24/2016, 1:03 AM



```
[EXPL] New ruid euid suid: 2000 2000 2000
[EXPL] New rgid egid sgid: 2000 2000 2000
[EXPL] Did we just root another process?
[EXPL] We found a matching struct cred at virtual address: 0x3c56f800
[EXPL] --> 00 b5 29 e2 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00
[EXPL] Our ruid euid suid: 2000 2000 2000
[EXPL] Our rgid egid sigd: 2000 2000 2000
[EXPL] Writing zeros to the struct cred
[EXPL] New ruid euid suid: 2000 2000 2000
[EXPL] New rgid egid sgid: 2000 2000 2000
[EXPL] Did we just root another process?
[EXPL] We found a matching struct cred at virtual address: 0x3c56fa00
[EXPL] --> 00 b6 29 e2 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00
[EXPL] Our ruid euid suid: 2000 2000 2000
[EXPL] Our rgid egid sigd: 2000 2000 2000
[EXPL] Writing zeros to the struct cred
[EXPL] New ruid euid suid: 2000 2000 2000
[EXPL] New rgid egid sgid: 2000 2000 2000
[EXPL] Did we just root another process?
[EXPL] We found a matching struct cred at virtual address: 0x3c56fb00
[EXPL] --> 00 b1 29 e2 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00
[EXPL] Our ruid euid suid: 2000 2000 2000
[EXPL] Our rgid egid sigd: 2000 2000 2000
[EXPL] Writing zeros to the struct cred
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[EXPL] New rgid egid sgid: 2000 2000 2000
[EXPL] Did we just root another process?
[EXPL] We found a matching struct cred at virtual address: 0x3c56fd00
[EXPL] --> 00 ba 29 e2 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00
[EXPL] Our ruid euid suid: 2000 2000 2000
[EXPL] Our rgid egid sigd: 2000 2000 2000
[EXPL] Writing zeros to the struct cred
[EXPL] New ruid euid suid: 2000 2000 2000
[EXPL] New rgid egid sgid: 2000 2000 2000
[EXPL] Did we just root another process?
[EXPL] We found a matching struct cred at virtual address: 0x3c59a200
[EXPL] --> 02 00 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00
[EXPL] Our ruid euid suid: 2000 2000 2000
[EXPL] Our rgid egid sigd: 2000 2000 2000
[EXPL] Writing zeros to the struct cred
[EXPL] New ruid euid suid: 2000 2000 2000
[EXPL] New rgid egid sgid: 2000 2000 2000
[EXPL] Did we just root another process?
[EXPL] We found a matching struct cred at virtual address: 0x3c59a300
[EXPL] --> 4b 00 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00 d0 07 00 00
[EXPL] Our ruid euid suid: 2000 2000 2000
[EXPL] Our rgid egid sigd: 2000 2000 2000
[EXPL] Writing zeros to the struct cred
[EXPL] New ruid euid suid: 0 0 0
[EXPL] New rgid egid sgid: 0 0 0
[EXPL] Here is a shell
sam_sepiol@hammerhead:/data/local/tmp # id
uid=0(root) gid=0(root) groups=0(root),1004(input),1007(log),1011(adb),1015(sdcard_rw),1028(sdcard_r),3001(net_bt_admin),3002(net_bt),3003(inet),3006(n
et_bw_stats) context=u:r:shell:s0
sam_sepiol@hammerhead:/data/local/tmp # 
```

Enlarge / An LG Nexus 5 at the moment it is rooted using Rowhammer-induced bit flips.

Source: https://goo.gl/82N8Wq

Based on Rowhammer

Wait for bit flips while massively reading adjacent memory regions

On Android?

- Vulnerability in ARM chips
- Combined with other non-patched issue → „Drammer“

Result

- Privilege Escalation Exploit
  - Requires no permissions
- Hard to fix…

IAIK TU Graz

Serious flaw in WPA2 protocol lets attackers intercept passwords and much more

KRACK attack is especially bad news for Android and Linux users.

DAN GOODIN - 10/16/2017, 6:37 AM

Source: https://goo.gl/5Ea555

What?

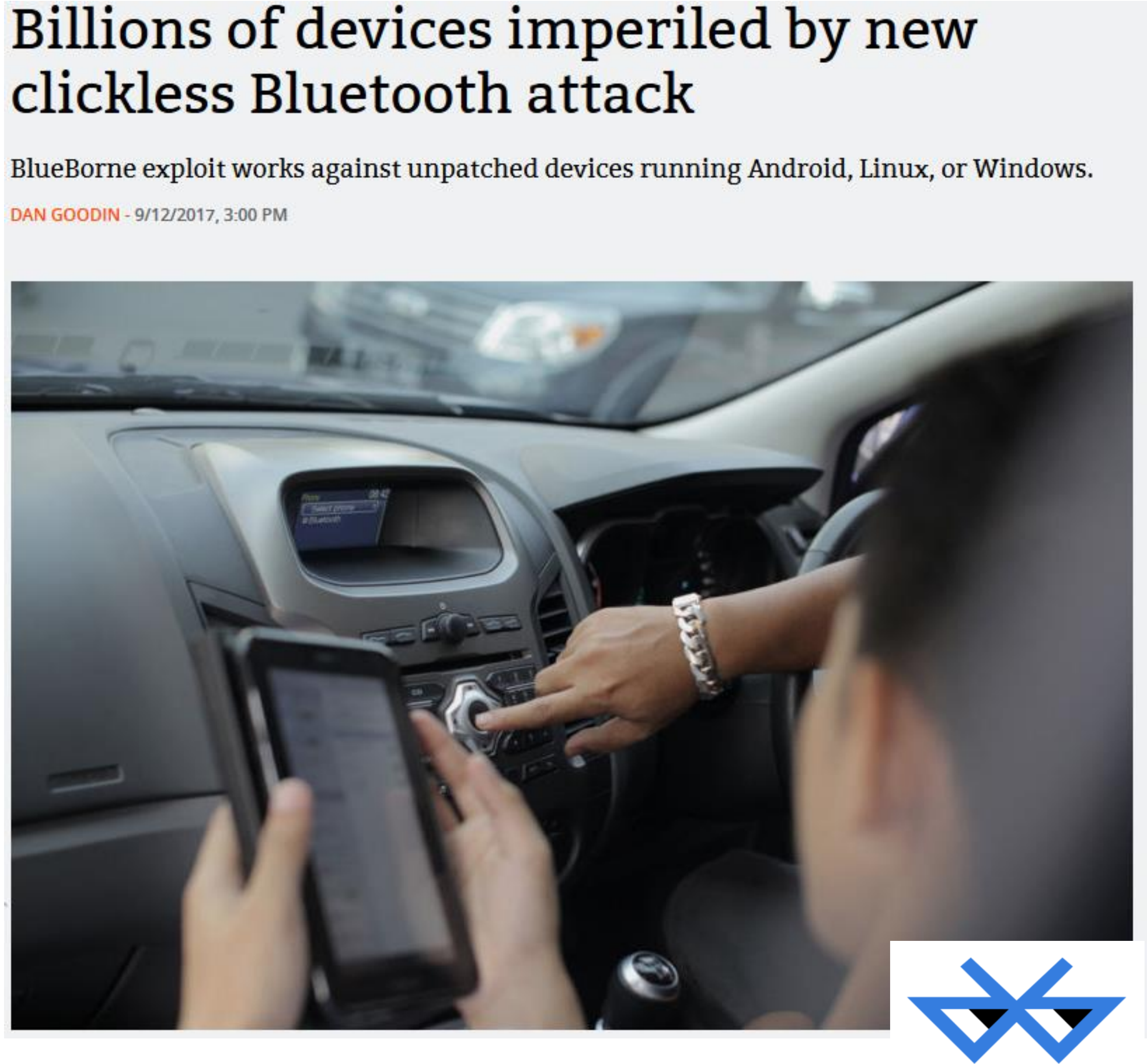
Android can be tricked into using an <u>all-zero encryption key</u> for WPA/WPA2 WiFi communication

How?

- Attacker resends message of 4-way handshake to device
- Real encryption key is replaced with zero key

Result

- Attacker can intercept and manipulate traffic from device



Billions of devices imperiled by new clickless Bluetooth attack

BlueBorne exploit works against unpatched devices running Android, Linux, or Windows.

DAN GOODIN - 9/12/2017, 3:00 PM

Source: https://goo.gl/sDiTuu

BlueBorne

What?

Implementation flaws in common Bluetooth stacks enable remote code execution

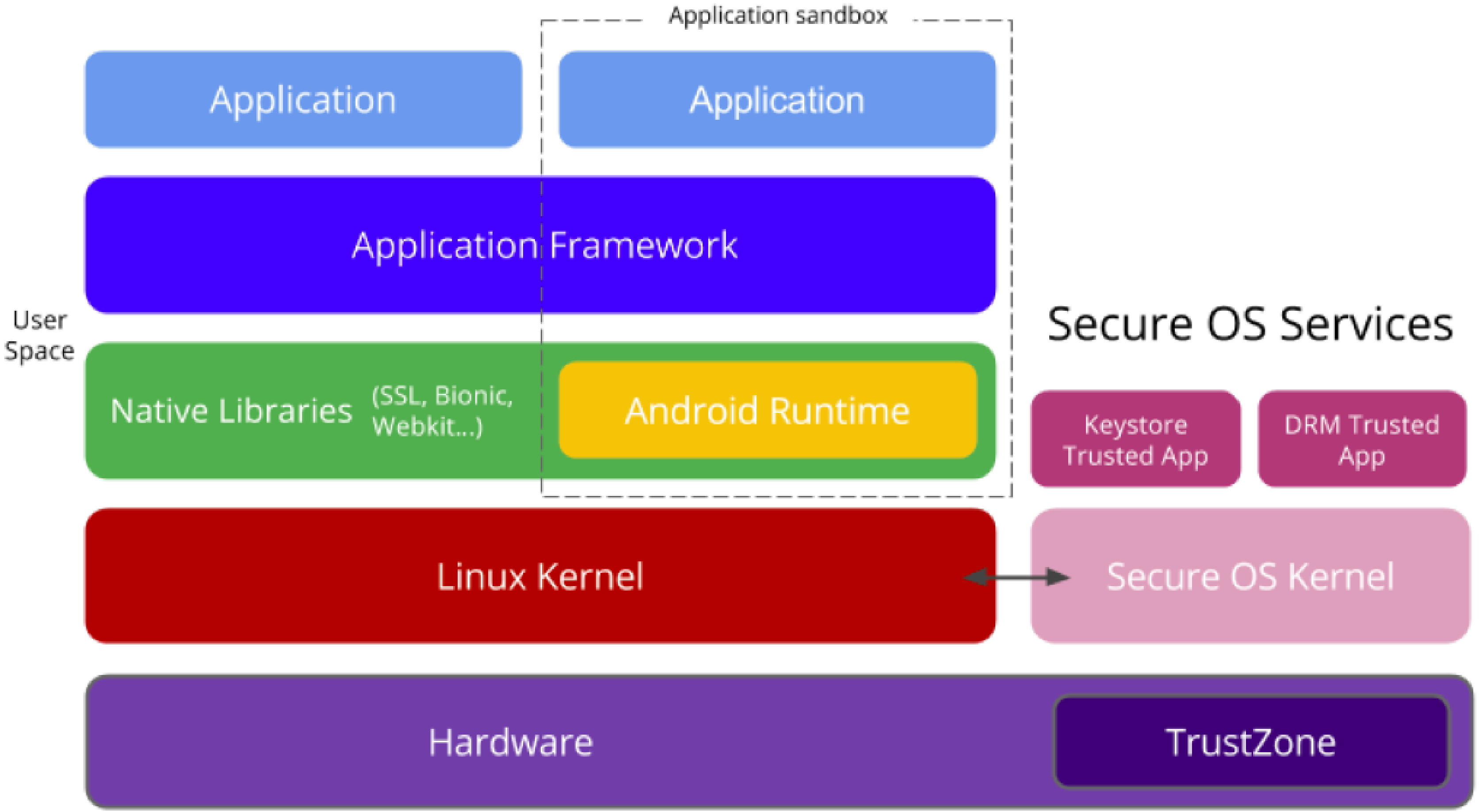
On Android?

- Device constantly scans for other devices nearby
- Bluetooth implementation runs with privileged permissions and is exploitable (heap overflows)

Result

- Remote code execution on phone without user noticing

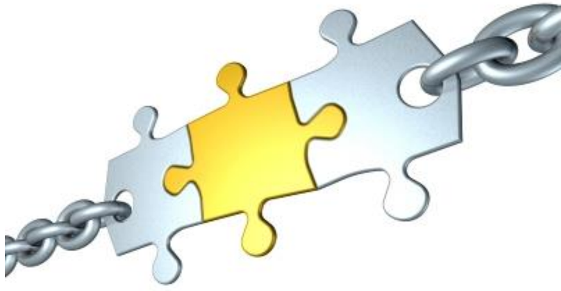
Android Security Architecture



Source: https://goo.gl/xp74UR

Low-Level System Security

Verified Boot



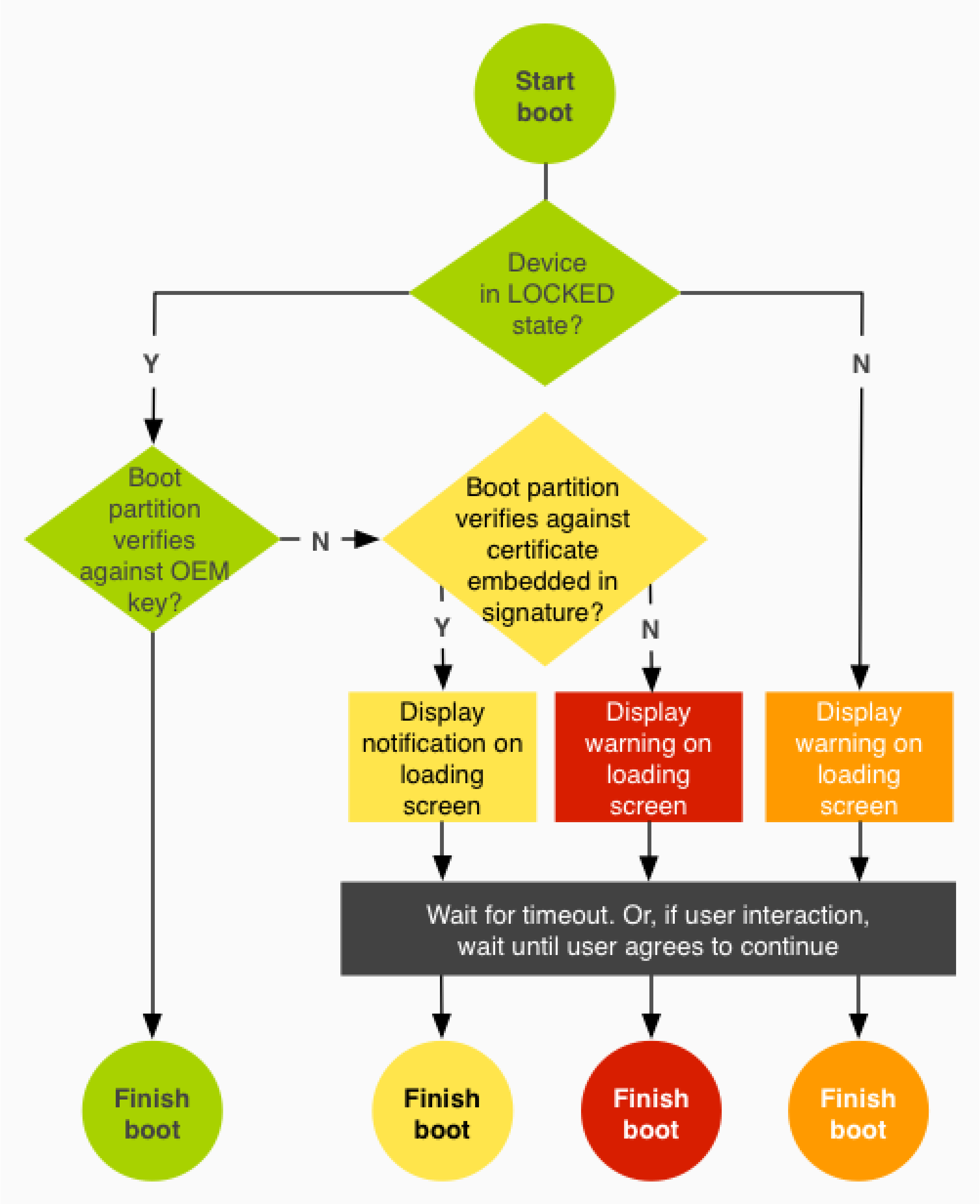
- „Chain of Trust“
  Established between bootloader and system image

- Transparent real-time integrity checking of block devices
  → Prevent persistent rootkits

- Based on Device Mapper verity (`dm-verity`) feature of Linux Kernel
  → Protection only effective if kernel can be trusted

Typical for OEMs:
Unmodifiable keys *burned* into device to verify boot partition‘s signature

Verified Boot – Workflow


Start boot
Device in LOCKED state?
Y
N
Boot partition verifies against OEM key?
N
Boot partition verifies against certificate embedded in signature?
Y
N
Display notification on loading screen
Display warning on loading screen
Display warning on loading screen
Wait for timeout. Or, if user interaction, wait until user agrees to continue
Finish boot
Finish boot
Finish boot
Finish boot

Boot chain (simplified)

- Verify bootloader using Chain of Trust
- Bootloader verifies boot / `recovery` partition
- Kernel verifies `system` partition

Device / bootloader state

- `LOCKED/UNLOCKED`
- Allows custom (non-OEM) keys

Boot state

- `GREEN/YELLOW/ORANGE/RED`
- Does not stop boot, only warning

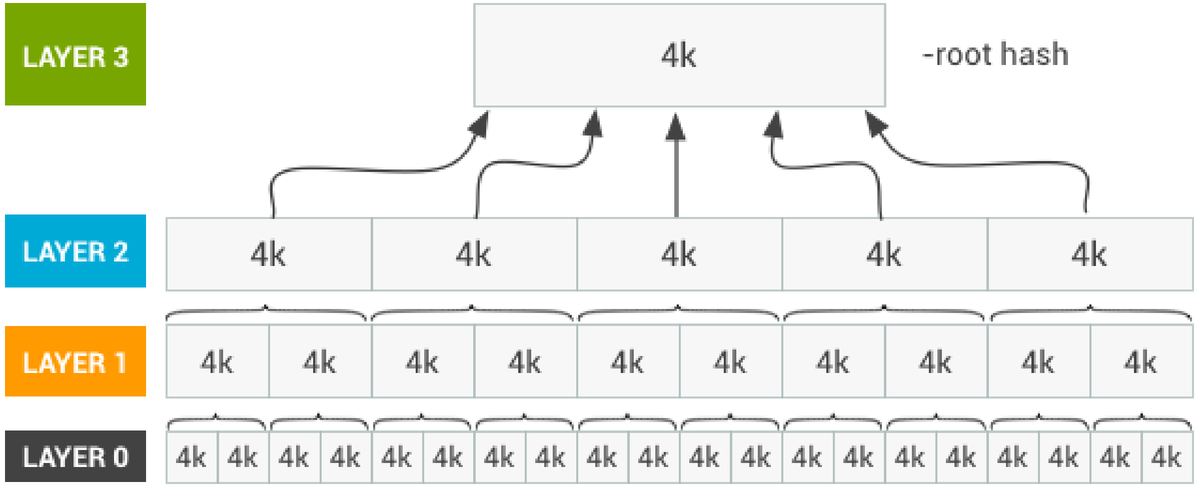
dm-verity – Insight

Idea: Look at block device and storage layer of file system using a hash tree

- Hash values stored in tree of pages
  - Only „root hash“ must be trusted to verify rest of tree

- Modification of any 4k-block would change the „root hash“

- Verify signature of „root hash“ using public key included on boot partition → Confirm that device‘s system partition is unchanged


LAYER 3
4k
-root hash
LAYER 2
4k 4k 4k 4k 4k
LAYER 1
4k 4k 4k 4k 4k 4k 4k 4k 4k 4k
LAYER 0
4k 4k 4k 4k 4k 4k 4k 4k 4k 4k 4k 4k 4k 4k 4k 4k 4k 4k 4k 4k

dm-verity

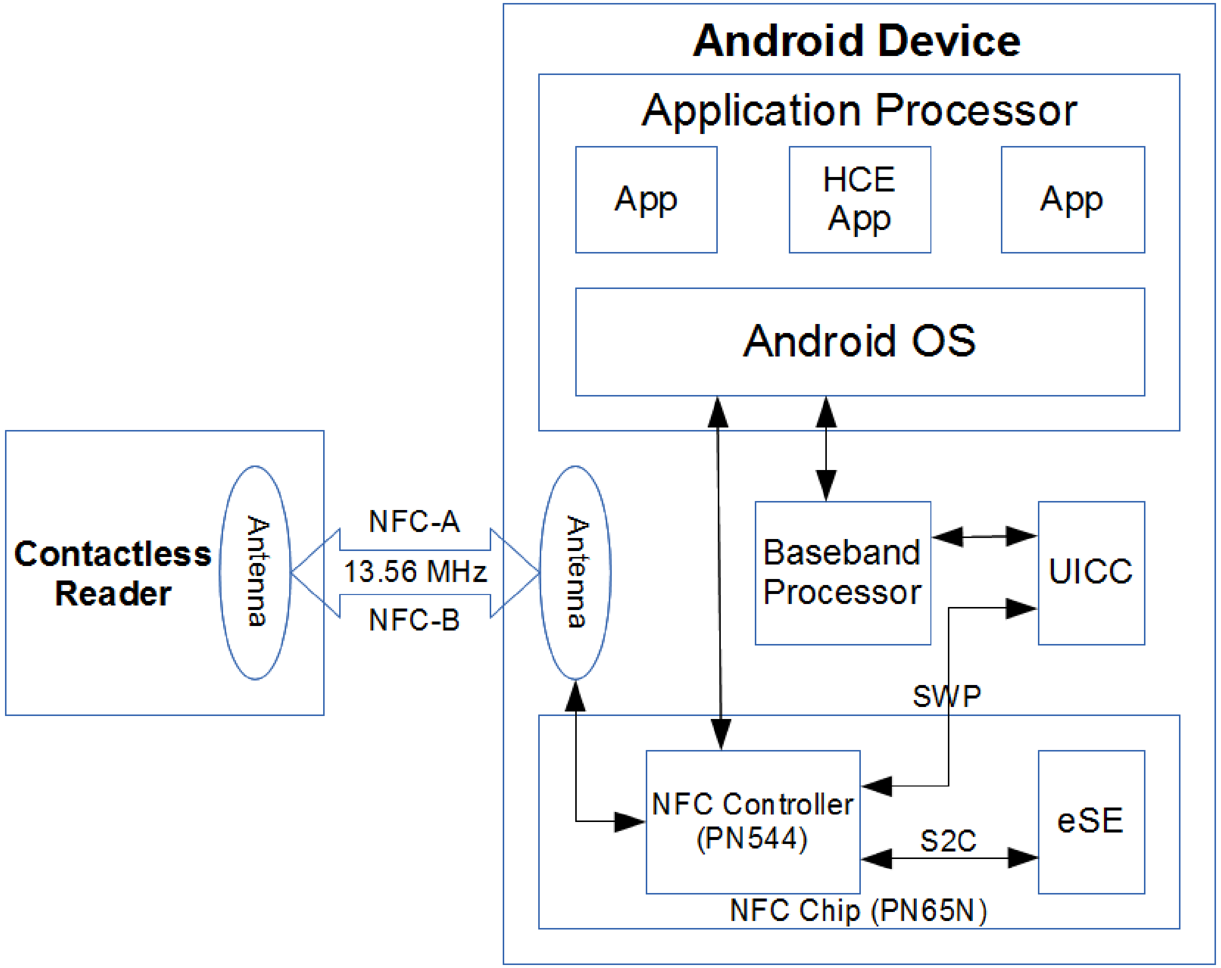
Limitations

- Only applicable to *read-only* partitions
  - *Read-write* partitions would update metadata when files are read
  - Any change in FS breaks the tree
→ but useful for /system partition (or where *read-only* is no drawback)
- Need block-based OTA updates
  - Need to ensure that all devices have same /system partition

Status on Android 10 („Q“)

- Default is *enforcing* mode, fallback to *logging* mode if metadata unverifiable
- State saved in dedicated metadata partition

Device Interfaces



Near Field Communication (NFC)

- Read/write mode (RW)
- Peer-to-peer mode (P2P)
- Card emulation mode (CE)

Secure Elements

- SIM card (UICC)
- microSD card (ASSD)
- Embedded SE (eSE)

APIs

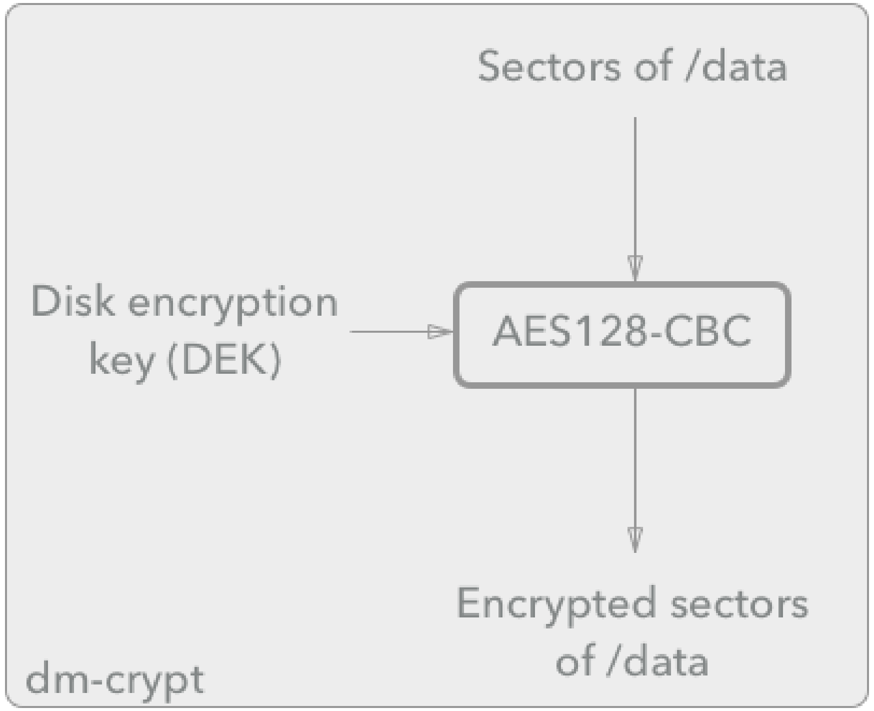
- Telephony APIs (restricted)
- Android HCE (`HostApduService`)
- OpenMobile API (SEEK)

Encryption System

Overview

Starting with Android 3.0…

- 4.4: Replaced PBKDF2 with scrypt
- 5.0: Hardware-backed key storage
- 7.0: Introduced file-based encryption



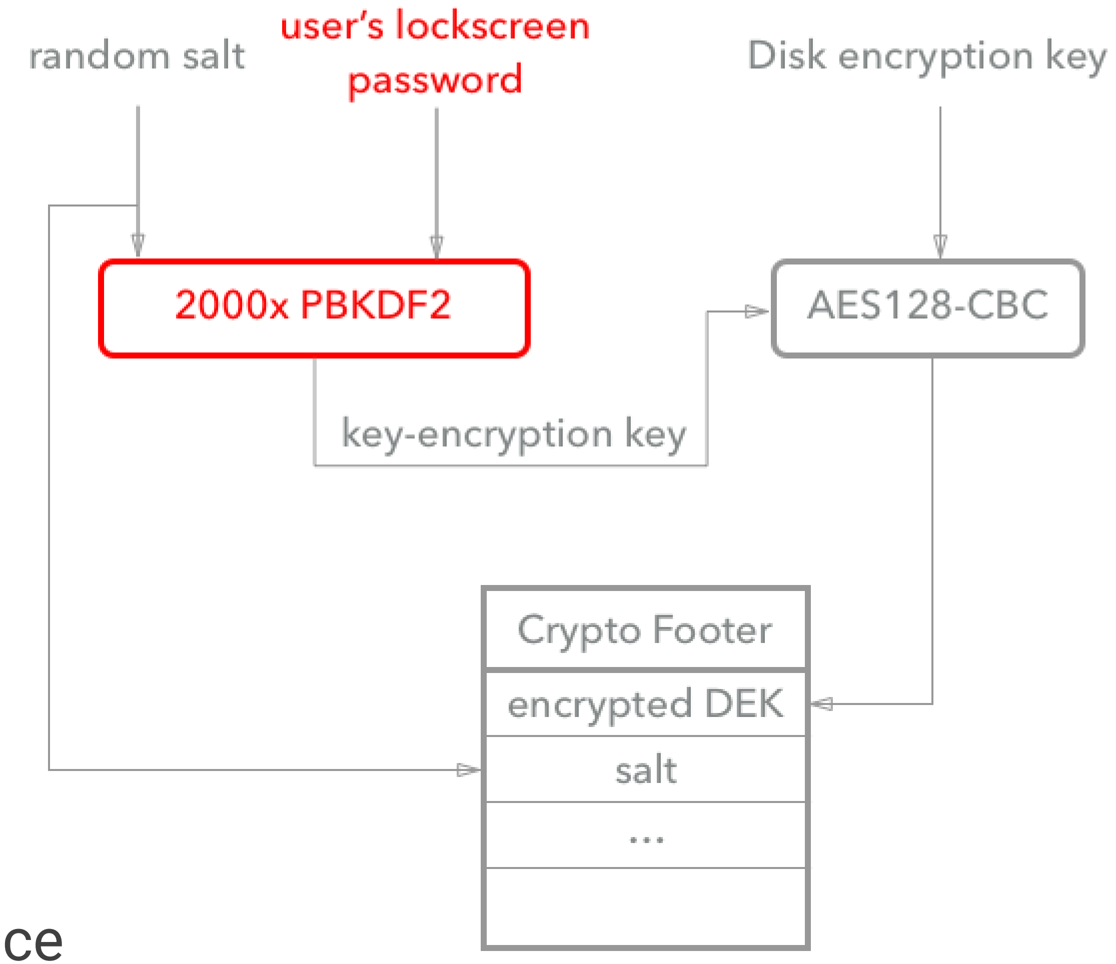
Full Disk Encryption

- Uses dm-crypt
- Operates on block-level
- Random-generated 128-bit disk encryption key (DEK)
  - < 5.0: Key file protected only by lock screen password
  - Now: Key file stored in Secure Element

FDE in Android 3.0

PBKDF2 with 2000 iterations

- < 16 chars lockscreen password
- Random salt
- Derivation based on SHA-1
  - Needs only little memory
  - Attack parallelizable :-)



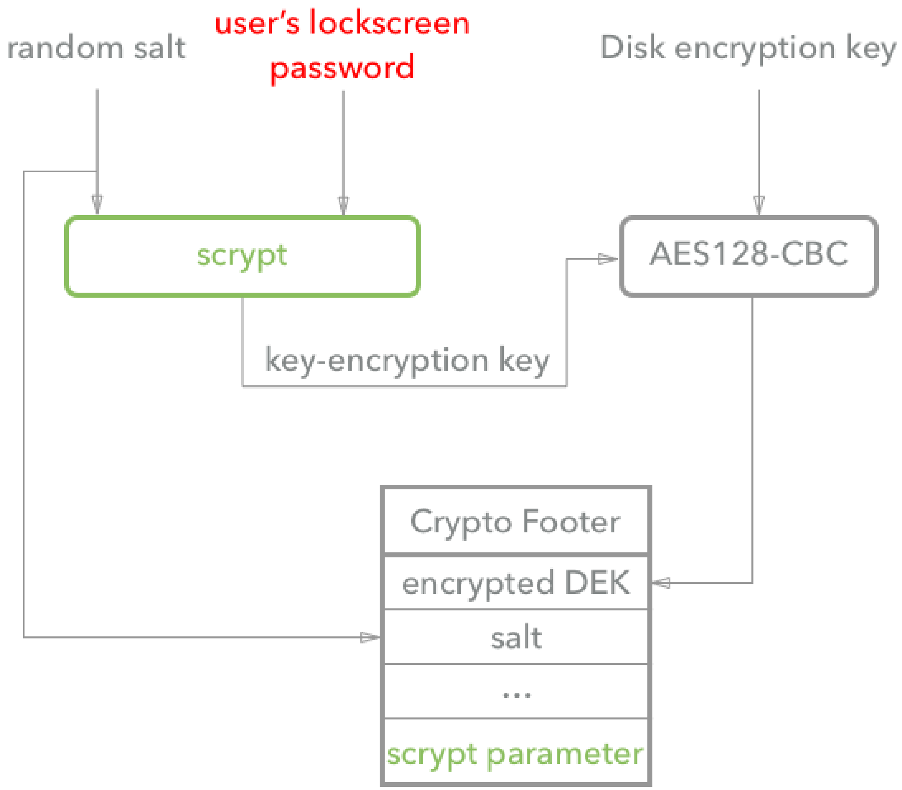
Brute-Force Attack

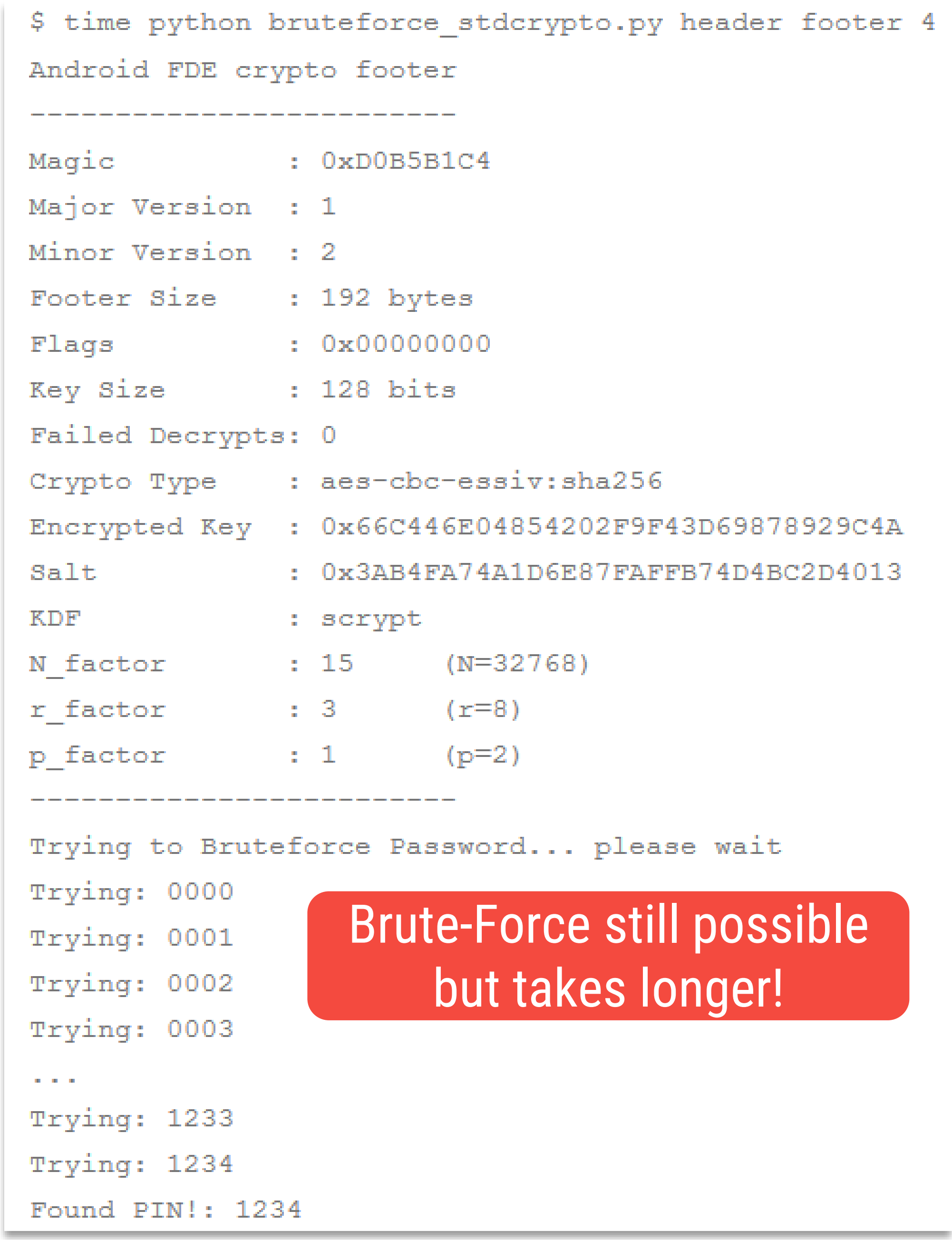
- Copy encrypted /data & crypto footer off device
  - Crypto footer found with „encryptable“ flag in /etc/fstab
- Bruteforce via GPU, validate key by decrypting → 6-digit PIN needs only seconds!

FDE in Android 4.4

Scrypt KDF instead of PBKDF2

- Salsa20-like hash function instead of SHA-1
- Prevent parallelizable large-scale attacks using „work factors



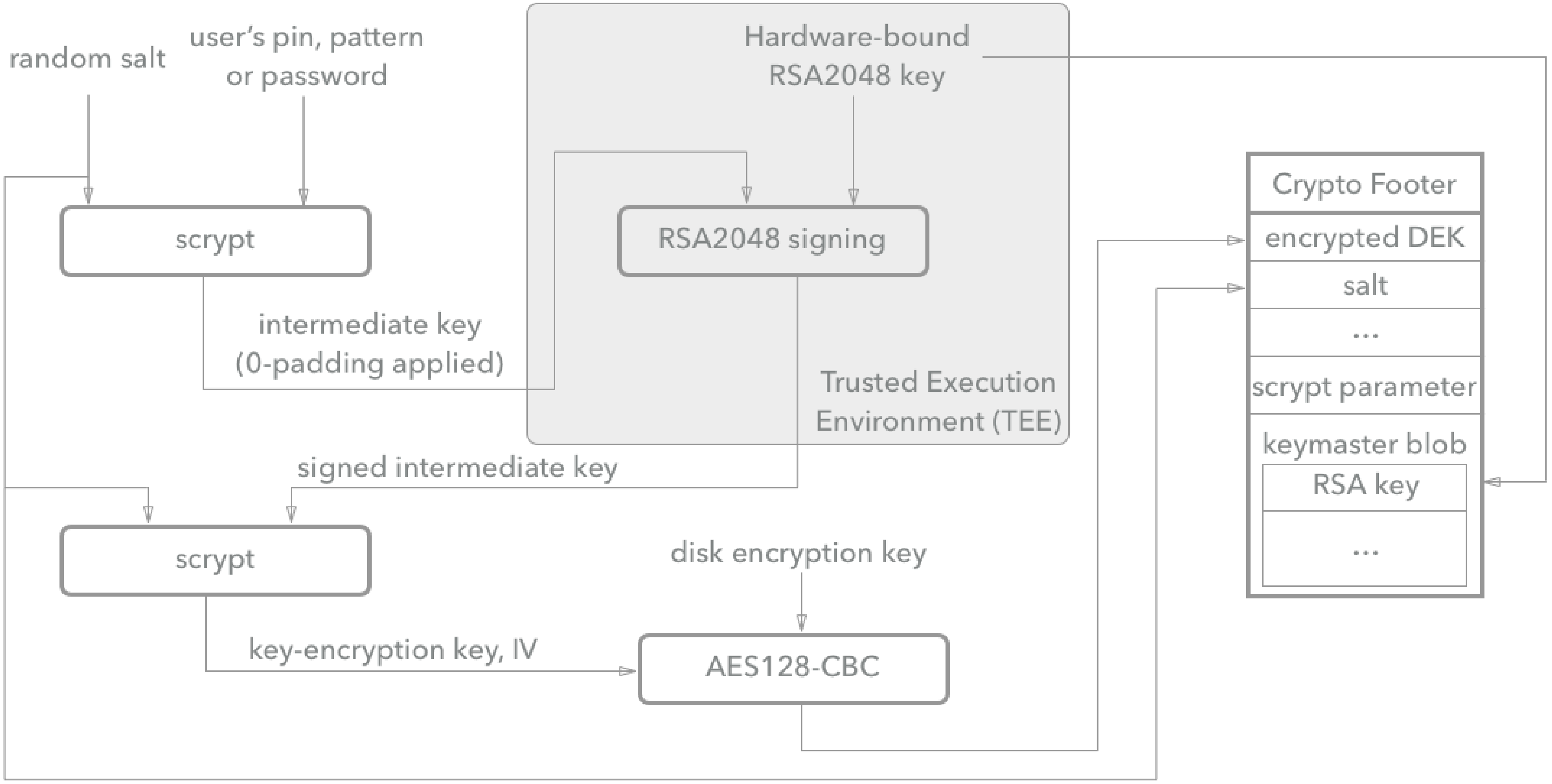


```
$ time python bruteforce_stdcrypto.py header footer 4
Android FDE crypto footer
-------------------------
Magic            : 0xD0B5B1C4
Major Version    : 1
Minor Version    : 2
Footer Size      : 192 bytes
Flags            : 0x00000000
Key Size         : 128 bits
Failed Decrypts: 0
Crypto Type      : aes-cbc-essiv:sha256
Encrypted Key    : 0x66C446E04854202F9F43D69878929C4A
Salt             : 0x3AB4FA74A1D6E87FAFFB74D4BC2D4013
KDF              : scrypt
N_factor         : 15      (N=32768)
r_factor         : 3       (r=8)
p_factor         : 1       (p=2)
-------------------------
Trying to Bruteforce Password... please wait
Trying: 0000
Trying: 0001
Trying: 0002
Trying: 0003
...
Trying: 1233
Trying: 1234
Found PIN!: 1234
```

Brute-Force still possible but takes longer!

See: https://goo.gl/a7Qjv1

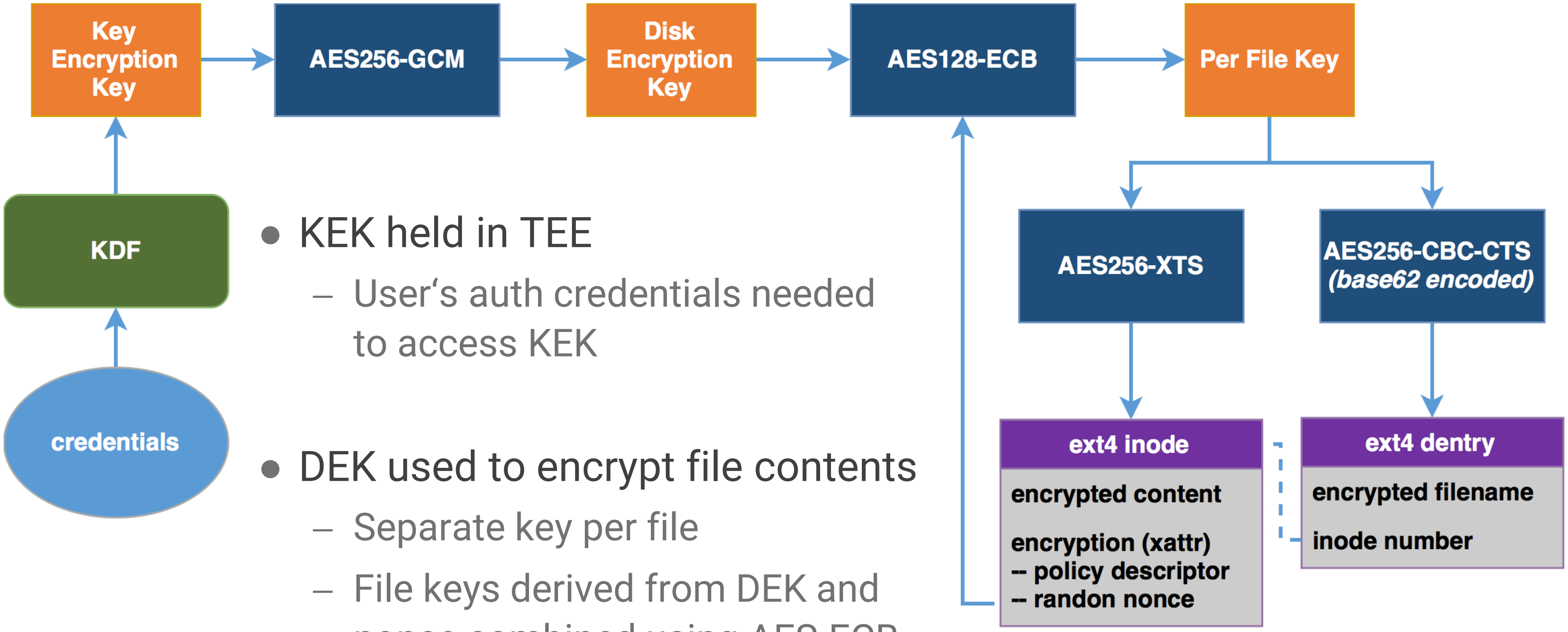
FDE in Android 5



- Support for patterns and encryption without password
- Hardware-backed key storage for encryption key using signing capabilities of TEE
- „Off device“ brute-force attack no longer feasible

File-Based Encryption

Since Android 7.0: Encryption of files instead of block-level



- KEK held in TEE
  - User's auth credentials needed to access KEK
- DEK used to encrypt file contents
  - Separate key per file
  - File keys derived from DEK and nonce combined using AES-ECB

Source: https://goo.gl/7zJ2c9

File-Based Encryption

Instead of crypto footer for partition,
key storage in */data/misc/vold/user_keys*

→ Different subdirectory in ce and de per Android user id

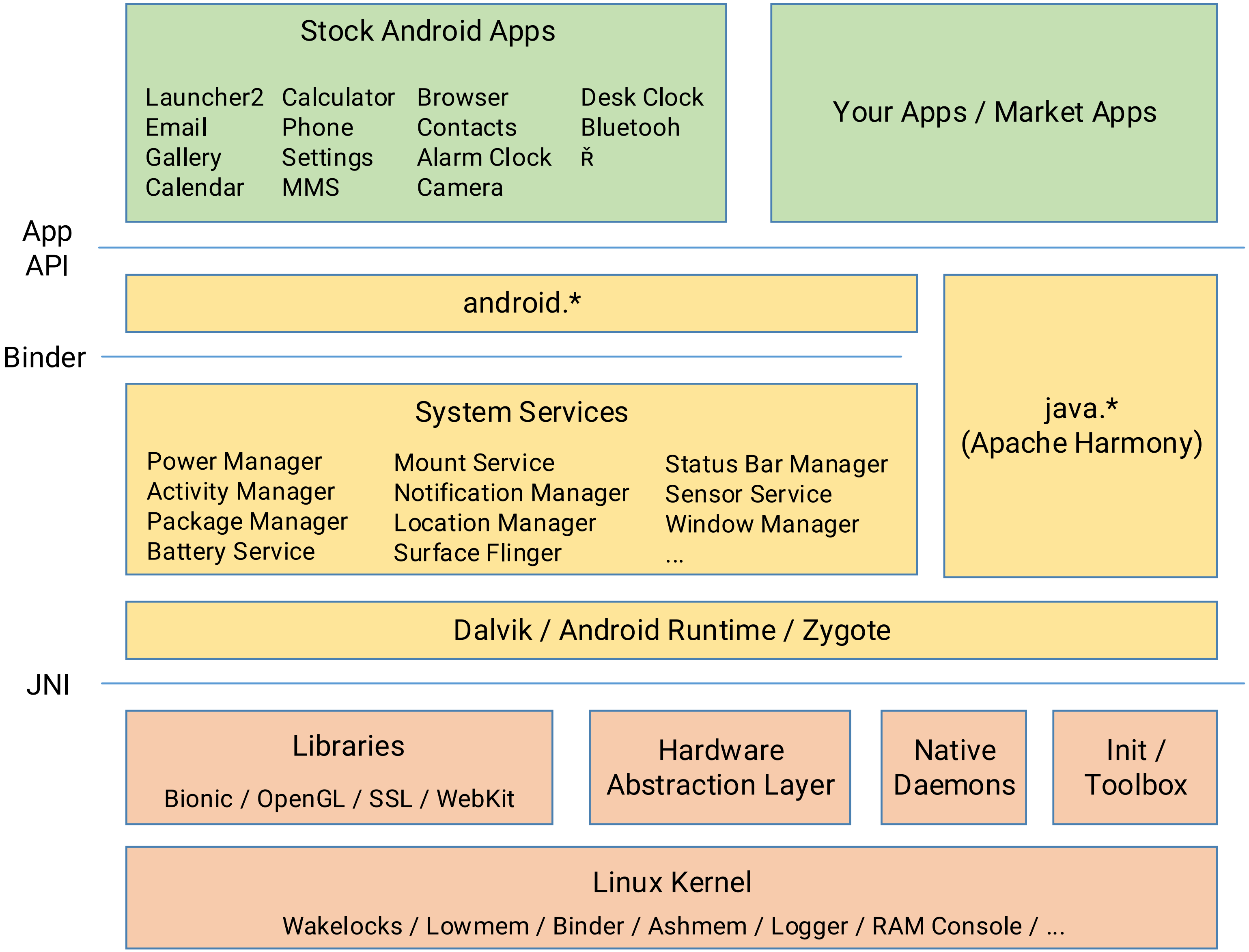
```
$ ls -R /data/misc/vold/user_keys
+ ce/0/current:
        - encrypted_key
        - keymaster_key_blob
        - salt
        - secdiscardable
        - stretching
        - version
+ de/0:
        - encrypted_key
        - keymaster_key_blob
        - secdiscardable
        - stretching
        - version
```

Two Areas

- Device Encrypted (DE)
  - Immediately available after device turn-on
  - *„Direct boot“* mode: Receive phone calls, set alarms, …
- Credential Encrypted (CE)
  - Available after user entered authentication credentials

Android OS Security

OS Architecture



Stock Android Apps

Launcher2 Calculator Browser Desk Clock
Email Phone Contacts Bluetooh
Gallery Settings Alarm Clock Ř
Calendar MMS Camera

Your Apps / Market Apps

App API

android.*

Binder

System Services

Power Manager
Activity Manager
Package Manager
Battery Service

Mount Service
Notification Manager
Location Manager
Surface Flinger

Status Bar Manager
Sensor Service
Window Manager
...

java.*
(Apache Harmony)

Dalvik / Android Runtime / Zygote

JNI

Libraries

Bionic / OpenGL / SSL / WebKit

Hardware Abstraction Layer

Native Daemons

Init / Toolbox

Linux Kernel

Wakelocks / Lowmem / Binder / Ashmem / Logger / RAM Console / ...

Android Security Model

- Kernel-based application sandbox
  - DAC (UID, GID-based access control) and MAC (SELinux type enforcement)
  - Dedicated, per-application UIDs
- Secure IPC (local sockets, Binder, intents)
- Systems running with reduced privileges
- Code signing
  - Application packages (APKs)
  - OS update packages (OTA packages)
- Permissions: System and custom (per app)

App Sandbox

- Android assigns unique UID to each application → separate processes

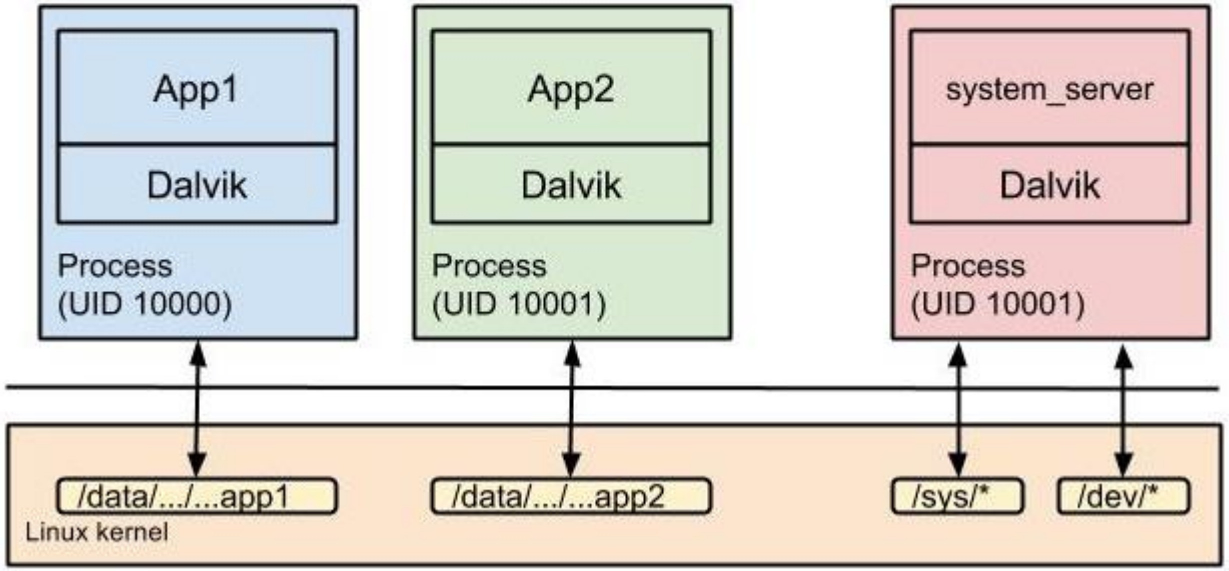
→ Kernel-level application sandbox

- Security enforced at process level through standard Linux facilities (UID, GID)

- Sandbox at kernel level

→ Security model extends to native code and OS applications too

- FS permissions as a mechanism to keep files / folder separate

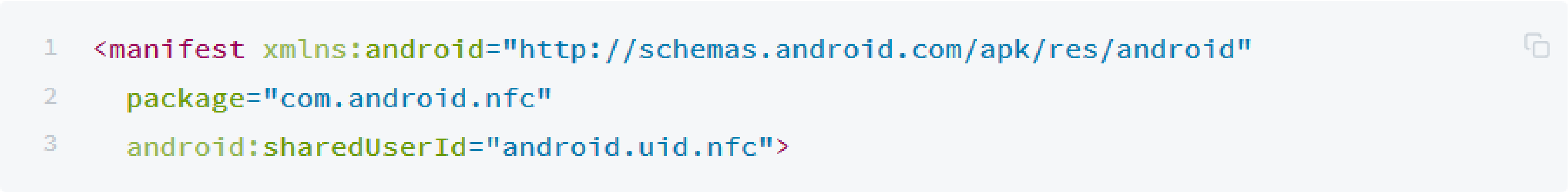


App Sandbox

- **Installing new apps**
  - Creates new directory /data/data/<Package name>/
    - E.g. /data/data/com.whatsapp/

```
$ ls -l /data/data/
drwx------  4 u0_a97       u0_a97        4096 2017-01-18 14:27 com.android.calendar
drwx------  6 u0_a120      u0_a120       4096 2017-01-19 12:54 com.android.chrome
...
```

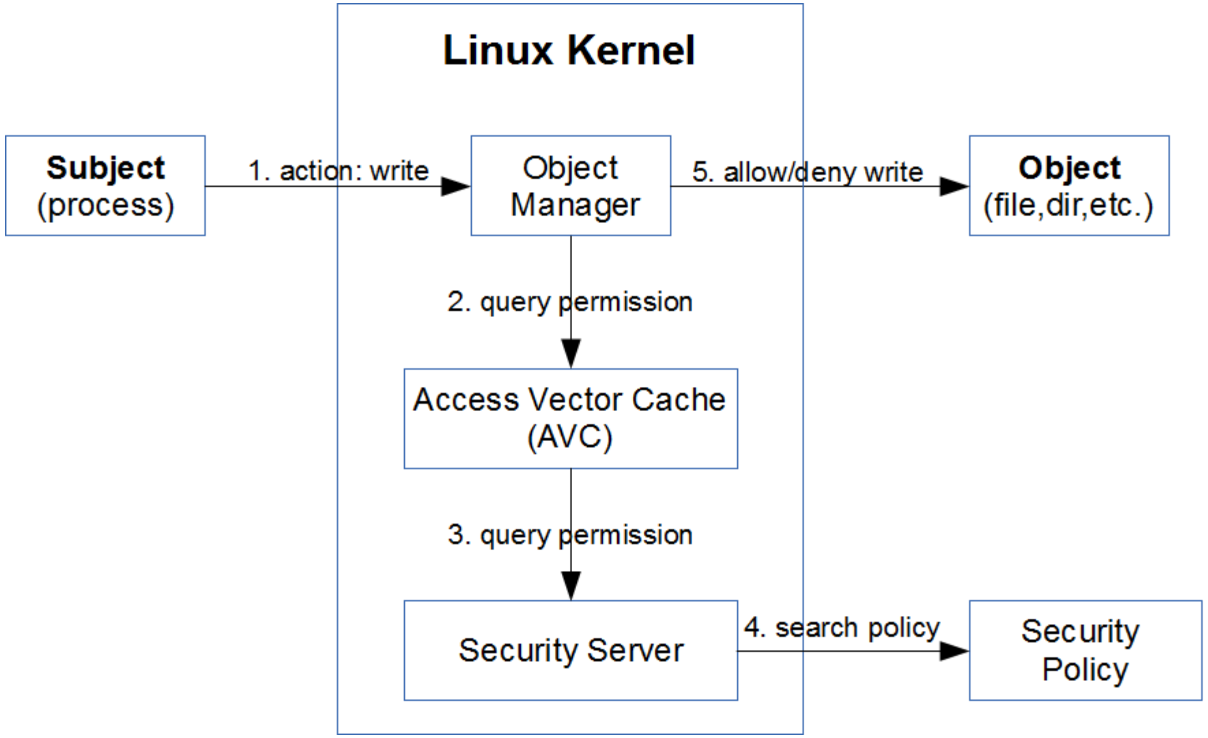
- Accessing other apps‘ directory → needs same UID
  - Apps signed with same developer certificate
  - Explicitly sharing same UID in AndroidManifest.xml



```
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
  package="com.android.nfc"
  android:sharedUserId="android.uid.nfc">
```

SELinux on Android

Security-Enhanced Linux



By default since Android > 4.3:
Define app boundaries with SELinux

Concept

„Not explicitly allowed? Then deny!“

Modes

- Permissive: Denials only logged
- Enforcing: Logged and enforced

Since Android 5: Enforce always (only)

SELinux on Android – Sample Rules

- No unlabeled files
- No ptrace
- No device node creation
- No raw I/O
- No mmap zero
- No mac_override
- No setting security properties
- No access to /data/security and /data/misc/keystore
- No /dev/mem or /dev/kmem access
- No /proc usermode helpers
- No ptrace of init
- No access to generically labeled /dev/block files
- Restrictions on mounting filesystems
- No execute of files from outside of /system
- No access to /data/properties
- No writing to /system or rootfs
- No registering of unknown services
- No entering init domain
- No /sys/kernel/debug read access
- No apps acquiring capabilities
- No raw app access to camera, microphone, NFC, radio, etc.
- No app-generic socket access
- No app/proc access to different security domains
- No access to GPS files
- Cannot disable SELinux

Meanwhile > 250 Rules

Multi-User support

- Originally for tablets only, now for phones too (> Android 5.0)

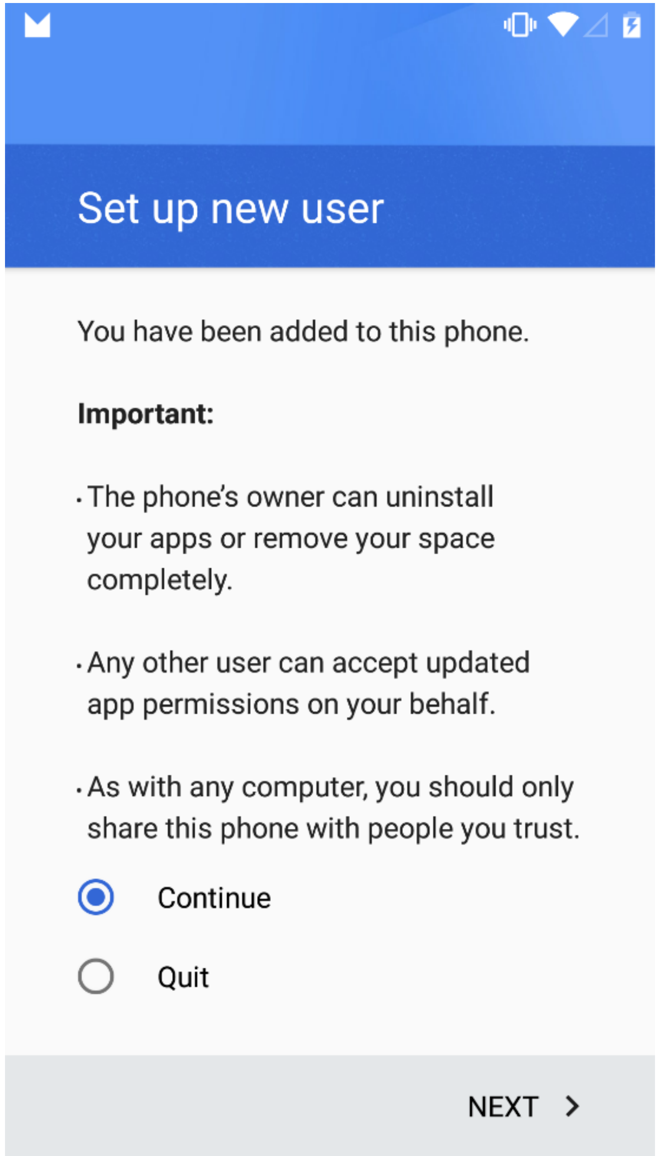
- Users isolated by UID / GID

- Separate settings & app data directories
  - System directory: `/data/system/users/<user ID>/`
  - App data directory: `/data/user/<user ID>/<pkg name>/`

- Apps have different UID and install state for each user
  - App UID: `uid = userId * 10000 + (appId % 10000)`
  - Shared Apps: Install state in per-user `package-restrictions.xml`

- External storage isolation

User Types



Set up new user

You have been added to this phone.

Important:

- The phone's owner can uninstall your apps or remove your space completely.
- Any other user can accept updated app permissions on your behalf.
- As with any computer, you should only share this phone with people you trust.

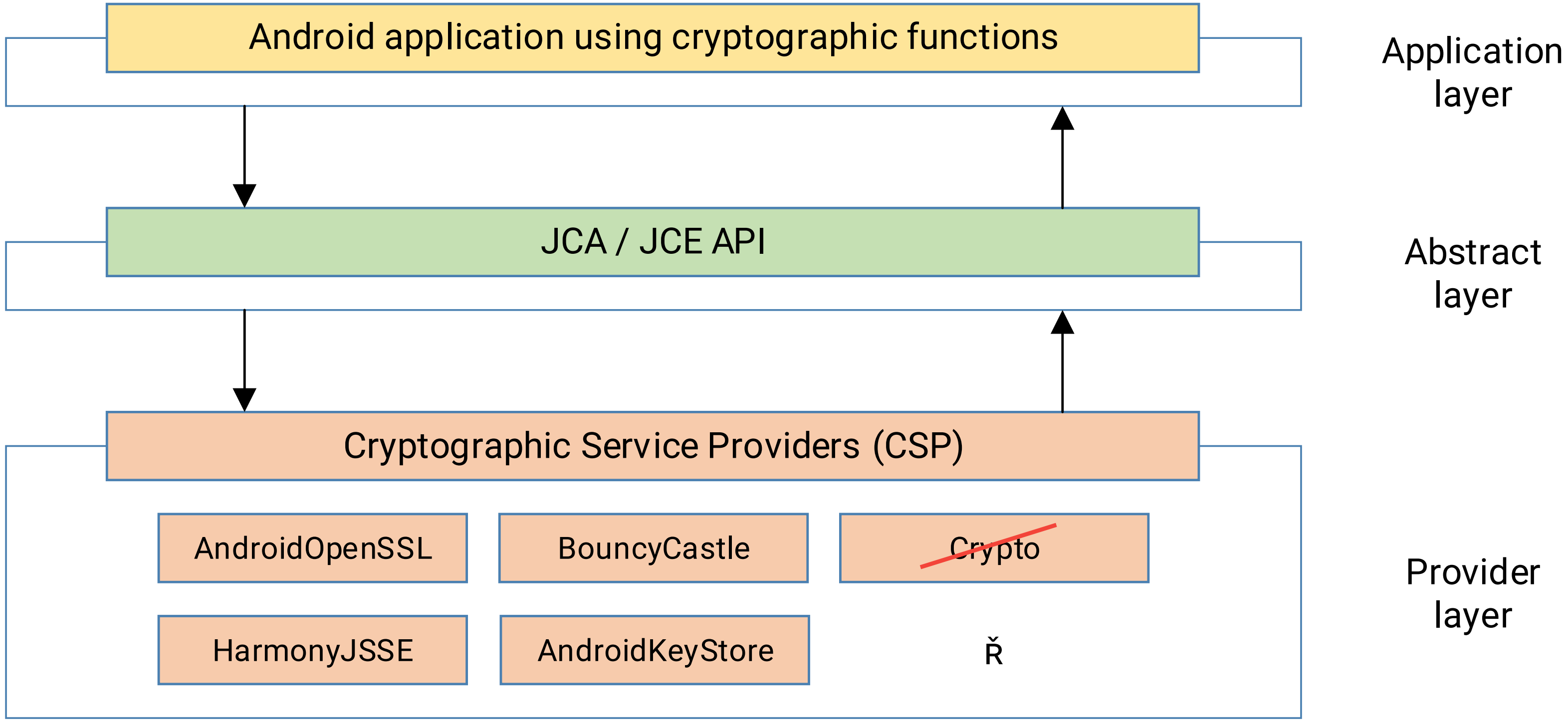
◉ Continue

○ Quit

- Primary user (owner)
  - Full control over device
- Secondary users
  - Restricted profile
    - Share apps with primary user
    - Only on tablets
  - Managed profile
    - Separate apps and data but share UI with primary user
    - Managed by Device Policy Client (DPC)
- Guest user
  - Temporary, restricted access to device
  - Data (session) can be deleted

Cryptography

- JCA Provider Architecture
- (SSLv3), TLS v1.0-v1.3 support via JSSE API



Cryptography

What makes correct Crypto difficult on Android?

- Insecure defaults imported from Java
  - E.g. Cipher.getInstance(„AES“) implicitly uses ECB mode
  - Bad / no documentation on how to use correctly

- Variety of crypto providers
  - Many apps bundle SpongyCastle library to fix issues in BouncyCastle
  - No full BouncyCastle library in Android → features depending on included version

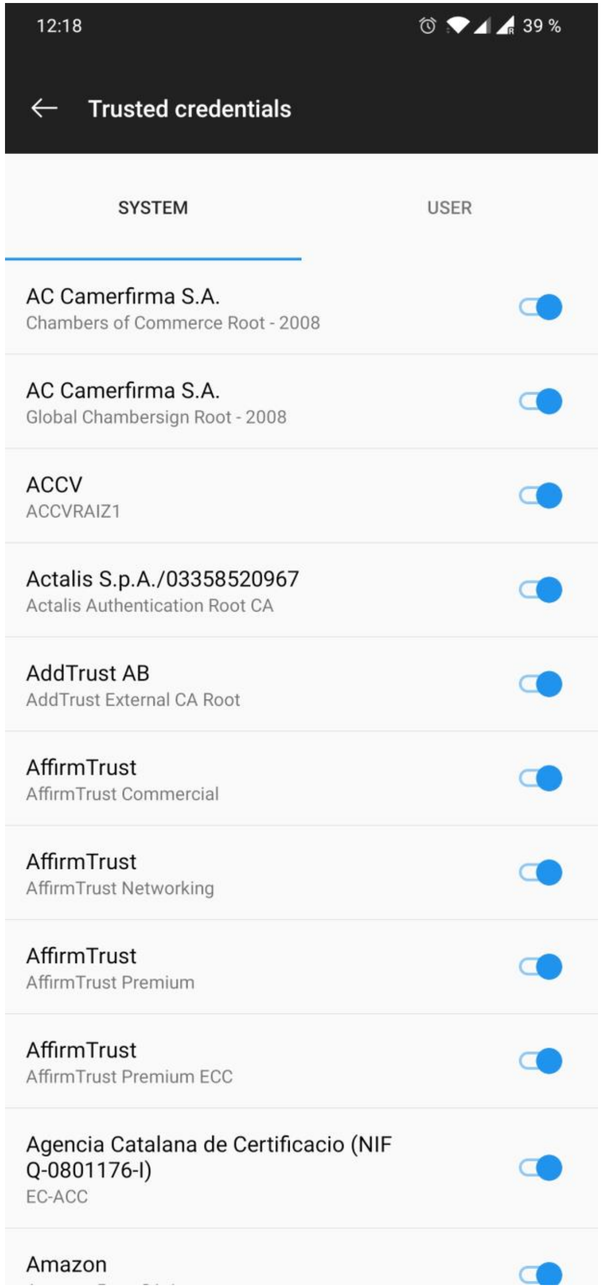
- Frequent changes in APIs
  - **Android 7:** „Crypto“ provider deprecated, SHA1PRNG replaced with OpenSSLRandom
  - **Android 8:** „You should not use IVParameterSpec for GCM but GCMParameterClass“
  - **Android 9:** „Crypto“ provider removed, developer must not explicitly select provider

Certificates & PKI

- Android-specific trust store

- Trust anchors
  - Pre-installed („trusted credentials“)
  - Per user / profile

- Modified certificate building chain
  - Based on BouncyCastle code
  - Dynamically updated certificate blacklists
  - Dynamically updated Certificate Pinning for Google Sites



12:18 39 %

Trusted credentials

SYSTEM USER

AC Camerfirma S.A.
Chambers of Commerce Root - 2008

AC Camerfirma S.A.
Global Chambersign Root - 2008

ACCV
ACCVRAIZ1

Actalis S.p.A./03358520967
Actalis Authentication Root CA

AddTrust AB
AddTrust External CA Root

AffirmTrust
AffirmTrust Commercial

AffirmTrust
AffirmTrust Networking

AffirmTrust
AffirmTrust Premium

AffirmTrust
AffirmTrust Premium ECC

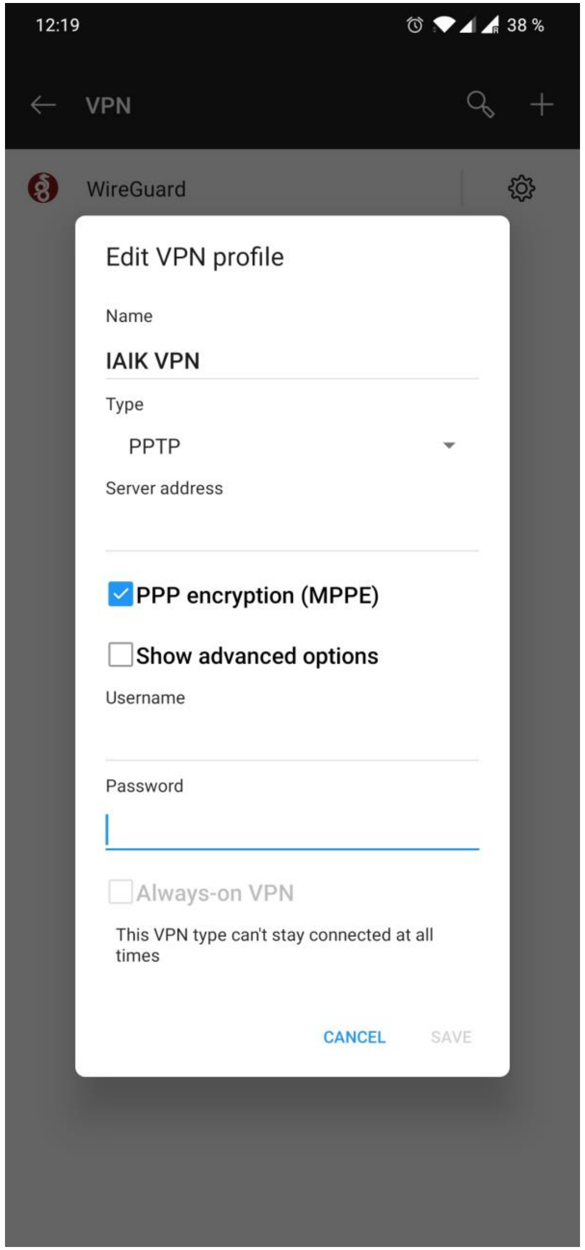
Agencia Catalana de Certificacio (NIF Q-0801176-I)
EC-ACC

Amazon

Networks

- WPA EAP2 Enterprise (802.11i)
  - EAP: EAP-TLS, EAP-TTLS, PEAP, EAP-SIM, EAP-AKA since Android 5.0
  - Integrates with system keystore
  - Integrated with Android for Work (device administrator APIs)

- VPN
  - Legacy: PPTP, IPSec
  - Always-on VPN: *No network access until VPN is up*
  - Per-user / profile VPNs: *Dynamic routing / firewall rules*
  - Per-application VPN since Android 5.0



Edit VPN profile

Name: IAIK VPN

Type: PPTP

Server address:

☑ PPP encryption (MPPE)

☐ Show advanced options

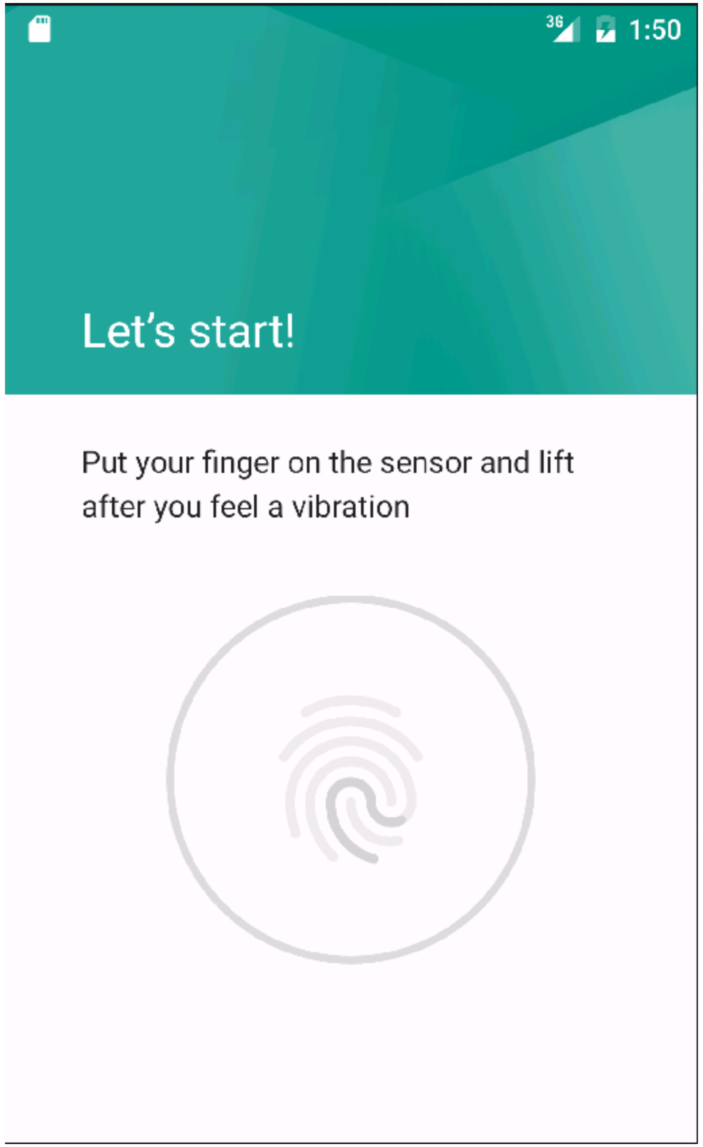
Username:

Password:

☐ Always-on VPN

This VPN type can't stay connected at all times

Device Security



1:50

Let’s start!

Put your finger on the sensor and lift after you feel a vibration

- Lockscreen (`keyguard` service)
  - Pattern (least secure)
  - PIN / Password
  - Stores hashes, uses Gatekeeper HAL since Android 6.0
- Smart Lock since Android 5.0
  - Extensible Trust Agents
  - Bluetooth, NFC, Location, Face Recognition
- Factory reset protection since Android 5.1
  - Google account info saved on `frp` partition
- Fingerprint API since Android 6.0

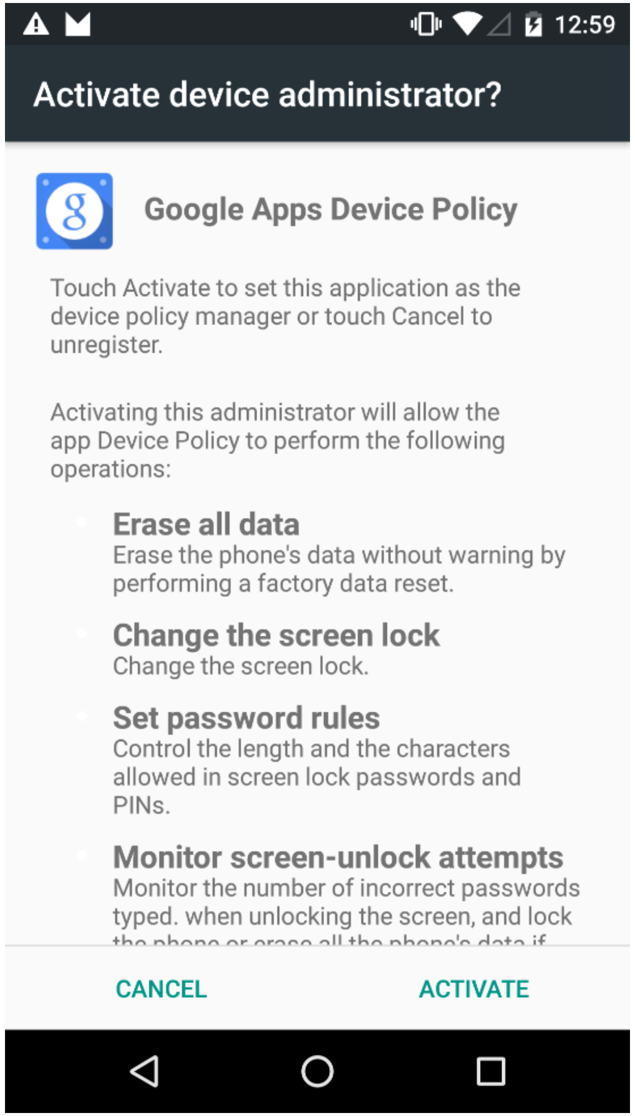
Credential Storage

- System-managed, secure cryptographic key store
  - Unexportable keys
  - Remain secure even if OS is compromised → Secure Element

- Implemented in the `keystore` system service
  - HAL interface (`keymaster`), hardware-backed implementations possible
  - Typically uses TEE (implemented using TrustZone) on ARM devices

- Framework APIs
  - `KeyChain` API
  - `KeyStore`
  - `KeyPairGenerator`, `KeyGenerator`

MDM



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Activate device administrator?

Google Apps Device Policy

Touch Activate to set this application as the device policy manager or touch Cancel to unregister.

Activating this administrator will allow the app Device Policy to perform the following operations:

- **Erase all data**
  Erase the phone's data without warning by performing a factory data reset.
- **Change the screen lock**
  Change the screen lock.
- **Set password rules**
  Control the length and the characters allowed in screen lock passwords and PINs.
- **Monitor screen-unlock attempts**
  Monitor the number of incorrect passwords typed. when unlocking the screen, and lock the phone or erase all the phone's data if

- Device security policy can be set by admin
  - Password / PIN policy
  - Device lock / unlock
  - Storage encryption
  - Camera access
- Needs to be activated by user
- Cannot be directly uninstalled
- May be required to sync account data
  - Microsoft Exchange (EAS)
  - Google Apps

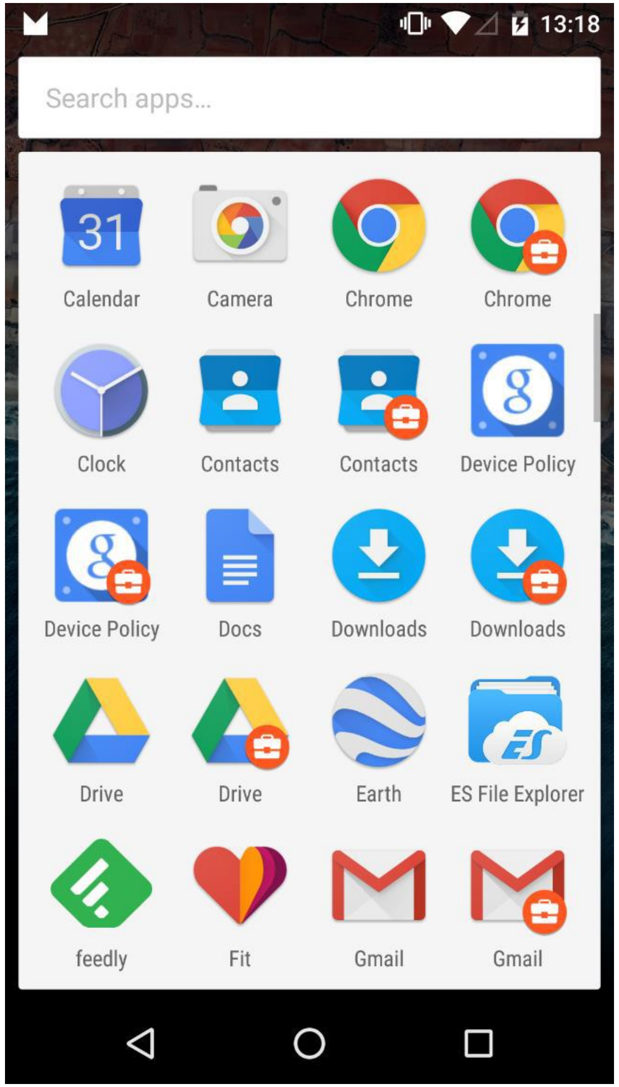
Android for Work

- Android > 5.0 provides “Work Profiles”
  - Pre-defined managed provisioning flow
  - Managed by “Profile Owner” (device admin)
  - Requires device encryption

- Separate apps and data: Can only install approved apps

- UI shared with primary user (Launcher, Notifications, …)

- “Device owner” is super-device admin
  - Installed upon first device initialization
  - Cannot be uninstalled
  - Extra privileges
  - Scoped to whole device



Outlook

- 07.05.2020
  - Application Security on Android

- 14.05.2020
  - Static and Dynamic Application Analysis