DroidGuard

A Deep Dive into SafetyNet

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Introduction

About

- Security engineer at UL
- Working on banking app certifications (EMVCo, VISA, ...)
- Author of LIEF: `https://lief.re`
- Enjoy Android, reverse engineering and, obfuscation.

The views and opinions expressed in this work are those of the author's and do not represent the official position of UL

SafetyNet

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- **integrity**?
  - Rooted
  - Custom firmware
  - Emulators
  - Bootloader unlocked
  - ...

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- **integrity**?
  - Rooted
  - Custom firmware
  - Emulators
  - Bootloader unlocked
  - ...
- It is used by a large number of app developers who need be sure their applications do not run on a *compromised* environment (games, fintech, messaging apps, ...)

SafetyNet API

```
SafetyNet.getClient(this).attest(nonce, API_KEY)
  .addOnSuccessListener(this) {
   // Indicates communication with the service was successful.
   // Use response.getJwsResult() to get the result data.
  }
  .addOnFailureListener(this) { e →
   // An error occurred while communicating with the service.
   if (e is ApiException) {
    // An error with the Google Play services API contains some
    // additional details.
    val apiException = e as ApiException

    // You can retrieve the status code using the
    // apiException.statusCode property.
   } else {
    // A different, unknown type of error occurred.
    Log.d(FragmentActivity.TAG, "Error: " + e.message)
   }
  }
}
```

→ The developer provides:

1. A **nonce** to avoid replay attack
2. An **API_KEY** to be authenticated by the Google's backend

← SafetyNet returns:

1. A JWS token[1] that wraps the device's integrity status
2. Or, an error

[1] Signed by Google's private key (in the backend)

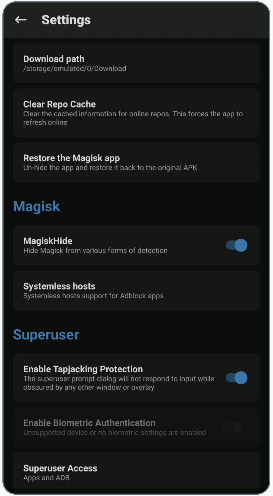
About This Talk

Why this talk?

Inside Android’s SafetyNet Attestation

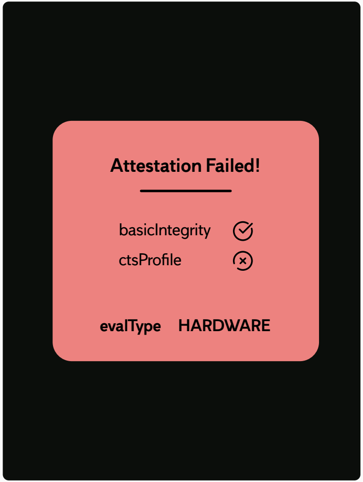
Collin Mulliner & John Kozyrakis

Magisk & Magisk Hide



Magisk & Magisk Hide

Magisk & Magisk Hide



basicIntegrity vs ctsProfileMatch

Basic Integrity

"A more lenient verdict of device integrity. If only the value of `basicIntegrity` *is* `true`*, then the device running your app likely wasn't tampered with. However, the device hasn't necessarily passed Android compatibility testing."*

CTS Profile Match

"A stricter verdict of device integrity. If the value of `ctsProfileMatch` *is* `true`*, then the profile of the device running your app matches the profile of a device that has passed Android compatibility testing and has been approved as a Google-certified Android device."*

`https://developer.android.com/training/safetynet/attestation`

basicIntegrity vs ctsProfileMatch

Basic Integrity

- Rooted device
- Emulator
- API Hooking

CTS Profile Match

- Rooted device
- Emulator
- API Hooking

+ Bootloader unlocked
+ Device with custom ROM (not rooted)
+ Genuine but uncertified device, such as when the manufacturer doesn't apply for certification

Magisk v24.0

MagiskHide Removal

I have lost interest in fighting this battle for quite a while;
plus, the existing MagiskHide implementation is flawed in so many ways.

Decoupling Magisk from root hiding is, in my opinion, beneficial to the community.
Ever since my announcement on Twitter months ago, highly effective "root hiding" modules (much MUCH better than MagiskHide) has been flourishing, which again shows that people are way more capable than I am on this subject.

So why not give those determined their time to shine, and let me focus on improving Magisk instead of drowning in the everlasting cat-and-mouse game

Magisk v24.0 Release Note – January 2022

SafetyNet

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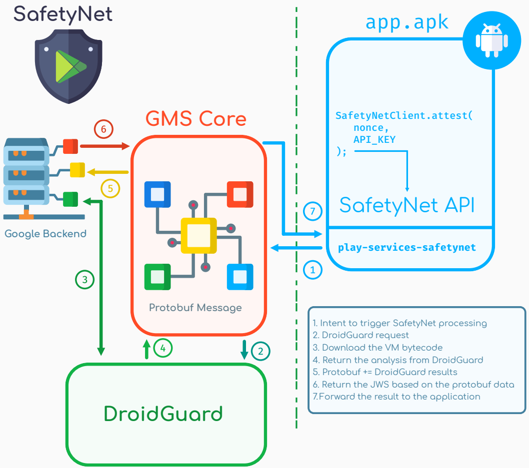

SafetyNet

```kotlin
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```
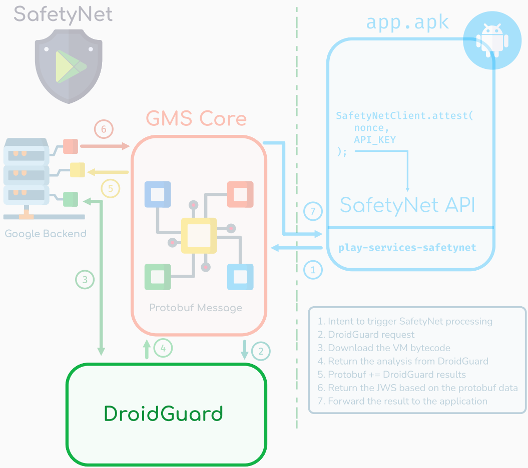
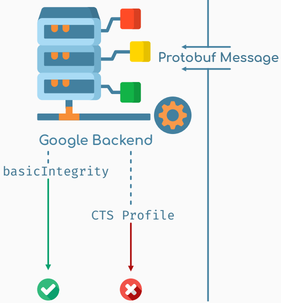



DroidGuard



com.google.android.gms

```
SafetyNetData = {
  nonce           = [ca ee ...]
  packageName     = "com.demo.snet"
  signatureDigest = [66 49 ...]
  fileDigest      = [fa 0a ...]
  gmsVersionCode  = 213918046
  suCandidates = {
    fileName = "/system/bin/su"
    digest   = [25 53 ...]
  }
  seLinuxState = {
    supported = true
    enabled   = true
  }
  currentTimeMs = 1638672572674
  googleCn      = false
```

/data/app/[...]/com.google.android.gms/base.apk

Code written in Java/Kotlin, lightly obfuscated.

com.google.android.gms.unstable

```
DroidGuardResult = "CgZpApMYiWYSi9cB [..]"
```

/data/data/com.google.android.gms/app_dg_cache/<hash>/the.apk

Code mostly written in C++ and obfuscated (VM, MBA, ...)

Why This Talk?

Goal of this talk

- Understand how SafetyNet works thanks to DroidGuard
- Describe the integrity's checks behind SafetyNet

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Non-goal of this talk

- Show methods to bypass or tricks the hardware attestation
- Promote/release a new click and play tool to replace MagiskHide

DroidGuard:
The VM behind SafetyNet

SafetyNet

```
DroidGuardResult = "CgZpApMYiWYSi9cB [..]"
```

1. How this token is generated?
2. What kind of information is stored?

How this token is generated?

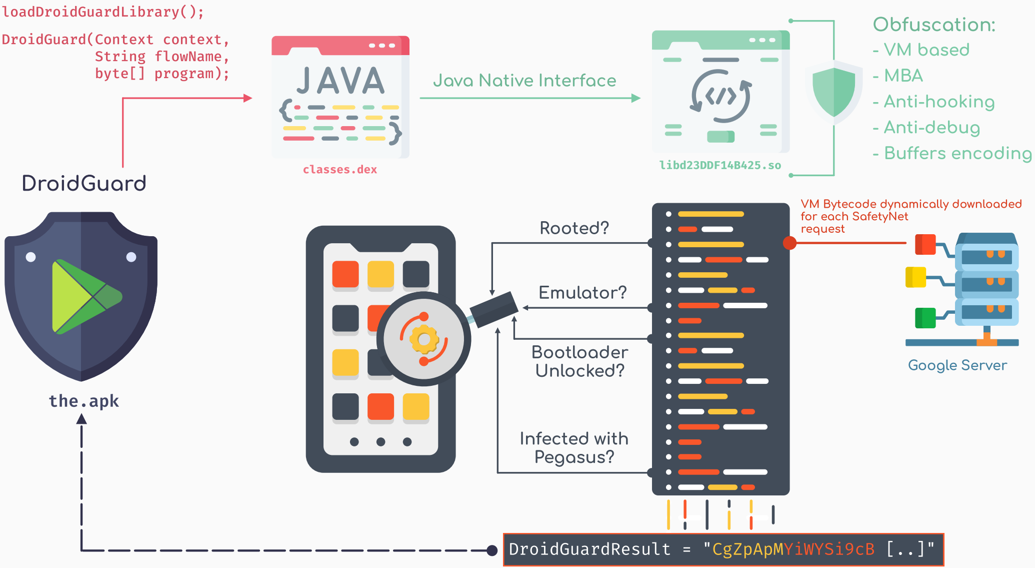
com.google.ccc.abuse.droidguard.DroidGuard

/data/data/com.google.android.gms/app_dg_cache/<hash>/the.apk

1. APK updated every $\sim$ 2 weeks from the Google's servers[2]
2. The Java layer is pretty small: about $\sim$ 60 classes.
3. Embed a native library that implements an **obfuscated VM**

[2] not from the PlayStore

How this token is generated?



DroidGuard VM

To highlight the logic behind SafetyNet, we have to understand how the bytecode behaves within the VM and how the VM is designed.

DroidGuard VM: Registers

`libd23DDF14B425.so`

- 256 **typed** registers

0. Pointer
1. Double
2. jobject (JNI object)
3. Int
4. Long
5. String/Buffer
6. None

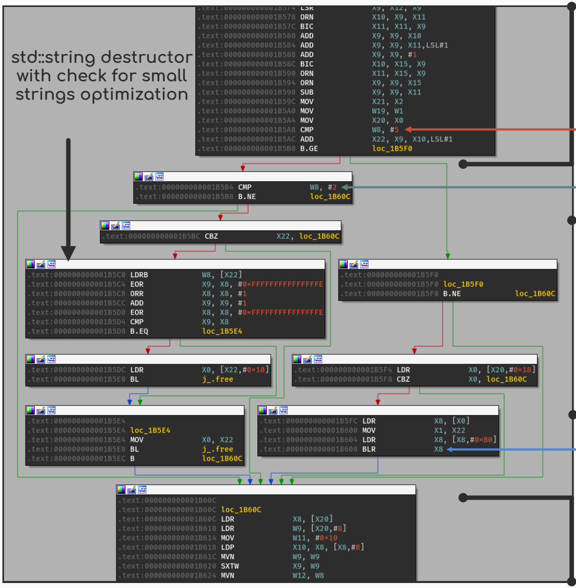
DroidGuard VM: Registers

`libd23DDF14B425.so`

- 256 **typed** registers, **shuffled for each new version of the VM**

0. String/Buffer
1. Int
2. Long
3. Double
4. jobject (JNI object)
5. Pointer
6. None

VM: How to Write a Register Value?



[READ]
Register value decoding
(with MBA)

In this version, register type 5 is a JNI Object

2 matches a std::string

Make sure the original register's value is properly released

`env->DeleteGlobalRef(reg_value)`

[WRITE]
Register value encoding
(with MBA)

DroidGuard VM: The Handlers

The DroidGuard VM is composed of a set of *handlers* that have a dedicated purpose:

- Perform a syscall
- Resolve a function (**`dlsym`**)
- Perform an add, xor, mult, div, ...
- Read an encoded buffer
- Perform a SHA256[3]
- Call a JNI function
- ...

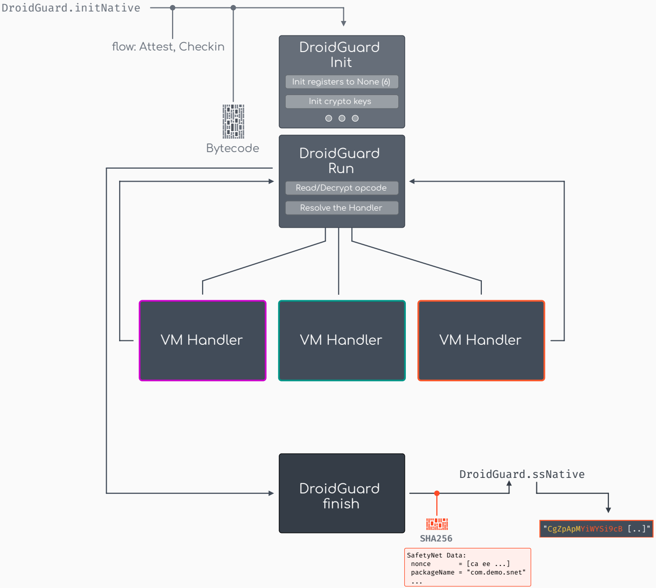
[3] Based on BoringSSL

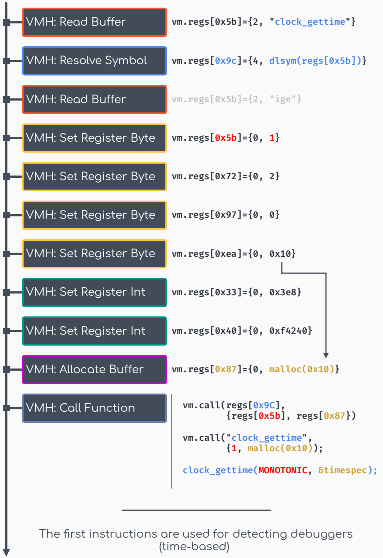
VM Handlers

libd23DDF14B425.so

```
.text:00000000000249B8
.text:00000000000249B8 vm_init_handlers
.text:00000000000249B8
.text:00000000000249B8 var_10= -0x10
.text:00000000000249B8
.text:00000000000249B8 STP             X30, X19, [SP,#var_10]!
.text:00000000000249BC MOV             X19, X0
.text:00000000000249C0 ADD             X0, X0, #0x20 ; ' ' ; s
.text:00000000000249C4 MOV             W2, #0x1000 ; n
.text:00000000000249C8 MOV             W1, WZR ; c
.text:00000000000249CC BL              .memset
.text:00000000000249D0 ADRL            X17, VMH_01c2b0
.text:00000000000249D8 STR             X17, [X19,#0xAA0]
.text:00000000000249DC ADRL            X17, VMH_02d568
.text:00000000000249E4 STR             X17, [X19,#0x820]
.text:00000000000249E8 ADRL            X17, VMH_030288
.text:00000000000249F0 STR             X17, [X19,#0x480]
.text:00000000000249F4 ADRL            X17, VMH_321A8
.text:00000000000249FC STR             X17, [X19,#0x690]
.text:0000000000024A00 ADRL            X17, VMH_JNI_CallStaticObjectMethod
.text:0000000000024A08 STR             X17, [X19,#0xDA0]
.text:0000000000024A0C ADRL            X17, VMH_0378d8
.text:0000000000024A14 STR             X17, [X19,#0xFB0]
.text:0000000000024A18 ADRL            X17, VMH_03951c
.text:0000000000024A20 ADRP            X0, #VMH_0297a0@PAGE
.text:0000000000024A24 STR             X17, [X19,#0x270]
.text:0000000000024A28 ADRP            X17, #VMH_03a2f0@PAGE
.text:0000000000024A2C ADD             X0, X0, #VMH_0297a0@PAGEOFF
.text:0000000000024A30 ADD             X17, X17, #VMH_03a2f0@PAGEOFF
.text:0000000000024A34 STR             X0, [X19,#0xF20]
.text:0000000000024A38 ADRP            X0, #VMH_02d754@PAGE
.text:0000000000024A3C STR             X17, [X19,#0x290]
.text:0000000000024A40 ADRP            X17, #VMH_set_uint32@PAGE
.text:0000000000024A44 ADD             X0, X0, #VMH_02d754@PAGEOFF
.text:0000000000024A48 ADD             X17, X17, #VMH_set_uint32@PAGEOFF
.text:0000000000024A4C STR             X0, [X19,#0x5E0]
.text:0000000000024A50 ADRP            X0, #VMH_xor@PAGE
```

VM Overview





The first instructions are used for detecting debuggers (time-based)

Device’s Integrity Checks

Device's Integrity Checks

With a good understanding of the VM and its handlers, we can target a few of them[4] to highlight the integrity checks.

[4] Mostly handlers which perform syscalls, calls, JNI calls

Example

```
[016667] VMH_read_buffer() {
 0x039748: vm->decode(sp!968, 0x4e2f, 0x2): 0x4e31
 0x0397b8: std::string(sp!968, 0x10, 0x0)
 0x0397fc: vm->decode(sp!967, 0x4e31, 0x10): 0x4e41
 0x0398a4: vm->decode(sp!94c, 0x4e41, 0x1): 0x4e42
 0x039910: operator_new(0x18): 0x6f08b44be0
 0x03991c: std::string::copy(malloc@0x6f08b44be0, sp!968)
 0x03992c: vm_set_register(0x4c, 0x2, 0x6f08b44be0): "/data/local/xbin"
}
// ...
[016674] VMH_call_function() {
 0x03c75c: vm->read_byte_vector(std::vector<uint8_t>@sp!980, KEY): {0x09, 0x4c, 0x3d, 0x09}
 0x03c780: vm->decode(sp!950, 0x4872, 0x1): 0x4873
 0x03c7e0: vm->decode(sp!950, 0x4873, 0x1): 0x4874
 0x03c824: vm->get_pointer(0xa): 0x6e6de1459c
 0x03c834: vm->read_register(0x7b): 0x30
 0x03c844: operator_new(0x10): 0x6ef8a9c470
 0x03c87c: memcpy(0x6ef8a9c470, 0x6e84242788, 0x10)
 0x03c8a0: vm->prepare_params(in: {09,4c,3d,09},
                              {&vm_sycall, 0x30, 0x0, 0x6f48d4fb61, 0x4, 0x0},
                              {"/data/local/xbin"}')
 {
  faccessat("/data/local/xbin"): 0xfffffffffffffffe
 }
 0x03c930: vm->set_register(0xc9, 0x0, 0xfffffffe)
}
```

Root Detection: Files Checks

- `/data/local/tmp/su`
- `/system/bin/.ext/su`
- `/system/bin/su`

Root Detection: System Properties

- `init.svc.magisk_service`
- `persist.magisk.hide`
- `ro.magisk.disable`

”Signs of active attacks, such as API hooking”

```
0×2171c VMH_read_buffer() {
 0×039748: vm→decode(sp!668, 0×3ad0, 0×2): 0×3ad2
 0×0397b8: std::string(sp!668, 0×15, 0×0)
 0×0397fc: vm→decode(sp!667, 0×3ad2, 0×15): 0×3ae7
 0×0398a4: vm→decode(sp!64c, 0×3ae7, 0×1):  0×3ae8
 0×039910: operator_new(0×18): 0×7c21437560
 0×03991c: basic_string_copy(malloc@7c21437560, sp!668): "'6V+0F`C"
 0×03992c: vm→set_register(0×6f, 0×2, 0×7c21437560): ":libriru_edxposed.so:"
}
0×2171c VMH_find_in_string() {
 0×043140: vm→decode(sp!660, 0×3ae9, 0×1): 0×3aea
 0×0431b8: vm→decode(sp!660, 0×3aea, 0×1): 0×3aeb
 0×043214: vm→decode(sp!660, 0×3aeb, 0×1): 0×3aec
 0×043270: vm→decode(sp!660, 0×3aec, 0×1): 0×3aed
 0×043304: vm→read_register(0×9): 0×0
 regs[0×ac].value → 0×c8e697a25b30b3fb | ":linker64:app_process64:[vdso]:libandroid_runtime.so:libbinder.so: [ … ]
 regs[0×6f].value → 0×239a5f05c8953bcf | ":libriru_edxposed.so:"
 // …
}
```

"Signs of active attacks, such as API hooking"

- `frida-agent-64.so`
- `libriru_snet-tweak-riru.so`
- `libsandhook.so`

Last but not least …

NSO's Pegasus

```
+----------------------------------------------------------------------+
| cd 2e 5f 64 61 65 6d 6f 6e 73 75 5f cd 70 65 67 | .._daemonsu_.peg |
| 61 73 75 73 2e 61 70 6b cd 63 70 cd 63 73 6b cd | asus.apk.cp.csk. |
| 68 74 66 73 6b cd 2e 6c 73 cd 2e 6c 64 2e 6a 73 | htfsk..ls..ld.js |
| cd 69 73 75 cd 61 6e 64 72 6f 56 4d 2d 70 72 6f | .isu.androVM-pro |
| 70 cd 62 75 73 79 62 6f 78 cd 6d 75 cd 64 61 65 | p.busybox.mu.dae |
| 6d 6f 6e 73 75 cd 2e 63 6f 6c 64 62 6f 6f 74 5f | monsu..coldboot_ |
| 69 6e 69 74 cd 73 75 5f cd 2e 63 70 2e 70 6d cd | init.su_..cp.pm. |
| 74 65 6d 70 5f 73 75 cd 69 6e 69 74 2e 6d 61 67 | temp_su.init.mag |
| 69 73 6b 2e 72 63 cd 62 61 73 65 72 76 69 63 65 | isk.rc.baservice |
| cd 62 61 64 61 6d 6f 6e cd 2e 70 65 cd 70 70 6d | .badamon..pe.ppm |
| cd 2e 5f 73 75 cd 2e 5f 73 75 5f cd 64 72 6f 69 | .._su.._su_.droi |
| 64 34 78 2d 70 72 6f 70 cd 74 74 56 4d 2d 70 72 | d4x-prop.ttVM-pr |
| 6f 70 cd 69 67 70 69 cd 71 65 6d 75 5f 70 72 6f | op.igpi.qemu_pro |
| 70 73 cd 2e 70 72 2e 69 6f cd 2e 74 65 2e 73 74 | ps..pr.io..te.st |
| cd 61 6d 70 6d 6c cd 69 70 6d cd 2e 74 73 cd 61 | .ampml.ipm..ts.a |
| 6e 6c 5f 36 34 cd 61 6e 6c cd 67 69 65 66 72 6f | nl_64.anl.giefro |
| 6f 74 cd 72 62 6e cd 6d 69 63 72 6f 76 69 72 74 | ot.rbn.microvirt |
| 2d 70 72 6f 70 cd 73 6d 73 64 61 6d 6f 6e cd 77 | -prop.smsdamon.w |
| 61 77 cd 73 6d 73 73 65 72 76 69 63 65 cd 6c 69 | aw.smsservice.li |
| 62 69 6d 63 72 63 5f 36 34 2e 73 6f cd 77 6c 61 | bimcrc_64.so.wla |
| 6e 64 cd 6d 69 63 72 6f 76 69 72 74 64 cd 6c 69 | nd.microvirtd.li |
| 62 69 6e 6a 65 63 74 6f 72 2e 73 6f cd 6e 6f 78 | binjector.so.nox |
| 2d 70 72 6f 70 cd 73 75 cd 73 75 32 cd 61 6d 70 | -prop.su.su2.amp |
| 6d 6c 5f 36 34 cd 2e 61 75 74 68 6f 72 cd       | ml_64..author.   |
+----------------------------------------------------------------------+
```

.coldboot_init | csk | pegasus.apk

Pegasus for Android
Technical Analysis and Findings of Chrysaor
2017

Second Pegasus Sample

This sample differs significantly from the first sample analyzed above. It has a considerably smaller code base and is clearly intended to be installed on a device that was previously rooted and already contains the `/system/csk` superuser binary.

Analysis of this sample showed that its sole purpose is to initiate a connection to a remote address, download an additional payload, save this data to the file `/data/data/com.network.android/.coldboot_init`, before copying it to `/mnt/obb/.coldboot_init` and changing the permissions on this file to 0711. The functionality to perform this download is located in the sample's only native binary, `libsgn.so`. The portion of the sample written in java is extremely minimal and exists just to load `libsgn.so`. Below is a section of code from the `libsgn.so` file that attempts to write the retrieved payload to various paths.

Lookout

Telemetry

Telemetry

In addition to pre-defined *boolean* checks[5]. DroidGuard collects information about the device (system properties, mount information, ...).

These information are used by the Google backend to enhance the device's integrity checks.

[5] Whether a file exists, if a library is present in memory, ...

Telemetry

```
ro_zygote    = "zygote64_32"
pointer_info = "7f3669240000-7f3669241000 rw-p 00000000"
cmdline      = "com.google.android.gms.unstable"
env_path     = "/product/bin:/apex/com.android.runtime/bin:/apex/com.android.art/bin:[ ... ]"
cache_dir    = "/data/user/0/com.google.android.gms/cache"

vbmeta_device_state = "locked"
vbmeta_digest       = "5c43a03e2a47d742deefb3a05c2bcdd1afadedb89ddbdba7651f99fdc92438f8"
verifiedbootstate   = "green"
security_patch      = "2021-12-12"
f134                = "com.google.android.gms" # Output of com.google.android.gms.droidguard.loader.RuntimeApi.c()
kernel_info         = "5.4.223-ga45ffa6db-74ceeb #1 SMP PREEMPT Tue Jul 21 01:52:07 UTC 2021"
flow                = "attest"
installer           = "com.android.vending"
proc_self_stat      = "561 (id.gms.unstable) S 949 949 0 0 -1 107832 324 0 0 0 "
```

Telemetry

```
f242 = [
  # List of KeyStore.getCertificateChain (Hardware attestation → CTS Profile)
]
mount_info = [
  "/dev/block/loop22 /apex/com.android.art@1"      "/dev/block/loop22 /apex/com.android.art",
  "/dev/block/loop23 /apex/com.android.i18n@1"     "/dev/block/loop23 /apex/com.android.i18n"
  "/dev/block/loop27 /apex/com.android.vndk.v30@1" "/dev/block/loop27 /apex/com.android.vndk.v30"
]
proc_self_maps_info = [
    "/apex/com.android.art/javalib/bouncycastle.jar",
    "/system/framework/boot-ims-common.vdex",
    "/data/data/com.google.android.gms/app_dg_cache/1FEFB755F7DFAAFB69E71C4B872D96A200EC65BF/the.apk"
    ...
]
current_class_loaders = """
dalvik.system.PathClassLoader[
    DexPathList[
        [zip file "/data/app/~~**********************==/com.google.android.gms-*************-******-*A==/base.apk"]
        nativeLibraryDirectories=[/system/lib64, /system/product/lib64]
    ]
]
"""
```

Telemetry & Device's Integrity Checks

DroidGuard

the.apk

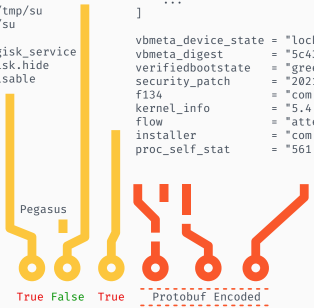
```
libriru_snet-tweak-riru.so
frida-agent-64.so
libva-native.so
libriru_edxp.so

/data/local/tmp/su
/vendor/bin/su

init.svc.magisk_service
persist.magisk.hide
ro.magisk.disable
```

```
proc_self_maps_info = [
    "/apex/com.android.art/javalib/bouncycastle.jar",
    "/system/framework/boot-ims-common.vdex",
    ...
]

vbmeta_device_state = "locked"
vbmeta_digest       = "5c43a03e2a47d742deefb3a05 [...]"
verifiedbootstate   = "green"
security_patch      = "2021-12-12"
f134                = "com.google.android.gms"
kernel_info         = "5.4.223-ga45ffa6db-74ceeb [...]
flow                = "attest"
installer           = "com.android.vending"
proc_self_stat      = "561 (id.gms.unstable) S [...] "
```




```
DroidGuardResult = "CgZpApMYiWYSi9cB [..]"
```

Conclusion

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After investigation, it seems that DroidGuard is not only used to run Google's bytecode related to SafetyNet.

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It can also run *programs* which are named:

attest/full : SafetyNet checks ($\sim$ 70 KiB)

msa-f : ??? ($\sim$ 7 KiB)

checkin : for Google account enrollment? ($\sim$ 50KiB)

ad_attest : to prevent ad-frauds? ($\sim$ 50KiB)

federatedMachineLearningReduced : ??? ($\sim$ 50 KiB)

po-token-fast,hades_persephone_risk,smartsetup_2,dcs_get_verdict ...

Conclusion

What is the cost of such *reverse engineering*?

What is the cost of such *reverse engineering*?

1. The reverse engineering of DroidGuard is not trivial and requires tooling:
    - Code lifting/emulation with QBDL and Unicorn
    - Dynamic analysis with Frida Gum[6]
    - Static code analysis with IDA
    - MBA simplifications with msynth on the top of Miasm
    - Dedicated tools to inspect the VM:
        - Dump the VM's registers
        - Decode the encoded buffers
        - ...

[6] Combined with LIEF for the runtime integrity bypass

What is the cost of such *reverse engineering*?

2. Regular updates which occur $\sim$ 2 weeks requires to automate the process.[7]

    - To have a good overview of the design: $\sim$ 5 weeks
    - To create dedicated tools: $\sim$ 2 weeks
    - In the end, a new version of the VM could be reversed[8] in a couple of hours

[7] Or you give-up

[8] Identifying the VM handlers, the mapping of the registers types, the encodings, ...

What is the cost of such *reverse engineering*?

3. Conclusion:

    - Well protected and difficult to circumvent
    - The `basicIntegrity` flag can – in the end – be bypassed without Magisk Hide[9]

[9] PoC: `https://www.romainthomas.fr/projects-images/safetynet/`

What are the limits of the SafetyNet's design?

What are the limits of the SafetyNet's design?

The VM runs in a dedicated process[10] and the checks are done in this memory space.

$\Rightarrow$ They **cannot** detect local tampering in the application that performed the SafetyNet request.

[10] com.google.android.gms.unstable

What are the limits of the SafetyNet's design?

This is why MagiskHide only had to target `com.google.android.gms.unstable`[11] to bypass SafetyNet.

[11] and, to a lesser extent `com.google.android.gms`

Conclusion

The hidden messages …

The hidden messages ...

”What brings you to these parts of town?
Say hi to droidguard-hello+xxxxxxxxxxxxxxxx@google.com”

The hidden messages ...

”You just keep pulling back the layers!
Say hi to droidguard-hello+xxxxxxxxxxxxxxxx@google.com”

The hidden messages …

1. The email's suffix is **unique** per-bytecode

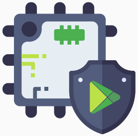
The hidden messages ...

1. The email's suffix is **unique** per-bytecode
2. The bytecode is **unique** per-request

The hidden messages …

1. The email's suffix is **unique** per-bytecode
2. The bytecode is **unique** per-request
3. Telemetry data embeds enough information to uniquely identify your device

Hardware Attestation



```java
KeyStore ks = KeyStore.getInstance("AndroidKeyStore");
ks.load(null);
ks.aliases(); // Iterate and check the aliases

long rndLong = (new Random()).nextLong();
String alias = "unstable.<hash>." + rndLong.toString();

KeyGenParameterSpec spec = new KeyGenParameterSpec.Builder(alias, KeyProperties.PURPOSE_SIGN)
  .setAlgorithmParameterSpec(new ECGenParameterSpec("secp256r1"))
  .setDigests(KeyProperties.DIGEST_SHA512)
  .setAttestationChallenge(<unique number>)
  .build();

KeyGenerator keyGenerator = KeyPairGenerator.getInstance("EC", "AndroidKeyStore");
keyGenerator.initialize(spec);
keyGenerator.generateKeyPair();

Certificate certificates[] = keyStore.getCertificateChain(alias);
```

Thank you for your attention

Thank you for your attention

Questions?

@rh0main