Perils of Running Apps in Android Virtual Containers

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Intro

Overview

- **Introduction** to Android virtual containers.
- **Use case** and current market status of virtual container apps.
- **Attacking** applications running inside virtual containers.
- How to **detect** virtual containers
- **Recommendation** for developers
- **Discussion**
- **Conclusion**

About Us

- **Gautam Arvind Pandian**
  - Security Researcher and Architect at *Thales DIS, Singapore*
  - Interests: Crypto, Hardening Mobile Apps

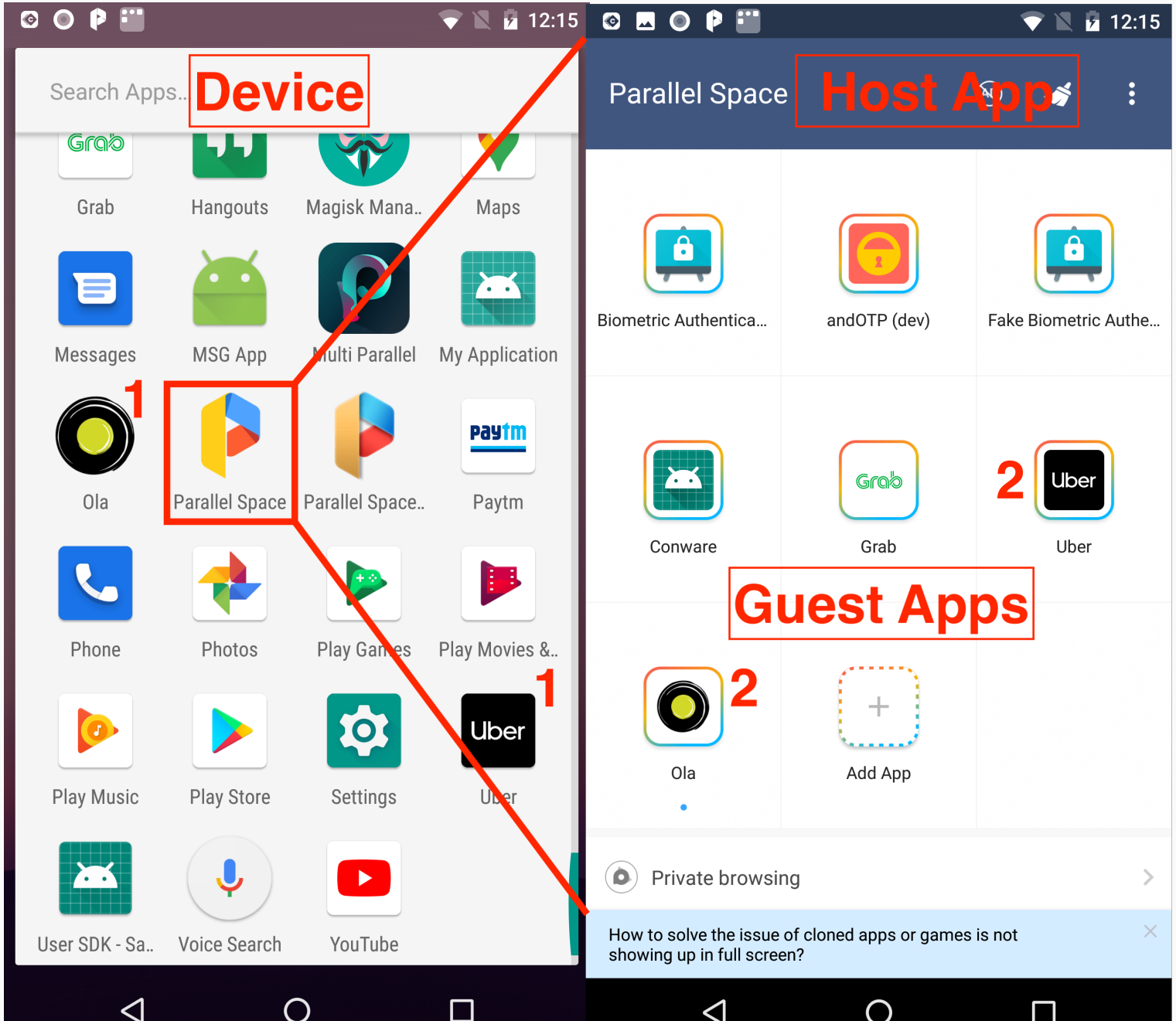
- **Vikas Gupta**
  - Security Researcher and Pentester at *Thales DIS, India*
  - M.Sc in Security, OSCP certified
  - Co-Author contributor for *OWASP MSTG* (Mobile Security Testing Guide)
  - Interests: Reverse Engineering, Obfuscation, Crypto

Android Virtual Containers

What are Virtual Containers?

- Innovative application-level virtualisation framework.
- Consists of an **Android application** (*host*) running multiple *guest* Android apps.
- *Guest* app does not require any installation.
- *Guest* app can be a second instance of an existing application on the actual device.
- **Virtual Containers reduces the security of *guest* apps.**

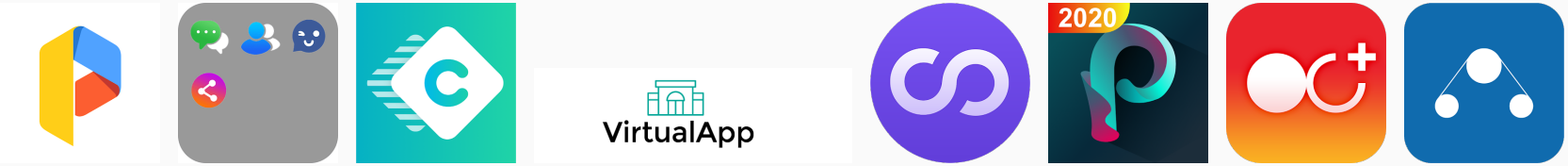
Android Virtual Containers



Android Virtual Containers

- *Android-Plugin: Don't Let Your App Play as an Android Plugin* in BlackHat Asia 2017.
- Detailed description on the working.
- Discussed from a malware-centric point of view.
- Proposed ideas for detecting virtual containers.
- **Note:** We find the term *Android Plugin* confusing and not descriptive enough, and instead we use **Virtual Container**.

Where Can I Get One?



- **Virtual App** - GitHub
  - Many virtual container apps derived from this project
- **Droid Plugin** - GitHub
- **Parallel Space** - 100M+ downloads
- **Dual Space** - 100M+ downloads
- **2 Accounts, Multi Parallel, Dual App** - 5M+ downloads
- **Dr.Clone, Clone App, Super Clone** - 1M+ downloads
- Download numbers suggest used by **millions of users**.

Parallel Apps on OnePlus Devices

- A hardcoded list of apps allowed to have multiple instances - around 56 apps.
- **Does not use virtual container approach.**
- **Creates a new Android user** internally for running second instance of an app.
- Messaging apps: Whatsapp, WeChat
- Social Media: FB, Instagram, Twitter, Pinterest
- Ride-Hailing: Uber, Ola
- Digital Payment: Paytm, AliPay
- And many other Chinese apps.
- **Xiaomi** supports similar functionality with name *Dual Apps*.

Is it Really Needed?

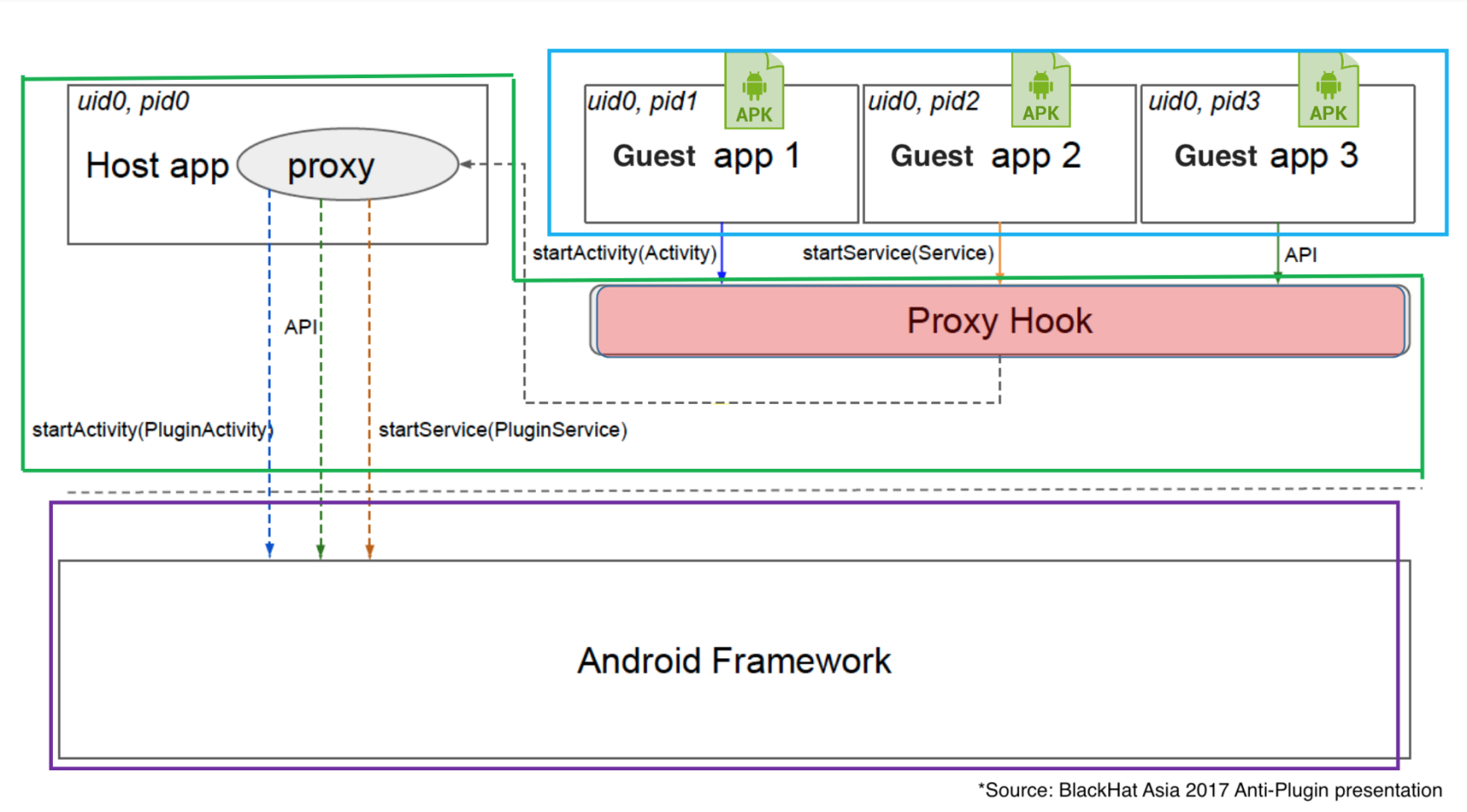
- With many dual sim devices, users need two accounts for each number.
- Run multiple instances of chat messengers, ride-hailing apps, social media accounts, e-commerce apps etc.
- Segregate personal and business apps on one device.
- Run games - enables to tinker with games without being root.

Working of Virtual Containers

Working Under the Hood

- **Create a virtual environment on top of and transparent to the Android framework.**
- Different from the widely used dynamic code loading approach.
- Hooking using **Java Dynamic Proxy API** and **reflection**.
  - Java provides JDP API for creating dynamic proxy of a class or an instance using proxy design pattern.
  - Uses reflection for APIs defined inside the Android framework.
- Hooks APIs related to app lifecycle and its components (activity, service, broadcast receiver, content providers)
- Redirect the *guest* apps data to an app specific folder within the *host's* data path.
- Hook libc APIs to provide alternative implementation using CydiaSubstrate

Working Under the Hood



*Source: BlackHat Asia 2017 Anti-Plugin presentation

Working Under the Hood

- **Shared UID:** All *guest* apps share the same UID with the *host* app
- **Pre-defined stub components and permissions**: The *host* app has pre-defined components and permissions for *guest* apps.
- **Component Lifecycle Management:** When the component in the *guest* app process is ready to be destroyed, the corresponding stub component should also be destroyed simultaneously.
- BlackHat Anti-Plugin paper discusses in good detail.

App Security in Virtual Containers

Application UID

- In Android, each application get unique UNIX user ID (UID) and a directory owned by the app.
- The unique per-app UID simplifies permission checking and eliminates racy per-process ID (PID) checks.
- Many security mechanisms depend on uniqueness of each app's UID.

Android Built-In Security

- From Android documentation, most of the Android core security features are broken for a *guest* app.

The following core security features help you build secure apps:

1. The Android Application Sandbox, which isolates your app data and code execution from other apps. X
2. An application framework with robust implementations of common security functionality such as cryptography, permissions, and secure IPC. X
3. Technologies like ASLR, NX, ProPolice, safe_iop, OpenBSD dlmalloc, OpenBSD calloc, and Linux mmap_min_addr to mitigate risks associated with common memory management errors. ✓
4. An encrypted file system that can be enabled to protect data on lost or stolen devices. ✓
5. User-granted permissions to restrict access to system features and user data. X
6. Application-defined permissions to control application data on a per-app basis. X

X - Broken
✓- Not Broken

- 3 & 4 are lower in abstraction layer than at which virtual container operates, and thus not affected.

Breaking Android Security Model

- Many Android security and privacy features depend upon UID assigned to an app:
  - **Application Permissions**
  - **Android Keystore**
  - **Android ID**
- Unauthorized access to other *guest* app's **sandbox data**.
- A *guest* app can get list of other running *guest* apps.

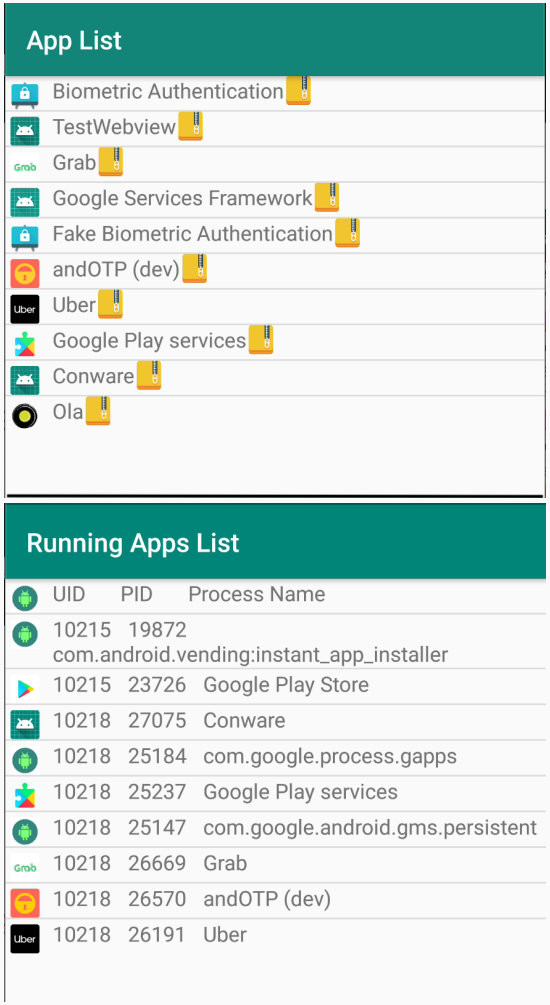
Android Manifest - Permissions

- **All or none**: For one granted permission, all *guest* apps get access for that permission.
- **DroidPlugin declares 141 permissions** in manifest file.
- In a virtual container, an app is never installed, thus manifest data is not really processed.
- Granted permissions persist even if the *guest* app that requested is uninstalled.
- A major **privacy concern**.
- On manually disabling a permission may break some other *guest* app.

```
<!--预申请很多权限。也是为了插件使用-->
<uses-permission android:name="android.permission.ACCESS_COARSE_LOCATION" />
<uses-permission android:name="android.permission.ACCESS_FINE_LOCATION" />
<uses-permission android:name="android.permission.ACCESS_LOCATION_EXTRA_COMMANDS" />
<uses-permission android:name="android.permission.ACCESS_NETWORK_STATE" />
<uses-permission android:name="android.permission.ACCESS_WIFI_STATE" />
<uses-permission android:name="android.permission.ACCESS_WIMAX_STATE" />
<uses-permission android:name="android.permission.AUTHENTICATE_ACCOUNTS" />
<uses-permission android:name="android.permission.BLUETOOTH" />
<uses-permission android:name="android.permission.BLUETOOTH_ADMIN" />
<uses-permission android:name="android.permission.BODY_SENSORS" />
<uses-permission android:name="android.permission.BROADCAST_STICKY" />
<uses-permission android:name="android.permission.CALL_PHONE" />
<uses-permission android:name="android.permission.CAMERA" />
<uses-permission android:name="android.permission.CHANGE_NETWORK_STATE" />
<uses-permission android:name="android.permission.CHANGE_WIFI_MULTICAST_STATE" />
<uses-permission android:name="android.permission.CHANGE_WIFI_STATE" />
<uses-permission android:name="android.permission.CHANGE_WIMAX_STATE" />
<uses-permission android:name="android.permission.CLEAR_APP_CACHE" />
<uses-permission android:name="android.permission.DISABLE_KEYGUARD" />
<uses-permission android:name="android.permission.DOWNLOAD_WITHOUT_NOTIFICATION" />
<uses-permission android:name="android.permission.EXPAND_STATUS_BAR" />
<uses-permission android:name="android.permission.FLASHLIGHT" />
<uses-permission android:name="android.permission.GET_ACCOUNTS" />
<uses-permission android:name="android.permission.GET_PACKAGE_SIZE" />
<uses-permission android:name="android.permission.GET_TASKS" />
<uses-permission android:name="android.permission.INTERNET" />
<uses-permission android:name="android.permission.KILL_BACKGROUND_PROCESSES" />
<uses-permission android:name="android.permission.MANAGE_ACCOUNTS" />
<uses-permission android:name="android.permission.MODIFY_AUDIO_SETTINGS" />
<uses-permission android:name="android.permission.NFC" />
<uses-permission android:name="android.permission.PERSISTENT_ACTIVITY" />
<uses-permission android:name="android.permission.PROCESS_OUTGOING_CALLS" />
<uses-permission android:name="android.permission.READ_CALENDAR" />
<uses-permission android:name="android.permission.READ_CALL_LOG" />
<uses-permission android:name="android.permission.READ_CELL_BROADCASTS" />
<uses-permission android:name="android.permission.READ_CONTACTS" />
<uses-permission android:name="android.permission.READ_EXTERNAL_STORAGE" />
<uses-permission android:name="android.permission.READ_INSTALL_SESSIONS" />
<uses-permission android:name="android.permission.READ_PHONE_STATE" />
```

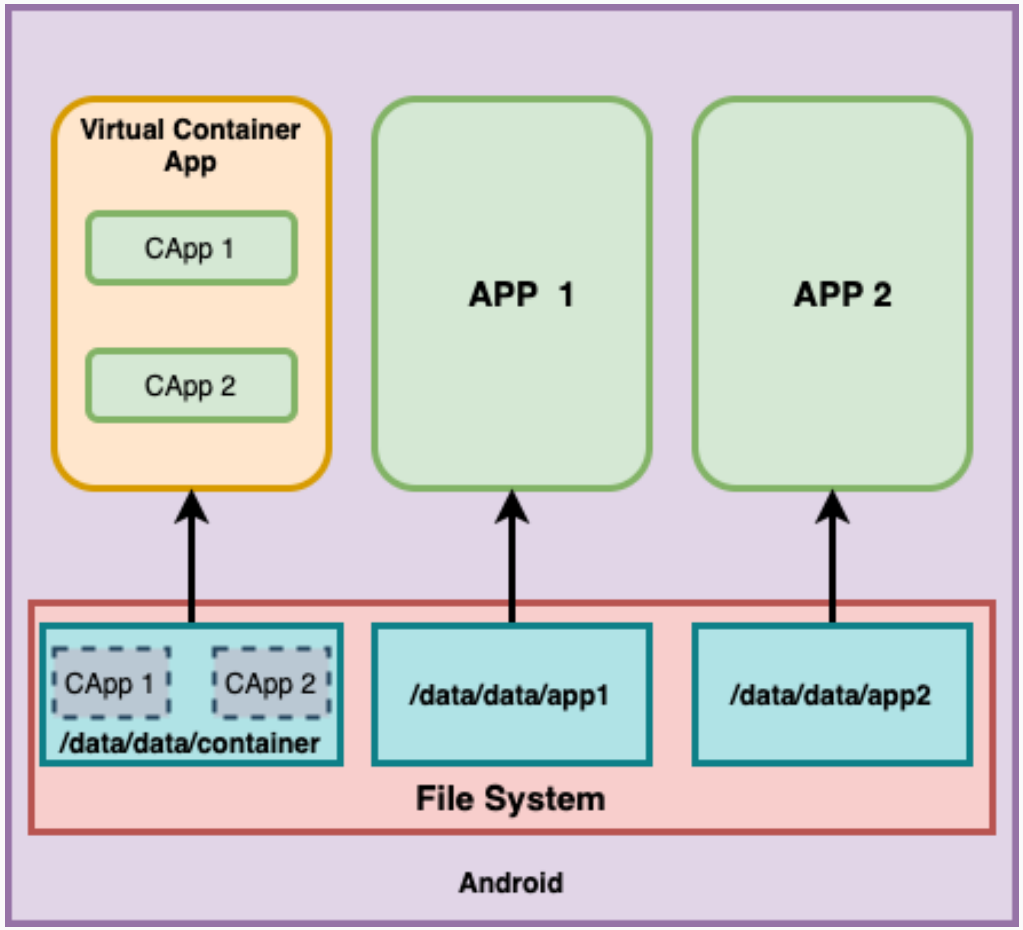
List Other Guest Apps

- Can get list of other **installed** and **running** *guest* apps in the virtual container.
- List of installed apps by iterating the storage directory.
- From API 22 (Android 5.1.1) it is deprecated to list running apps.
- A **privacy** concern.



Android Filesystem Sandbox

- Data sandboxing: One app cannot access data from another app.
  - Implemented and enforced at the kernel level.
- No data sandboxing between *guest* apps in a virtual container.

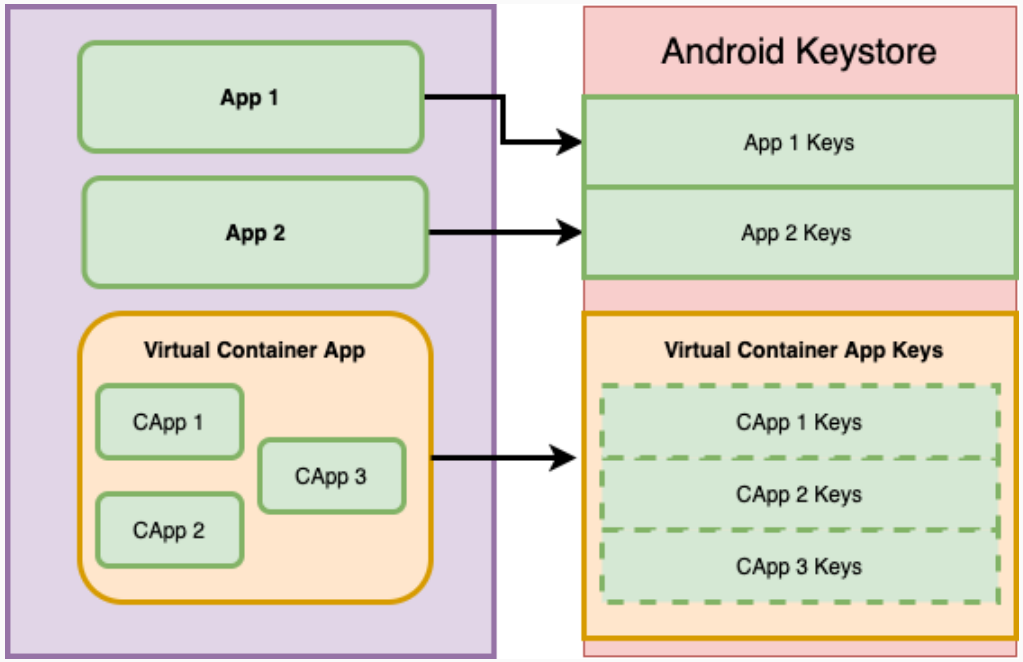


Android Keystore

- *The Android Keystore system lets you store cryptographic keys in a container to make it more difficult to extract from the device.*
- A secure system level credential storage.
- Can be either hardware-backed or in software, as per device support.
- Only the app that creates/imports a key can perform crypto operations with the key (UID based).

Android Keystore

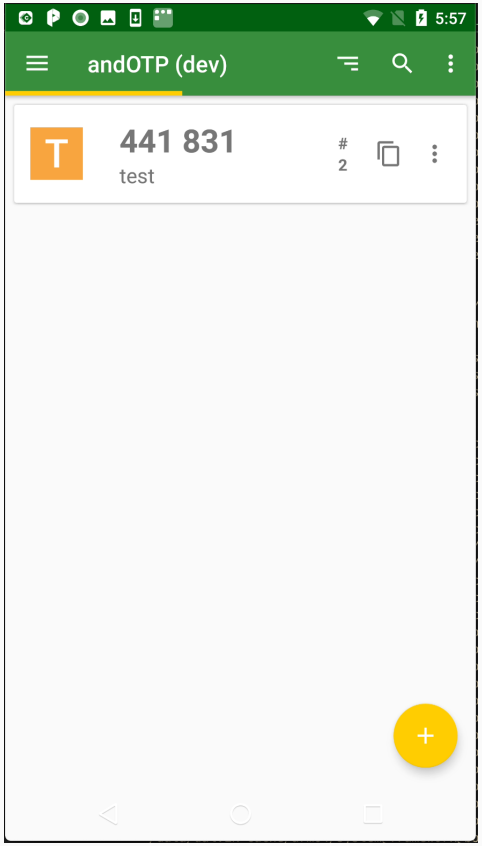
- In a virtual container, all apps have same UID!!



- *Host* and *Guest* apps have access to all the keys generated by other *guest* apps.
- Keys remain in keystore even if the *guest* app that generated it is removed from the container.
- Brings back an old bug - key leakage between security domains

DEMO: Attacking Filesystem and Keystore

- **andOTP** - App for generating 2FA TOTP and HOTP tokens.
- **Version**: 0.7.0
- https://github.com/andOTP

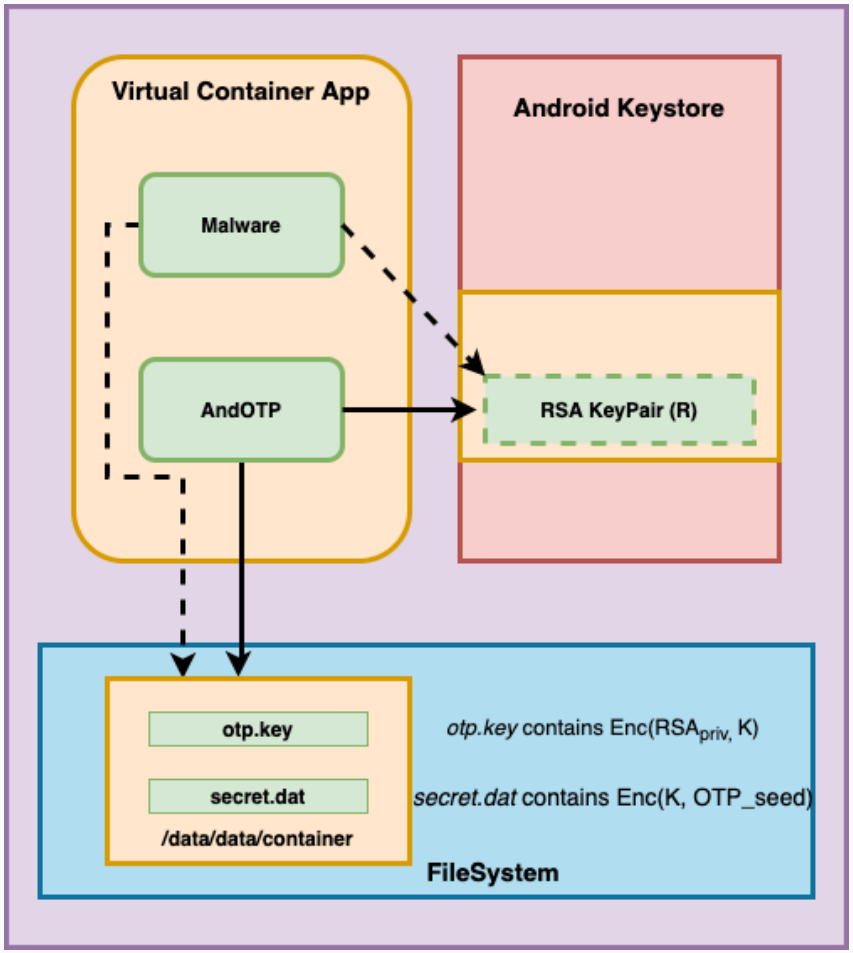


DEMO: Attacking Filesystem and Keystore

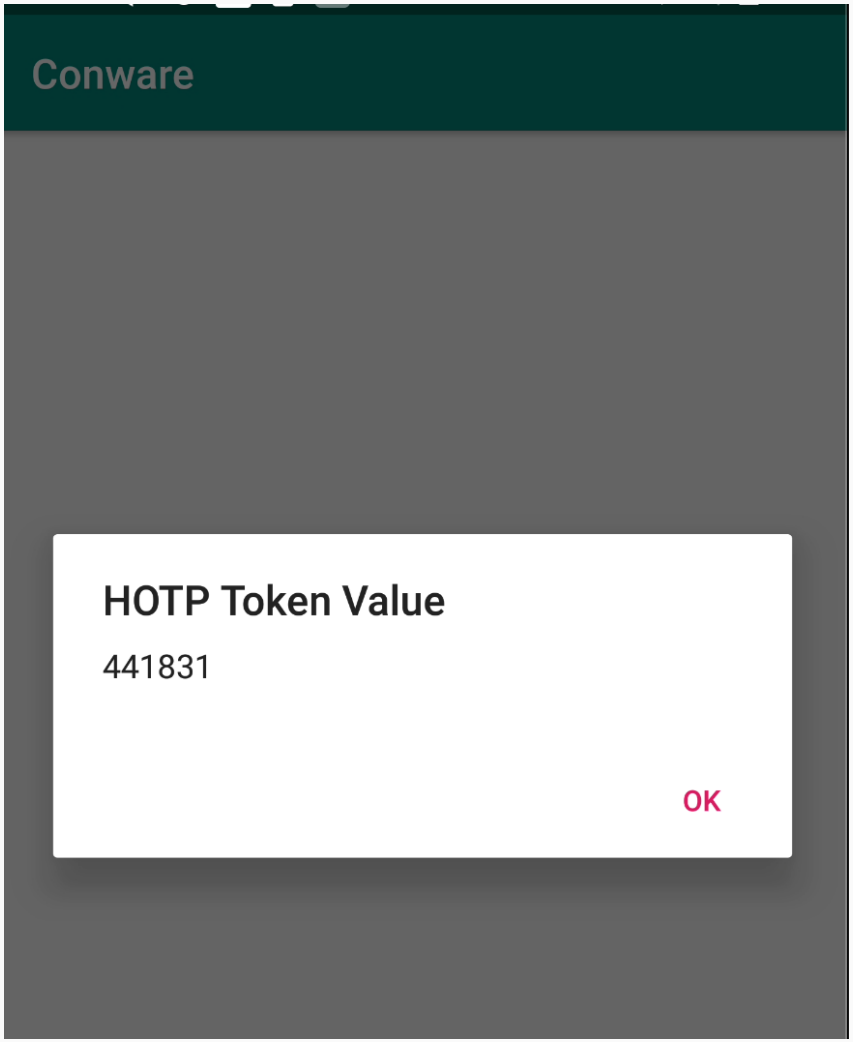
- Option to have **encrypted data backup** using a hardware-backed keystore.
- OTP seeds and related data is encrypted using AES `key K` and stored in **secret.dat** file.
- AES `key K` is generated using the user provided password.
- `Key K`, in turn, is encrypted using a RSA keypair generated in a hardware-backed keystore and stored in **otp.key** file.
- In this attack, a *guest* app will access sandbox data and keystore keys of *guest* andOTP app.

DEMO: Attacking Filesystem and Keystore

- Using a malware *guest* app, we can decrypt the data, steal the OTP seeds and generate OTPs.



DEMO: Video



Pentesting Environment

Virtual Containers as a Pentesting Environment

- A virtual container can provide a basic pentesting environment.
- No need to always **patch**, **re-compile** and **re-sign** a *guest* app while pentesting.
- Many *runtime application self-protection* (RASP) mechanisms can be bypassed in such environment.

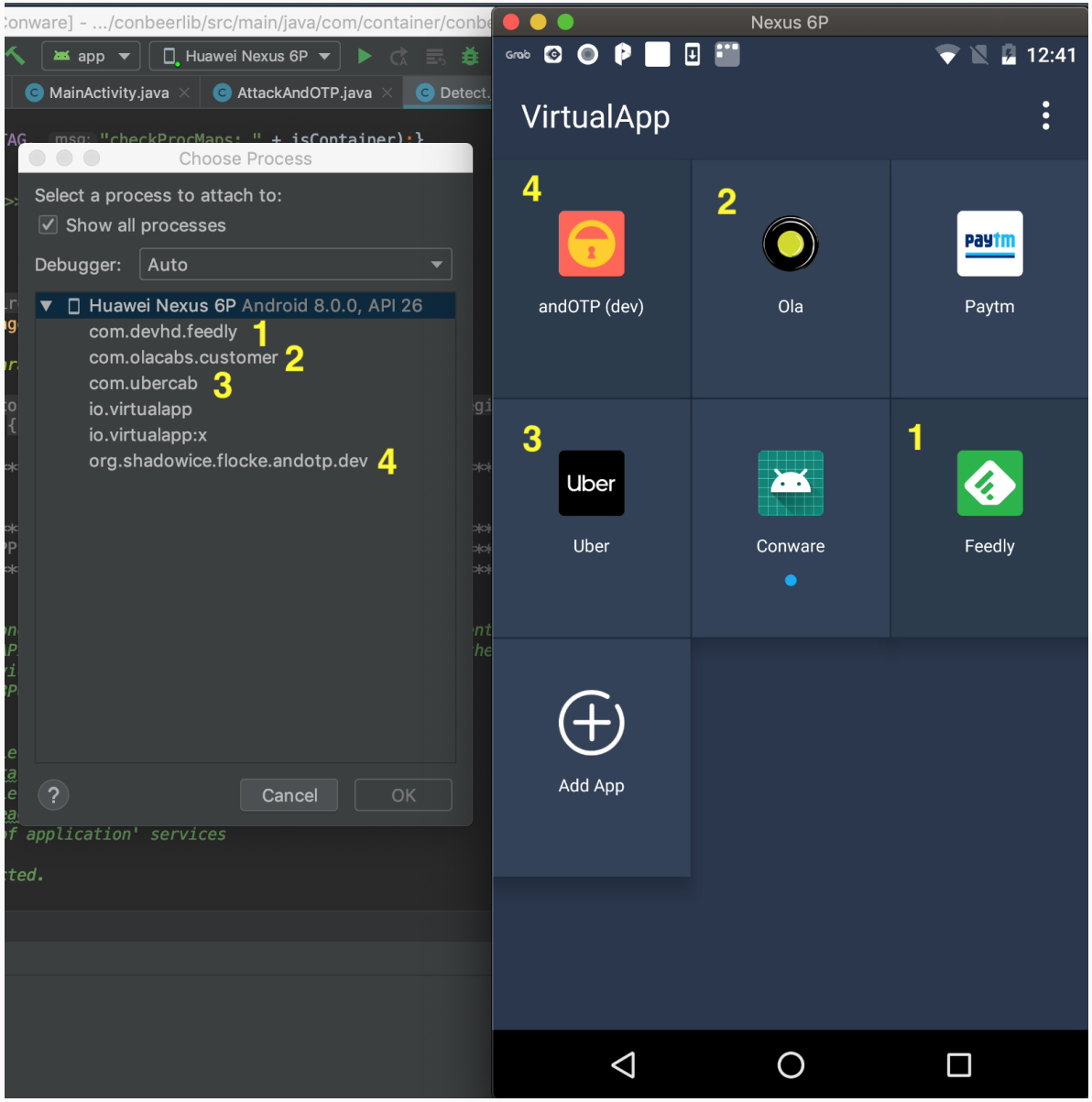
Apktool can fail sometimes

```
└─ apktool d test.apk
I: Using Apktool 2.4.1 on test.apk
I: Loading resource table...
I: Decoding AndroidManifest.xml with resources...
I: Loading resource table from file: /Users/lostboy/Library/apktool/framework/1.apk
I: Regular manifest package...
I: Decoding file-resources...
I: Decoding values */* XMLs...
Exception in thread "main" java.lang.NullPointerException
        at brut.androlib.res.data.value.ResEnumAttr.serializeBody(ResEnumAttr.java:56)
        at brut.androlib.res.data.value.ResAttr.serializeToResValuesXml(ResAttr.java:64)
        at brut.androlib.res.AndrolibResources.generateValuesFile(AndrolibResources.java:742)
        at brut.androlib.res.AndrolibResources.decode(AndrolibResources.java:263)
        at brut.androlib.Androlib.decodeResourcesFull(Androlib.java:129)
        at brut.androlib.ApkDecoder.decode(ApkDecoder.java:124)
        at brut.apktool.Main.cmdDecode(Main.java:170)
        at brut.apktool.Main.main(Main.java:76)
```

Android Manifest - Debuggable

- `android:debuggable='true'` is needed to debug an Android application.
- By default an application is **not** debuggable.
- For a 3rd party app from Play Store, requires recompiling and resigning an app using `apktool`
- If the *host* is debuggable, then all the *guest* apps become debuggable.
  - Possible to attach Android debugger to *guest* apps
  - *ptrace* can be attached between guest apps and from host app to guest app and vice versa
- With container being debuggable, no additional steps for recompiling and resigning needed.

Android Manifest - Debuggable



Android Manifest - Network Security Config

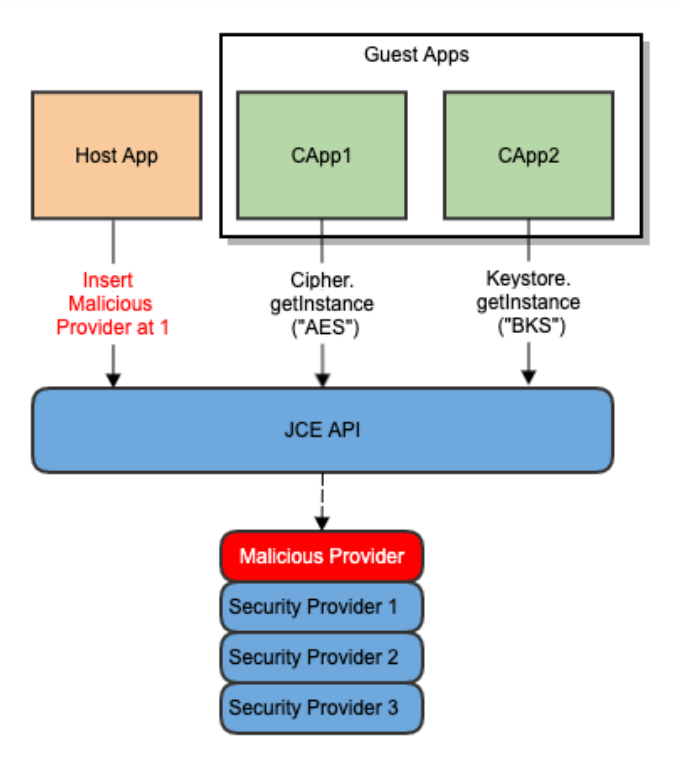
- Since Android Nougat (7.0), apps can customize their network security settings.
- User installed TLS CA certs are not trusted by default, requires explicit declaration in manifest file.
- By setting attribute *android:networkSecurityConfig*.
- Network Security Configuration of *host* will be inherited by all the *guest* apps.
- If *host* trusts self-signed certs, a *guest* app will trust too.

```
<?xml version="1.0" encoding="utf-8"?>
<manifest ... >
    <application android:networkSecurityConfig="@xml/network_security_config"
                    ... >
        ...
    </application>
</manifest>
```

```
<network-security-config>
      <base-config>
            <trust-anchors>
                <!-- Trust preinstalled CAs -->
                <certificates src="system" />
                <!-- Additionally trust user added CAs -->
                <certificates src="user" />
            </trust-anchors>
      </base-config>
 </network-security-config>
```

Java Security Provider

- A provider for Java Security API
  - Cryptographic engines
  - Keystore
- *Host* app can override the security provider used in the *guest* apps, if not explicitly specified in *guest* apps.
- *Guest* apps relying on system default security provider are at risk.



Java Secruity Provider: andOTP

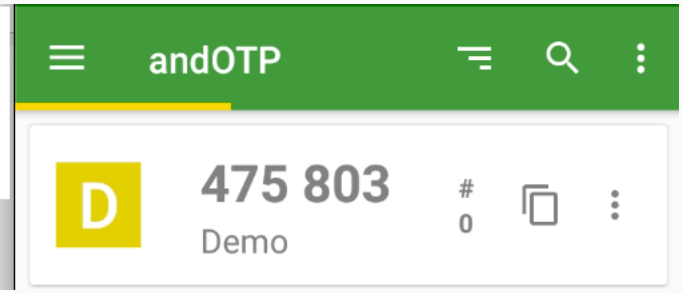
Logs from Malicious
Security Provider

```
HMAC:Init key:3BBBBA0209A347BFD3A14F87A924AEE4154DA2741E8DF4CDD076469CF513879C518F61
HMAC:Init keylength:35
HMAC:Init DigestSize:32
HMAC:dofinal output:BF80E5859C85053FFBF0DBB0C759313B7AEE81A95F5C86DBB10D39AB657085B7
```

OTP Seed

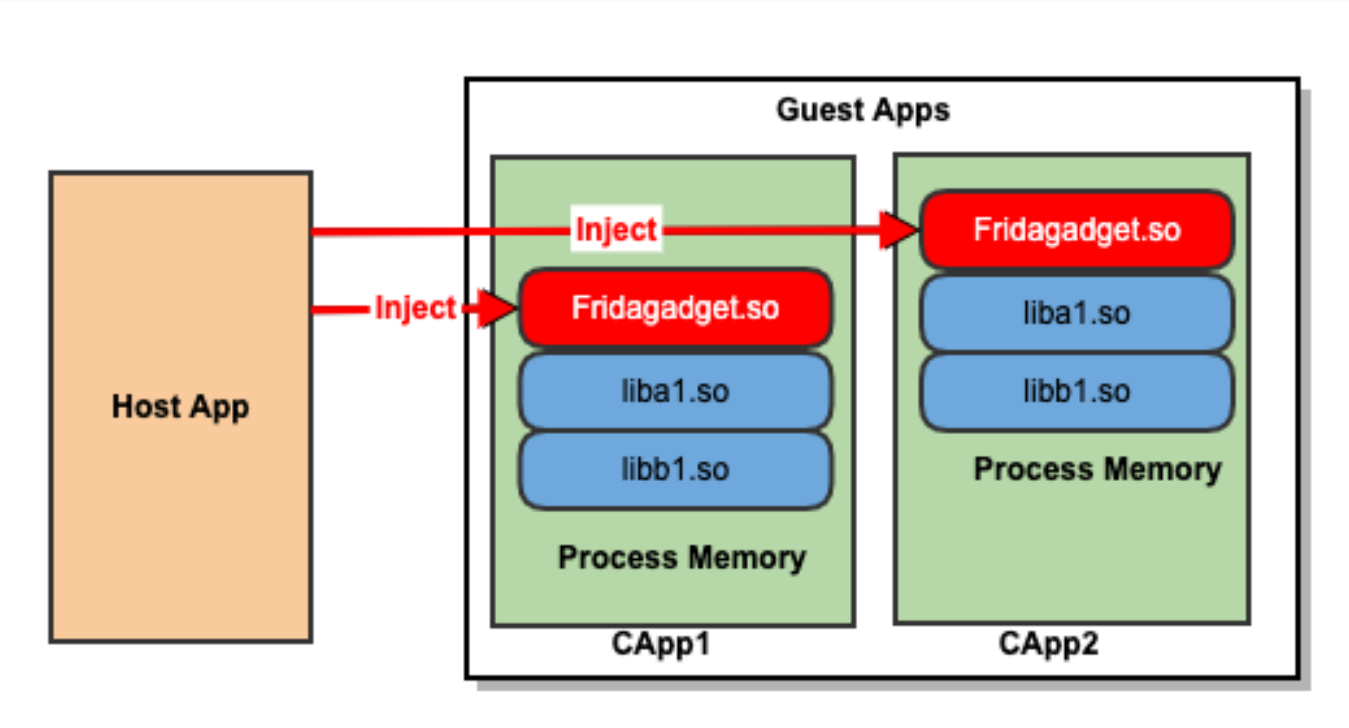
OTP Value

OTP Offset



Dynamic Instrumentation

- Pre-load native libraries
  - *Fridagadget* can be pre-loaded when a *guest* app is invoked.
  - Easy to perform dynamic instrumentation on *guest* apps



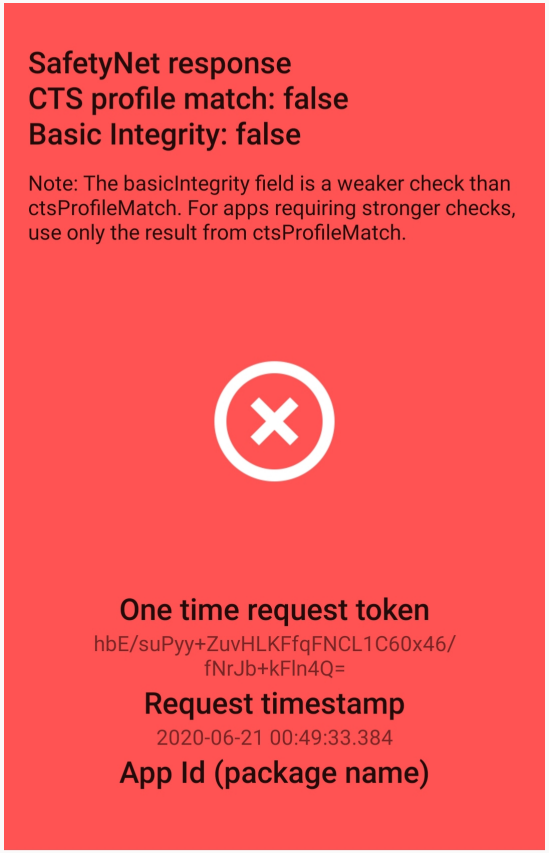
Summary of Attacks

- **Android Manifest**
  - Permissions
  - Debuggable
  - Network Security Config
- List all running *guest* apps
- Application's **Filesystem Sandbox**
- **Android Keystore**
- Manipulating **Java Security Providers**
- **Dynamic instrumentation** of a *guest* app
- Not an exhaustive list, many other attacks may be possible.
  - **Android ID:** Used for anti-cloning purposes but it is same for all *guest* apps.

Detecting Virtual Containers

SafetyNet

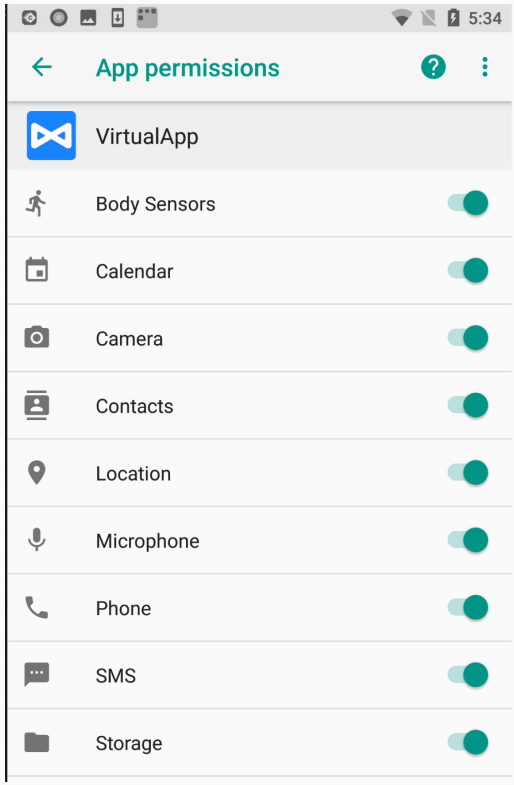
- A set of services and APIs that help protect app against security threats:
  - Device tampering
  - Bad URLs
  - Potentially harmful apps
  - Fake users
- SafetyNet check **fails** for a *guest* app.
- The *basic integrity & CTS profile match* checks fail.
- Not all virtual containers support Google Play Services.



Detection Using Heuristics

1. Manifest Permissions

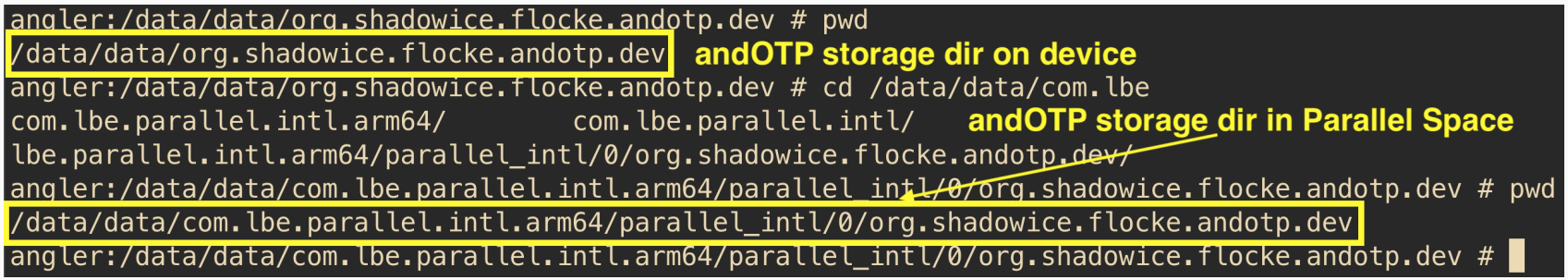
- In a container, a *guest* app may have more permissions than declared in manifest.




```
<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
    package="com.container.conware">
    <uses-permission android:name="android.permission.INTERNET" />
    <uses-permission android:name="android.permission.READ_EXTERNAL_STORAGE" />
    <uses-permission android:name="android.permission.WRITE_EXTERNAL_STORAGE" />
```

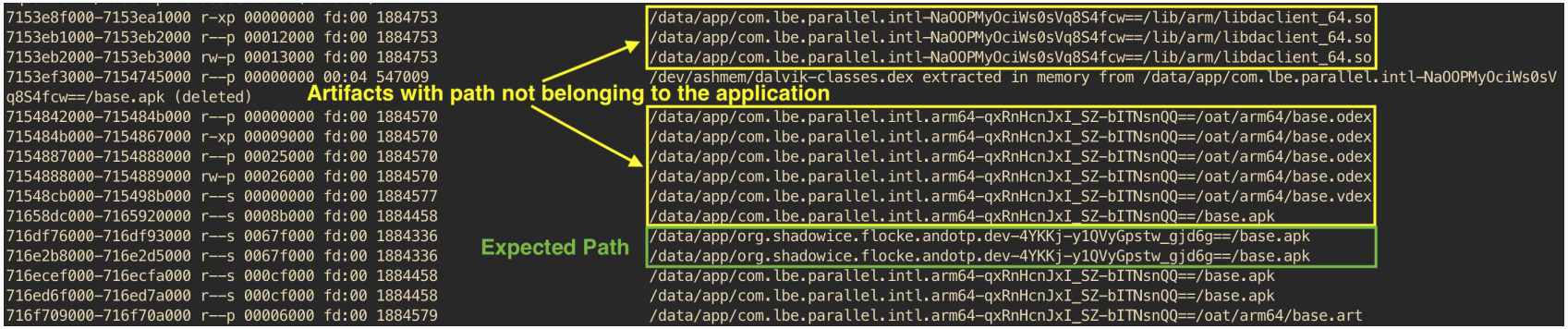
Detection Using Heuristics

2. **Storage directory**
   - Data stored inside virtual container app's directory.
   - On device - `/data/data/app_package_name`
   - In Parallel Space - `/data/data/com.lbe.parallel.intl.arm64/...`



Detection Using Heuristics

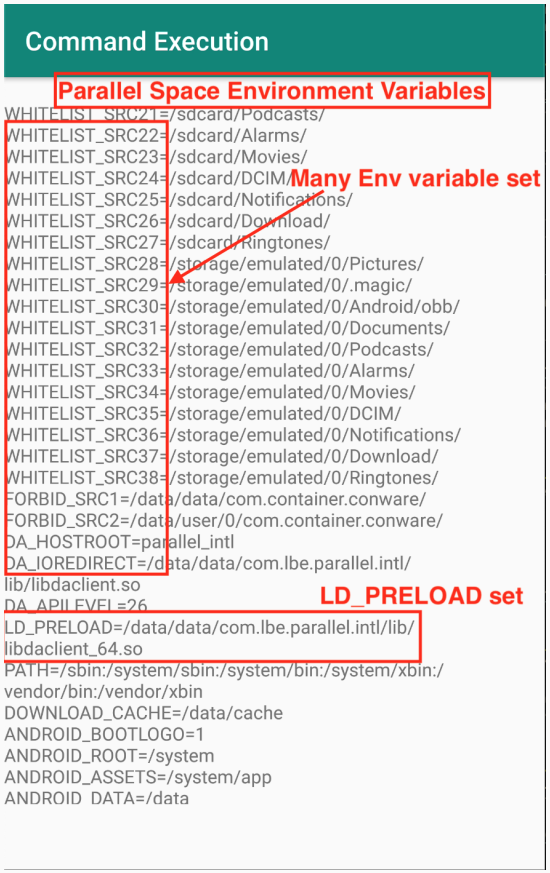
3. **Process Memory**
   - Check for files in memory not belonging to the app's filepath.
   - In `/proc/self/maps` artifacts should be only from either paths:
     - `/data/app/app_package_name`
     - `/data/data/app_package_name`



Detection Using Heuristics

4. **Environment Variables**

   - Check declared environment variables like *LD_PRELOAD* and many other custom variables.
   - Example: Parallel Space declare variables like *WHITELIST_SRC22*



Detection Using Heuristics

5. **Running Services**
   - Many containers have their own services running.
   - Check for the presence of services not belonging to the app.
   - e.g: `com.lbe.parallel.service.KeyguardService`

```
CONBEER  D  >>>>>>>> APP SERVICE NAMES <<<<<<<<<<<<
CONBEER  D  com.lbe.parallel.service.KeyguardService
CONBEER  D  cn.thinkingdata.android.TDQuitSafelyService$TDKeepAliveService
CONBEER  D  com.lbe.parallel.install.AppInstallService
CONBEER  D  com.lbe.doubleagent.service.proxy.KeepAliveService
CONBEER  D  checkAppServiceName: true
CONBEER  D  >>>>>>>> APP SERVICE NAMES: DONE <<<<<<<<<<<<
```

Running services for Parallel Space

Detection Using Heuristics

6. **App Components**
   - Declare **disabled** app components in the Manifest and **enable** them dynamically.
   - **Enabling** such components will **not work** in a virtual container.

Manifest - Component Disabled

```
<application>
    <receiver
        android:name=".utils.FakeBroadcastReceiver"
        android:enabled="false"
        android:exported="false"
        android:process=":fake_receiver">
        <intent-filter>
            <action
                android:name="com.container.conbeer.intent.TEST" />
        </intent-filter>
    </receiver>
```

Dynamically Enabled

```
ComponentName componentName = new ComponentName(this.getApplicationContext(), FakeBroadcastReceiver.class);
this.getPackageManager().setComponentEnabledSetting(componentName,
        PackageManager.COMPONENT_ENABLED_STATE_ENABLED,
        PackageManager.DONT_KILL_APP);
```

conbeerlib

- Releasing **conbeerlib**
  - In spirit of *rootbeerlib* :)
  - Open source, and will be available at https://github.com/su-vikas/conbeerlib
- Detects presence of virtual containers using various heuristic techniques discussed.
- *Caution:* Currently the library is not tested for all real world Android device madness, and may have rough edges.

conbeerlib

Apps / Checks	Parallel Space	Virtual App	Dual Space	Clone App	2Accounts	Dual Apps	Multi Parallel	Dr.Clone
Manifest Permissions	✓	✓	✓	✗	✓	✓	✓	✓
Process Memory	✓	✓	✓	✓	✓	✓	✓	✓
Environment	✓	✓	✓	✗	✓	✓	✗	✗
Storage Directory	✓	✓	✓	✓	✓	✓	✓	✓
Running Services	✓	✗	✗	✓	✓	✗	✗	✓
App Components	✓	✓	✓	✗	✗	✗	✓	✓

Recommendation for Developers

Recommendations

- Do not let your app run inside a virtual container, detect and take action.
  - Also increases the cost of re-packing an app as a malware (using virtual containers).
- Do not only depend on security offered by OS.
  - Encrypt data at rest.
- **Network**:
  - Prevent MITM
    - Certificate Pinning
  - Another layer of encryption or signing network traffic to avoid sniffing or tampering of data in transit.

Recommendations

- **Crypto**:
  - Use combination of hardware and software components for crypto key derivation.
  - Do not rely only on default platform Crypto and Keystore providers
  - Use crypto APIs directly, e.g. from BouncyCastle
  - Add and use explicit security providers, for crypto and keystore both
    - `Cipher.getInstance("AES", "BC")`
    - `KeyStore.getInstance("BKS", "BC")`
- Recommendations applicable as per threat model.

Discussion & Conclusion

Discussion

- Implications for end users
  - Users should avoid using virtual containers for sensitive apps, at least.
- More OEMs should support running multiple instances of an app - like OnePlus and Xiaomi.
- Support implemented in AOSP itself?
- Why is virtual containers supported by Android?
  - Leaving security decision in hands of an end user is not a good idea.
- Given the security implications, we are not able to reason why it is allowed.

Conclusion

- There is a need to **run multiple instances** of an app on a device.
- Virtual containers are **convenient** to use, but **breaks Android built-in security** model.
- Both security and privacy is a concern for *guest* apps.
- Virtual containers can be used as a basic **pentesting environment**.
- SafetyNet and heuristics can be used to detect virtual containers.
- **Our contribution:**
  - Documenting and demonstrating the attacks
  - New detection techniques and releasing conbeerlib

Thank You