Summer School on Real-World Crypto and Privacy 2024

Empirical Security Research in the Android Ecosystem

Three Short Pieces

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Talk based on several studies co-authored with

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This talk

The Android ecosystem

- 3+ billion active users
- 9+ million mobile apps

Complex supply chain

- Android Open Source Project (AOSP)
- Original Equipment Manufacturers (OEMs)
- Mobile Network Operators (MNOs)
- Device resellers
- Third-party developers
- Application markets
- Advertising and Tracking Services (ATS)

How do we conduct empirical security and privacy research in this ecosystem?

Examples, with a focus on the methods:

- **Preinstalled software**
- **Over-the-air system updates**
- Customizations of the permission system
- Software attribution
- **Sensitive data leakages through side channels**

Roadmap

An Analysis of Pre-installed Android Software
IEEE SP 2020

Trouble Over-The-Air: An Analysis of FOTA Apps in the Android Ecosystem
IEEE SP 2021

Log: It’s Big, It’s Heavy, It’s Filled with Personal Data! Measuring the Logging of Sensitive Information in the Android Ecosystem
USENIX Security 2023

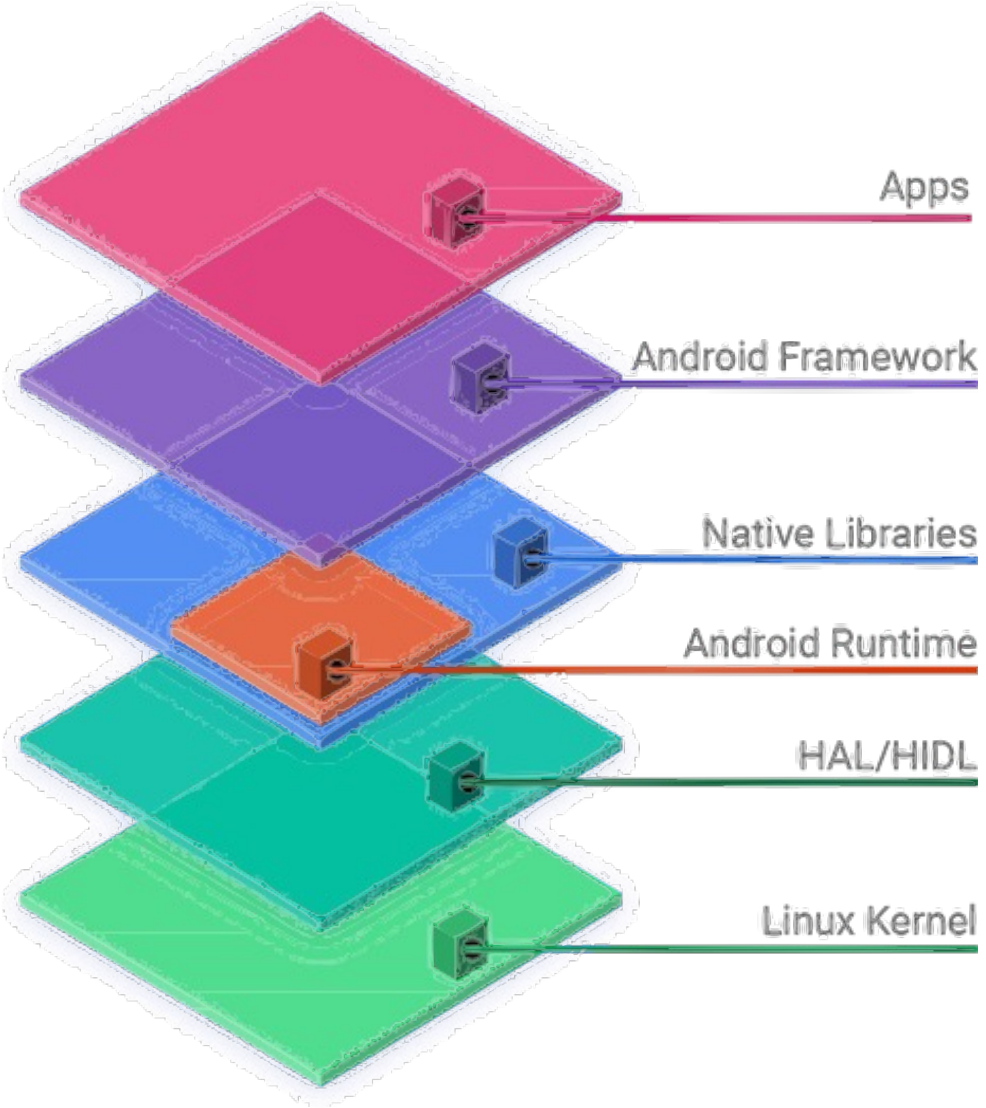
An Analysis of Pre-installed Android Software

Julien Gamba, Mohammed Rashed, Abbas Razaghpanah
Juan Tapiador, Narseo Vallina-Rodriguez

41st IEEE Symposium on Security and Privacy

3 billion active users
… and counting

Android Open Source Project (AOSP)



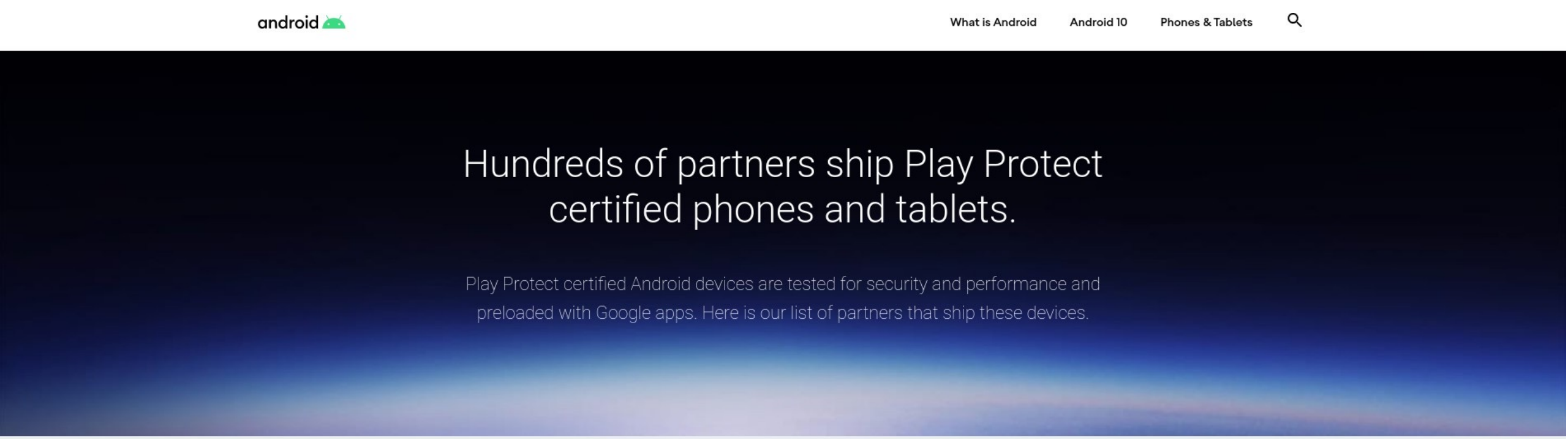
System applications

- are privileged by the system
- can run in background without user interaction
- cannot (easily) be uninstalled

The supply chain can be *very* large

The supply chain can be *very* large

Google Play Protect



Brands | ODMs

ACER	ADVAN DIGITAL	AIRTEL	AIWA
ALLVIEW	ALTICE	AMGOO	ANS
ARCHOS	ASUS	AT&T	AZUMI
BITEL	BLU	BLUEBIRD	BMOBILE

This has serious privacy and security implications

Let’s take a deep look at this ecosystem

Research questions

1. who pre-installs applications on Android devices?

13

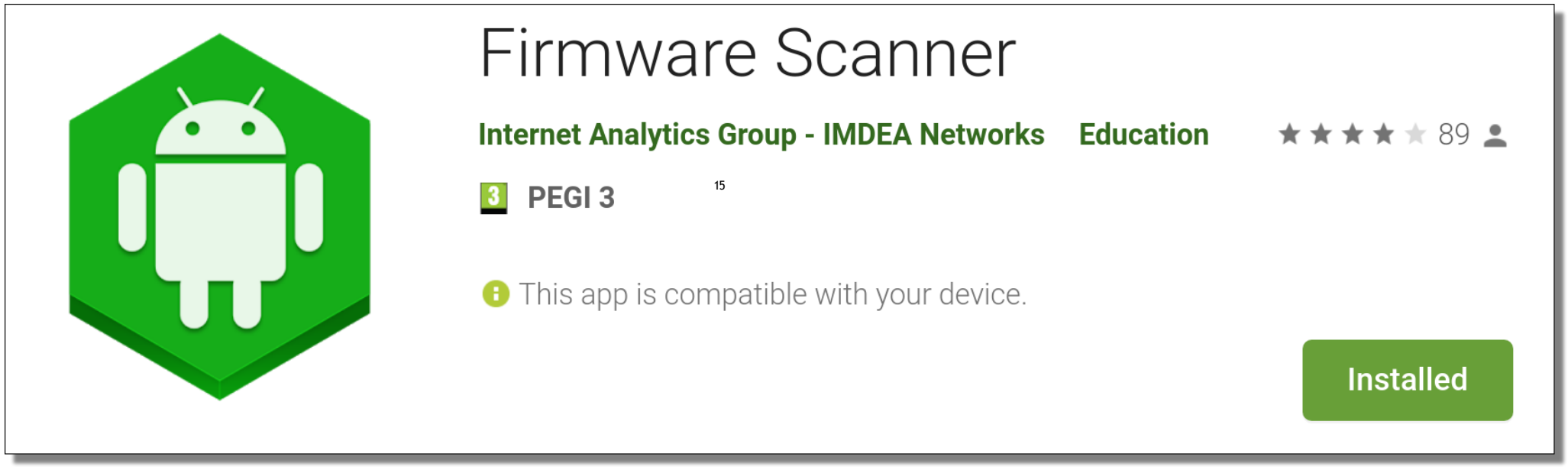
2. what are these apps doing?

3. what can we do about it?

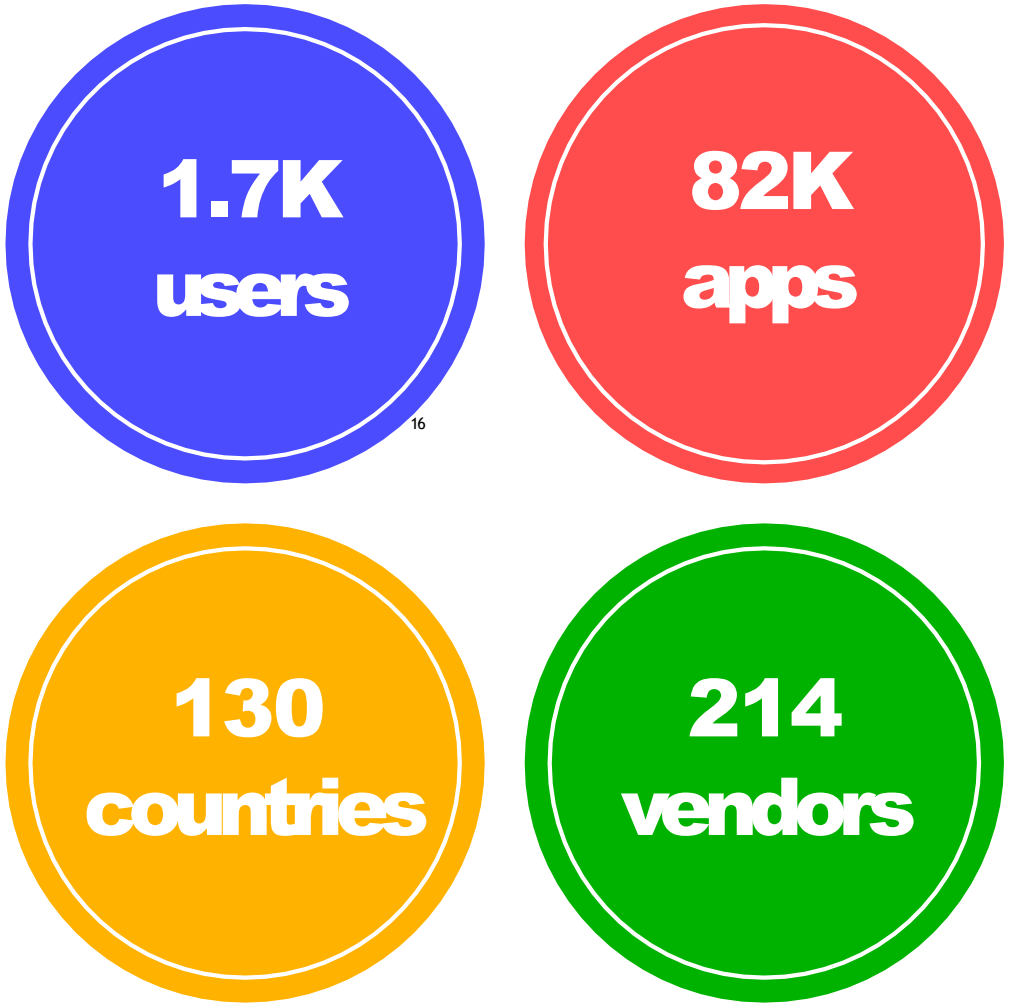
Data collection at scale

14

Data collection at scale



Data collection at scale



https://androidobservatory.com/datasets/

RQ1: Who put this here?

Supply chain analysis of pre-installed applications

How to identify app developers?

```
================================================================================
Package name: com.google.uid.shared
SHA-2 (APK): 49572bd409287faf62e4049033283da580d849825180e43761619f53affaf6db
--------------------------------------------------------------------------------
Certificate:
    Data:
        Version: 3 (0x2)
        Serial Number:
            c2:e0:87:46:64:4a:30:8d
    Signature Algorithm: md5WithRSAEncryption
        Issuer: C=US, ST=California, L=Mountain View, O=Google Inc.,
                OU=Android, CN=Android
        Validity
            Not Before: Aug 21 23:13:34 2008 GMT
            Not After : Jan 7 23:13:34 2036 GMT
        Subject: C=US, ST=California, L=Mountain View, O=Google Inc.,
                 OU=Android, CN=Android
```

How to identify app developers?

```
================================================================================
Package name: com.ppswipe.blurewards
SHA-2 (APK): 31623c4a5d08262018409851e00c71fb18422b4b9364eabeb344686d5fcb1b85
--------------------------------------------------------------------------------
Certificate:
    Data:
        Version: 3 (0x2)
        Serial Number:
            6f:81:bf:fd:bd:a8:cb:08:d5:c2:3a:2f:05:8b:77:76:34:88:c9:88
    Signature Algorithm: sha256WithRSAEncryption
        Issuer: C=US, ST=California, L=Mountain View, O=Google Inc.,
                OU=Android, CN=Android
        Validity
            Not Before: Sep 1 21:10:53 2017 GMT
            Not After : Sep 1 21:10:53 2047 GMT
        Subject: C=US, ST=California, L=Mountain View, O=Google Inc.,
                 OU=Android, CN=Android
```

How to identify app developers?

Company name	# of certificates	Country	Certified partner?
Google	92	United States	—
Motorola	65	US/China	Yes
Asus	60	Taiwan	Yes
Samsung	38	South Korea	Yes
Huawei	29	China	Yes

How to identify app developers?

Company name	# of certificates	Country	# of vendors
MediaTek	19	China	17
Aeon	12	China	3
Tinno Mobile	11	China	6
Verizon Wireless	10	United States	5
Unknown company	7	—	1

How to identify app developers?

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Unknown company	7	—	1

There is **no** reliable way to identify the developer of an application

Third-party libraries

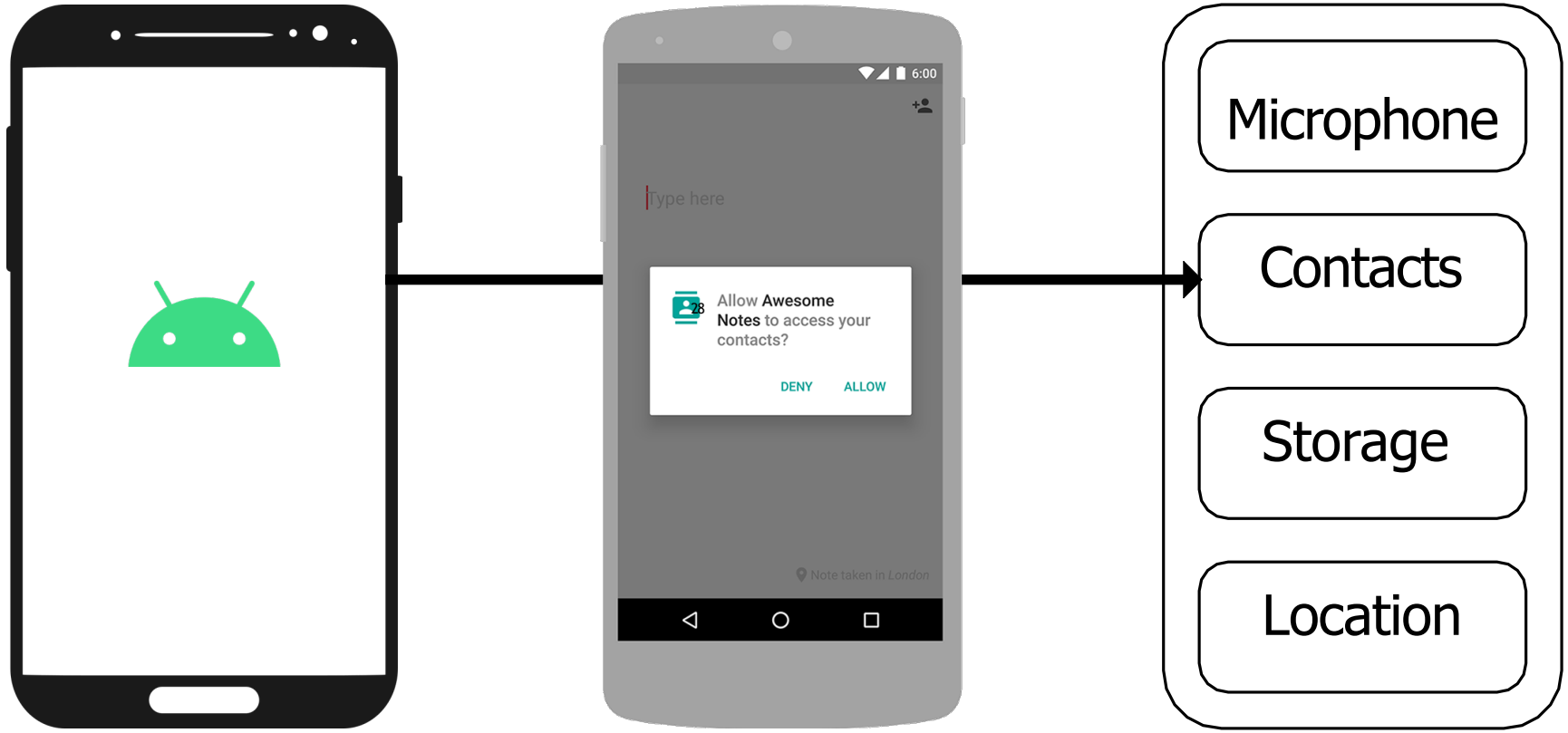
Category	# libraries	# apps	# vendors	Example
Advertisement	164	11,935	164	Braze
Mobile analytics	100	6,935	158	Apptentive
Social networks	70	6,652	157	Twitter

There is virtually **no** user consent

RQ2: What are these apps doing?

Capability and behavioral analysis of pre-installed apps

A quick Android permissions primer



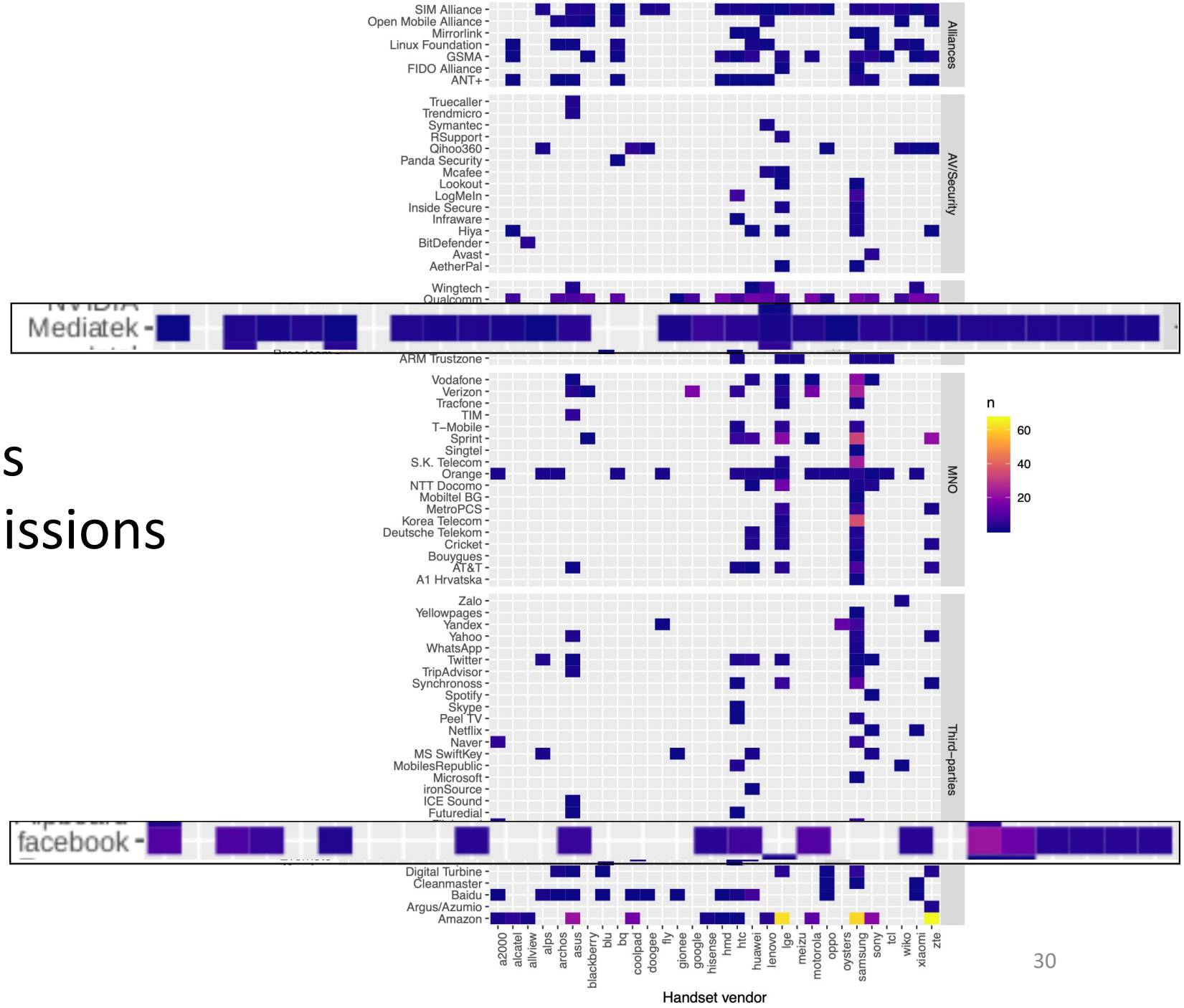
Custom permissions

```
android.permission.BAIDU_LOCATION_SERVICE
com.digitalturbine.ignite.ACCESS_LOG
...
```

	Custom	Providers							
	permissions	Vendor	Third-party	MNO	Chipset	AV / Security	Ind. Alliance	Browser	Other
Total	4,845 (108)	3,760 (37)	192 (34)	195 (15)	67 (63)	46 (13)	29 (44)	7 (6)	549 (75)
Android Modules									
android	494 (21)	410 (9)	—	12 (2)	4 (13)	—	6 (7)	—	62 (17)
com.android.systemui	90 (15)	67 (11)	1 (2)	—	—	—	—	—	22 (8)
com.android.settings	87 (16)	63 (12)	—	1 (1)	—	—	—	—	23 (8)
com.android.phone	84 (14)	56 (9)	—	5 (2)	3 (5)	—	—	—	20 (10)
com.android.mms	59 (11)	35 (10)	—	1 (2)	—	—	1 (1)	—	22 (8)
com.android.contacts	40 (7)	32 (3)	—	—	—	—	—	—	8 (5)
com.android.email	33 (10)	18 (4)	—	—	—	—	—	—	15 (17)

Custom permissions

Revealing partnerships
through custom permissions



Access to sensitive information

Accessed PII	Apps (#)	Apps (%)
IMEI	687	21.8
IMSI	379	12
MCC	552	17.5
MNC	552	17.5
Operator name	315	10
SIM State	383	12.1
Installed apps	1,286	40.8
Phone type	375	11.9

Accessed PII	Apps (#)	Apps (%)
Logs	2,568	81.4
Current network	1,373	43.5
Data plan	699	22.2
Network type	345	10.9
Contacts	164	11
Phone calls	339	10.7
Native code	775	24.6
Linux commands	563	17.9

Where does all that info ends up?

Organization	# of apps	# of domains
Alphabet	566	17052
Facebook	322	3325
Amazon	201	991
Verizon Communications	171	320
Twitter	137	101
Microsoft	136	408
Adobe	116	302
AppsFlyer	98	10
comScore	86	8
AccuWeather	86	15
MoatInc.	79	20
Appnexus	79	35
Baidu	72	69
Criteo	70	62
PerfectPrivacy	68	28
Other ATS	221	362

Other stuff

Malware

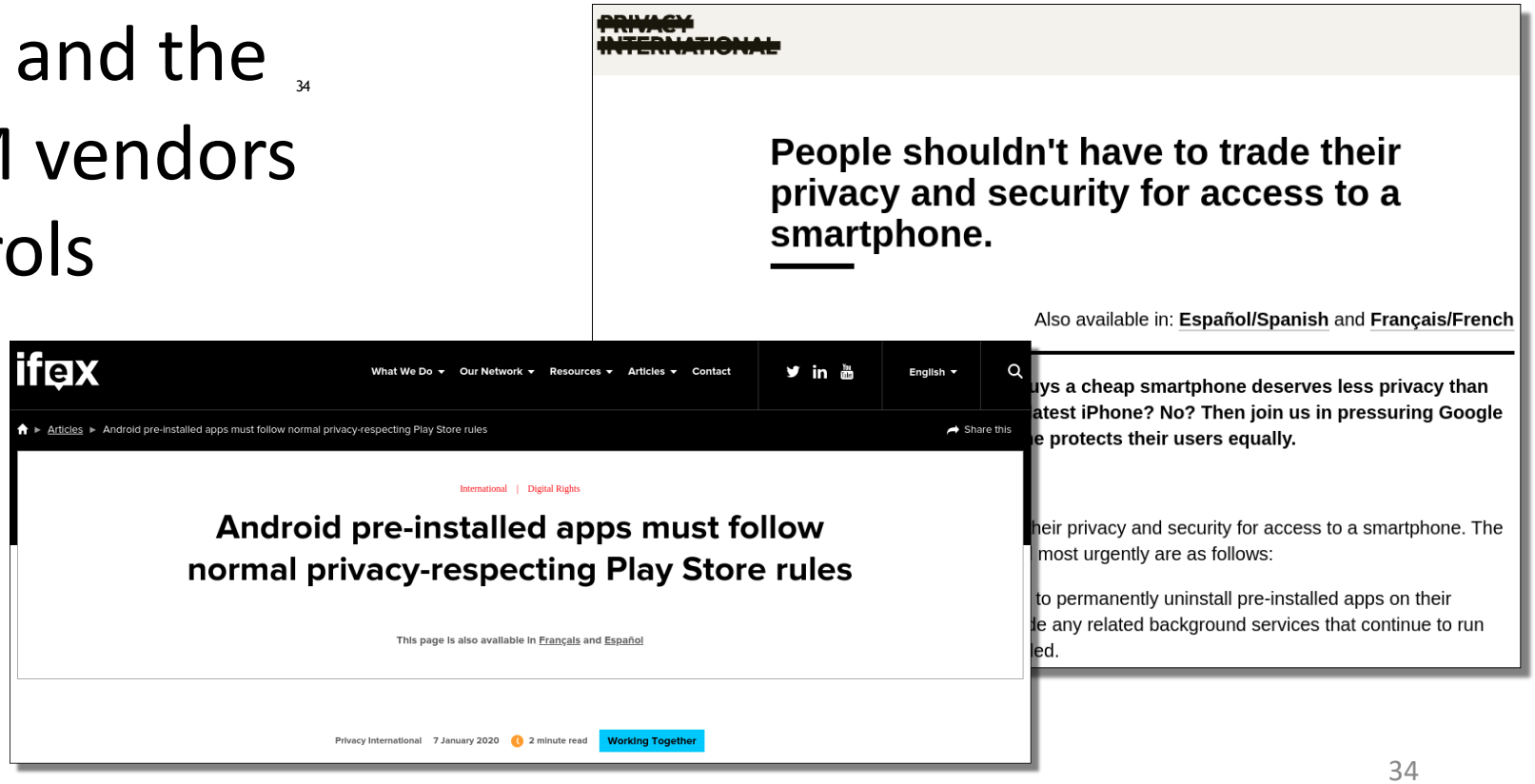
- Triada
- Rootnik
- Gmobi

Also

- Rooting apps
- Engineering mode apps
- Blockers

Recommendations for stakeholders and regulators

1. Improve documentation of APIs and custom permissions
2. Improve transparency (e.g., publish official certificates)
3. Set stricter policies to control the supply chain and the activities of OEM vendors [34]
4. Regulatory controls

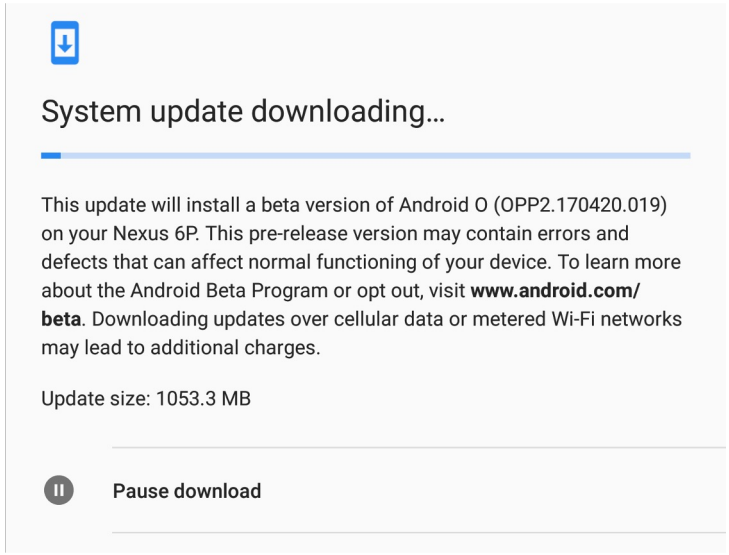


Trouble Over-The-Air: An Analysis of FOTA Apps in the Android Ecosystem

Eduardo Blázquez, Sergio Pastrana, Álvaro Feal, Julien Gamba, Platon Kotzias, Narseo Vallina-Rodriguez and Juan Tapiador

42nd IEEE Symposium on Security and Privacy

FOTA: Firmware-Over-The-Air



- Critical pre-installed app
- Manages Android system updates
- Turns a static supply chain into a dynamic one

The Real World: Motivation

Jan 11, 2020 • Tech News

Chinese Smartphone privacy issues in 2020

Posted by madbadgadgets

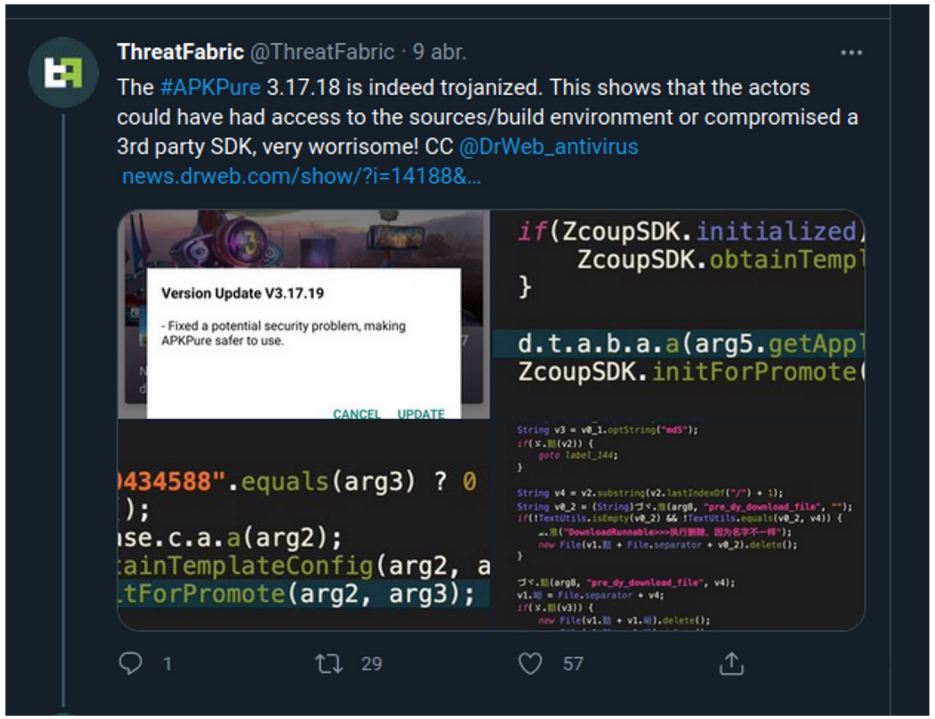
ANDROID

Pre-installed auto installer threat found on Android mobile devices in Germany

Posted: April 6, 2021 by Nathan Collier

Last updated: April 10, 2021

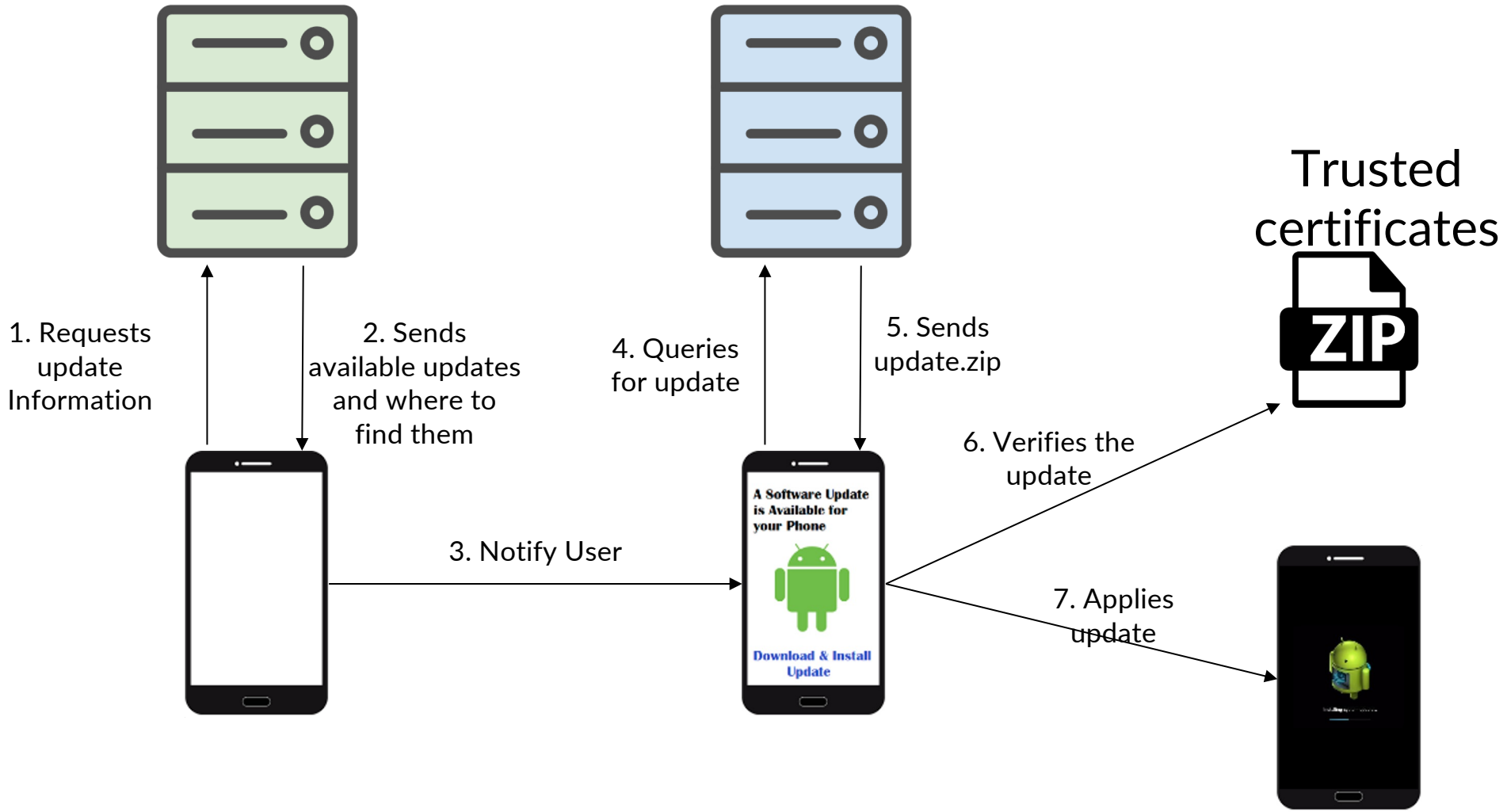
Gigaset Android Update Server Hacked to Install Malware on Users' Devices



Research Questions

- How to **detect** a **FOTA** app?
- **Who** is behind this software?
- What **capabilities** do these apps have?
- What **behaviors** do they have?

FOTA Lifecycle



Datasets

Firmware Scanner[1]

- +400K pre-installed apps
- Device information

Reputation and Installation Logs

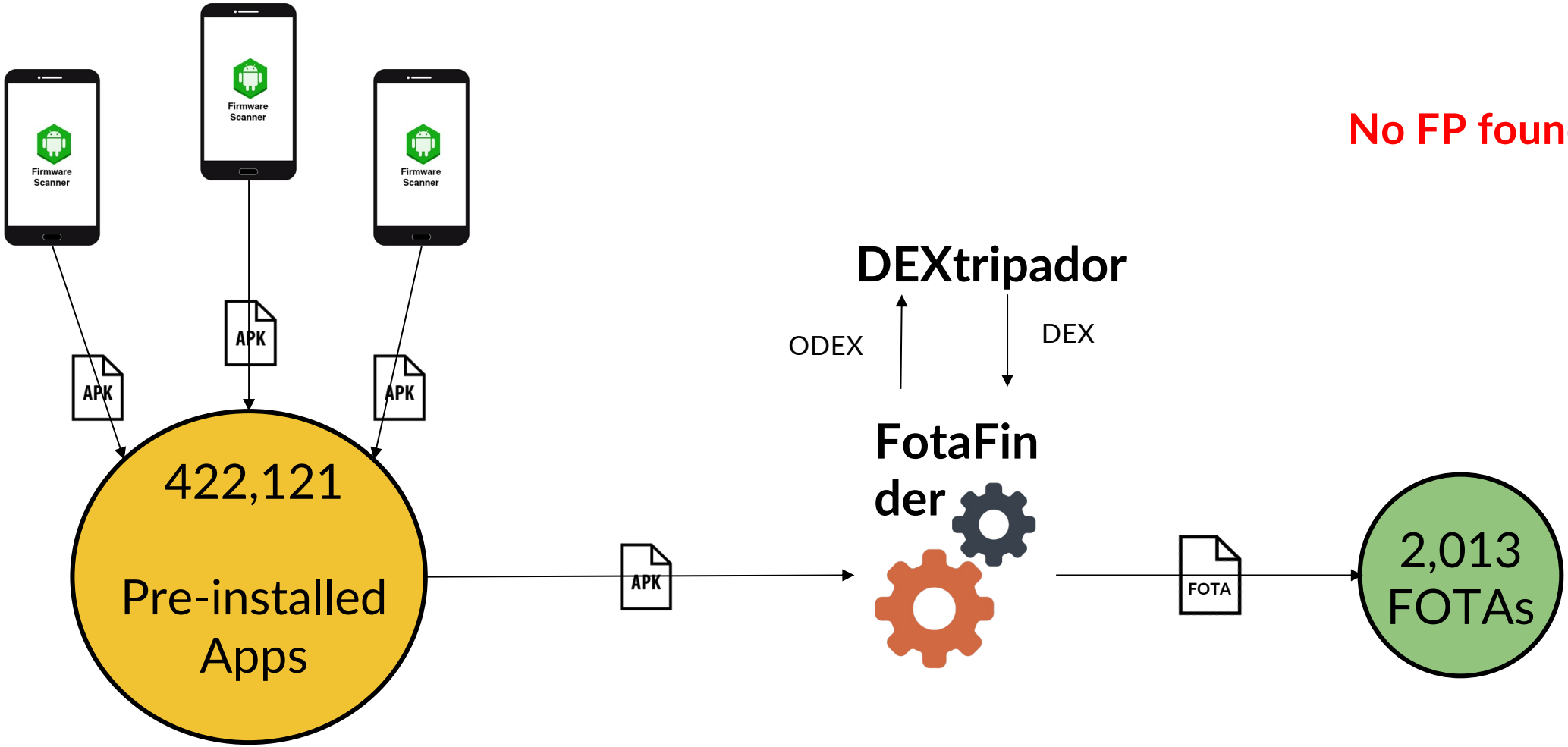
- Reputation logs
- Installed packages information

FOTA Finder

- Static analysis tool to automatically detect FOTA applications.
- Search for 4 specific signals related to FOTA:

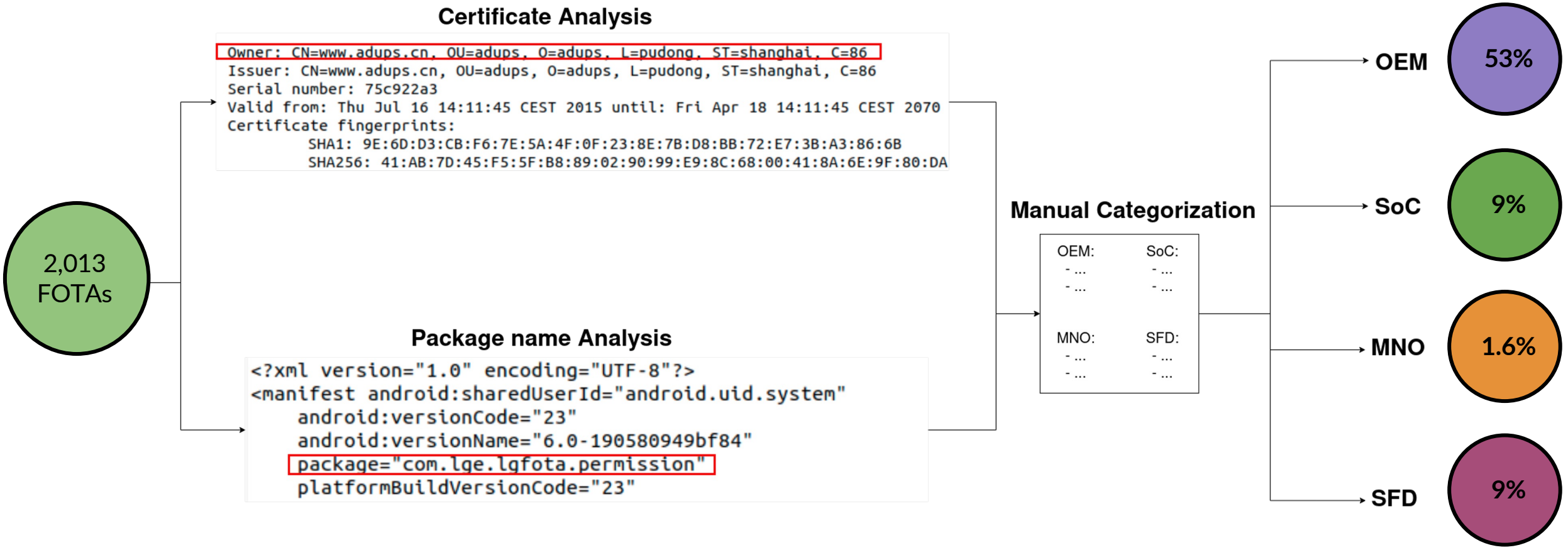
- `verifyPackage()`
- `installPackage()`
- `applyPayload()`
- "*`/cache/recovery/command`*" and "*`--update-pacakge`*"

FOTA Discovery Process and Results

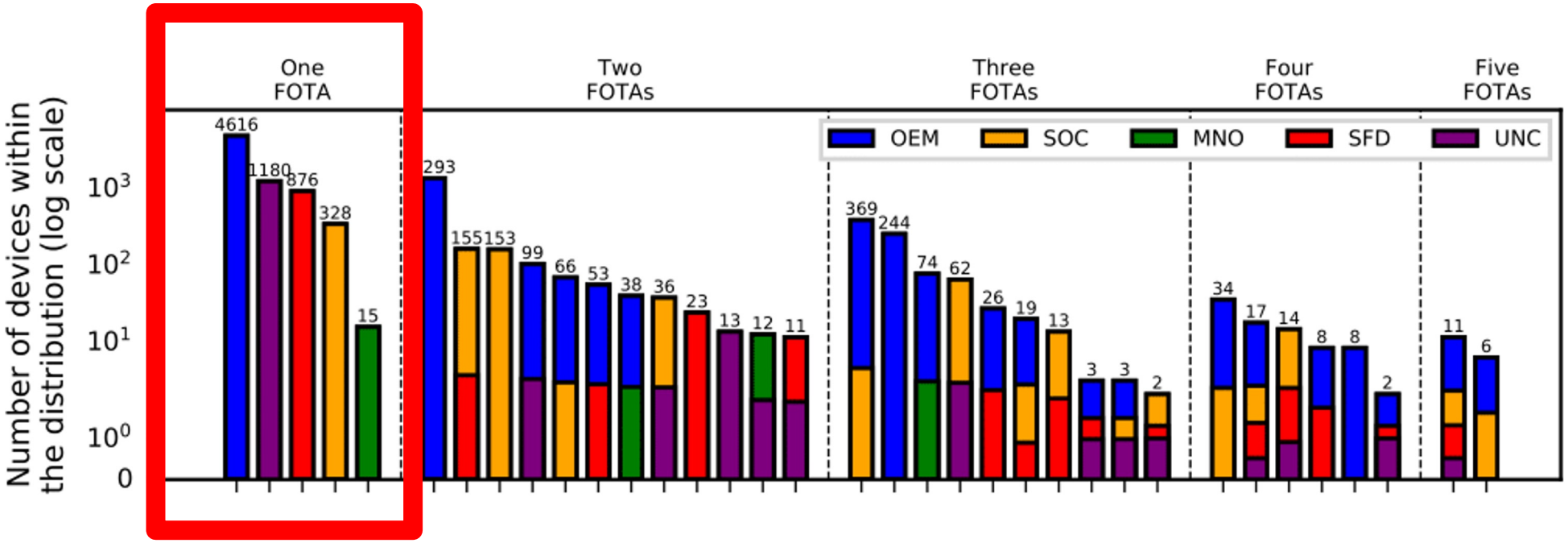


No FP found!

FOTA Stakeholder Analysis



Distribution of FOTA Stakeholders in Devices



Security Implications

AOSP default test keys were used to sign FOTAs

Package	# dev.
com.adups.fota.sysoper	98
com.mediatek.systemupdate.sysoper	16
pl.zdunex25.updater	13
com.abastra.android.goclever.otaupdate	11
com.mediatek.googleota.sysoper	10
com.redstone.ota.ui	8
com.freeme.ota	6
com.fw.upgrade.sysoper	4
com.fota.wirelessupdate	3
org.pixelexperience.ota	3
com.android.settings	2
com.adups.fota	1
com.rock.gota	1

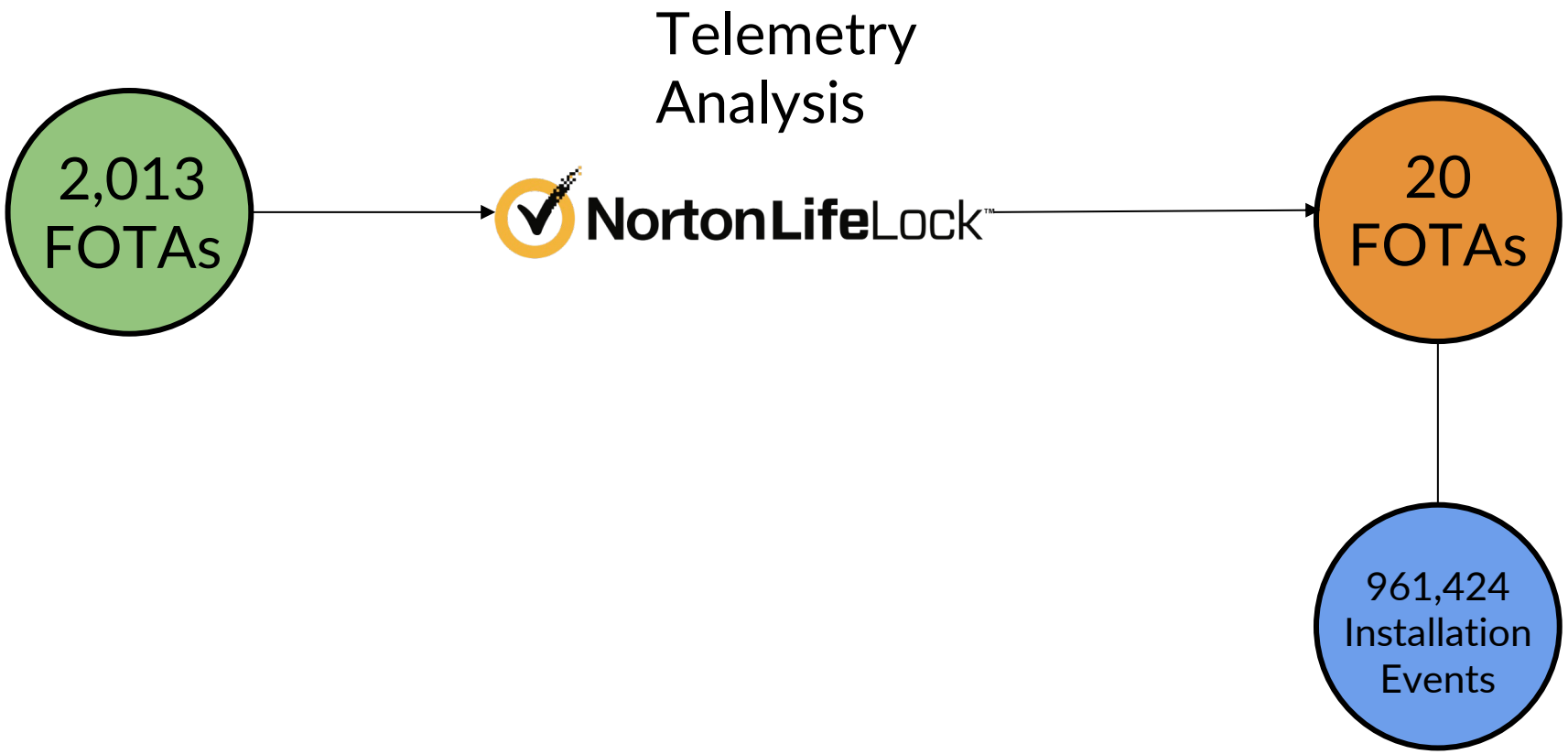
Brand	# dev.
Alps	80
Xiaomi	16
Samsung	12
Goclever	11
Allview	10
Doogee	9
Iku	8
Blackview	6
Bravis	6
Cubot	3
Elite_5	2
BQ	2
Others (9)	11

Static analysis of FOTA behavior

Accessed data type / behaviors		% Apps (#)	% Third-party (#)
Telephony identifiers	IMEI	33.7 (577)	15.2 (260)
	IMSI	31.4 (538)	8.2 (140)
	Phone number	8.8 (151)	4.4 (75)
	MCC & MNC	19.1 (327)	6.3 (108)
	Operator name	5.7 (98)	3.3 (56)
	SIM Serial number	6.5 (111)	2.7 (446)
	SIM State	13.1 (224)	4.5 (77)
	Current country	6.7 (115)	1.3 (22)
	SIM country	7.6 (131)	3.2 (55)
Device settings	Software version	1.0 (17)	1.0 (17)
	Phone state	25.1 (430)	5.5 (95)
	Installed apps	49.2 (843)	17.9 (307)
	Phone type	14.4 (247)	8.3 (143)
	Logs	65.3 (1,119)	24.8 (425)
Location	GPS	0.7 (12)	0.6 (11)
	Cell location	4.3 (73)	2.7 (47)
	CID	4.8 (82)	2.6 (44)
	LAC	3.7 (63)	2.0 (34)

Accessed data type / behaviors		% Apps (#)	% Third-party (#)
Network interfaces	Wi-Fi configuration	2.0 (35)	1.9 (32)
	Current network	50.0 (856)	15.1 (259)
	Data plan	34.9 (598)	8.9 (153)
	Connection state	4.3 (73)	1.7 (29)
	Network type	17.3 (296)	6.2 (106)
Phone service abuse	SMS sending	0.1 (1)	0.0 (0)
	Phone calls	8.5 (146)	3.3 (57)
Audio/video interception	Audio recording	2.6 (44)	2.4 (41)
	Video capture	2.3 (40)	2.3 (40)
Arbitrary code execution	Native code	27.1 (465)	11.4 (196)
	Linux commands	30.9 (530)	10.8 (185)
Socket conn.	Remote connection	6.7 (114)	1.9 (32)

FOTA apps in Telemetry data



FOTA installers

Installer		Installations		Children	
Package name	Type	Events	Devices	APKs	Mal. APKs (%)
com.samsung.android.app.omcagent	OEM	3.0M	332K	1.9K	29 (1.5%)
com.coloros.sau	OEM	191K	65K	985	28 (3%)
com.android.settings	Unknown	35K	4.7K	1.4K	494 (35%)
com.qiku.android.ota	OEM	310	77	12	11 (92%)

Malicious Installations

Potentially Unwanted Programs

- adware
- smsreg
- hiddad

Malware families

- triada
- necro
- guerilla

Conclusions

- Many different stakeholders lead to a complex and fragmented ecosystem
- Dynamic Android supply chain due to FOTA updates
- Potential privacy-intrusive practices
- Unwanted and malicious software installations

Recommendations

No an easy-to-solve problem

We recommend:

- ❑ Following best practices in FOTA development
- ❑ Increase transparency through public documentation
- ❑ Separate system from non-system installation capabilities

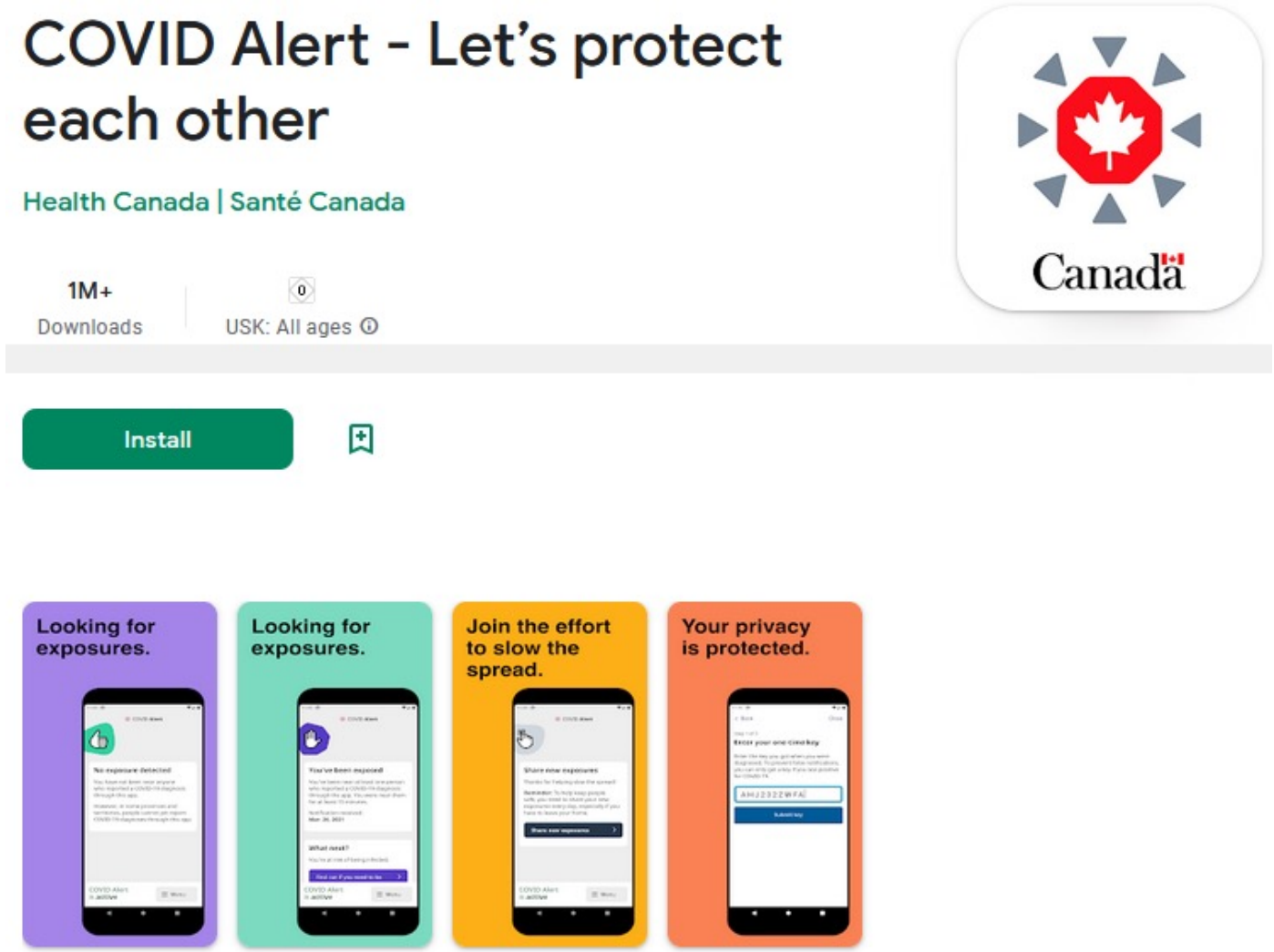
Log: It's Big, It's Heavy, It's Filled with Personal Data!

Measuring the Logging of Sensitive Information in the Android Ecosystem

Allan Lyons Julien Gamba Austin Shawaga

Joel Reardon Juan Tapiador Serge Egelman Narseo Vallina-Rodríguez

Google-Apple Exposure Notification



Menu

The Markup

Donate

Big Tech Is Watching You. We're Watching Big Tech.

Privacy

Google Promised Its Contact Tracing App Was Completely Private—But It Wasn't

Solid algorithm, but…

Researchers say hundreds of preinstalled apps can access a log found on Android devices where sensitive contact tracing information is stored

By Alfred Ng

April 27, 2021 08:00 ET

GAEN logged “Anonymous” Identifiers

```
W ExposureNotification: getCurrentRollingProximityId: generated a new
RollingProximityId=768D2E1DC786F9FD6ACE4A17B37CDDE4 [CONTEXT service_id=236 ]
```

```
5698  5698 W ExposureNotification: Scan device 56:6F:40:2A:0E:10, type=1,
                                   id=9C2731EE6D544F03180F78F509E63337,
                                   raw_rssi=-66, calibrated_rssi=-70,
                                   meta=D0E2489A, previous_scan=0
                                   [CONTEXT service_id=236 ]
5698  5698 W ExposureNotification: BleDatabaseWriter.writeBleSighting,
                                   id=9C2731EE6D544F03180F78F509E63337
                                   CONTEXT service_id=236 ]
5698  5698 W ExposureNotification: Scan device AB:B1:E9:9E:1B:BA, type=1,
                                   id=EB7E87FA877BA96DC07554D5D5508074,
                                   raw_rssi=-12, calibrated_rssi=-16,
                                   meta=391ECC52, previous_scan=0
                                   [CONTEXT service_id=236 ]
5698  5698 W ExposureNotification: BleDatabaseWriter.writeBleSighting,
                                   id=EB7E87FA877BA96DC07554D5D5508074
                                   [CONTEXT service_id=236 ]
```

Exposure status also logged

```
W ExposureNotification: [MatchingTracer] Sending exposure status update
                                         with no new exposures to client.
                                         [CONTEXT service_id=236 ]
```

Privacy Security Best Practices

This page contains a collection of data collection guidance and recommendations to ensure that Android users have control over the handling of their data.

Logging data

Logging data increases the risk of exposure of that data and reduces system performance. Multiple public security incidents have occurred as a result of logging sensitive user data.

- Do not log to the sdcard.
- Apps or system services should not log data provided from third-party apps that might include sensitive information.
- Apps must not log any Personally Identifiable Information (PII) as part of normal operation, unless it's absolutely necessary to provide the core functionality of the app.

CTS includes tests that check for the presence of potentially sensitive information in logs.

READ_LOGS Permission

“Not for use by **third-party** applications, because Log entries can contain the user's private information.”

2020 IEEE Symposium on Security and Privacy

An Analysis of Pre-installed Android Software

Julien Gamba*†, Mohammed Rashed†, Abbas Razaghpanah‡, Juan Tapiador † and Narseo Vallina-Rodriguez*§

* IMDEA Networks Institute, † Universidad Carlos III de Madrid, ‡ Stony Brook University, § ICSI

Abstract

The open-source nature of the Android OS makes it possible for manufacturers to ship custom versions of the OS along with a set of pre-installed apps, often for product differentiation. Some device vendors have recently come under scrutiny for potentially invasive private data collection practices and other potentially harmful or unwanted behavior of the pre-installed apps on their devices. Yet, the landscape of pre-installed software in Android has largely remained unexplored, particularly in terms of the security and privacy implications of such customizations. In this paper, we present the first large-scale study of pre-installed software on Android devices from more than 200 vendors. Our work relies on a large dataset of real-world Android firmware acquired worldwide using crowd-sourcing methods. This allows us to answer questions related to the stakeholders involved in the supply chain, from device manufacturers and mobile network operators to third-party organizations like advertising and tracking services, and social network platforms. Our study allows us to also uncover relationships between these actors, which seem to revolve primarily around advertising and data-driven services. Overall, end up packaged together in the firmware of a device is not transparent, and various isolated cases reported over the last few years suggest that it lacks end-to-end control mechanisms to guarantee that shipped firmware is free from vulnerabilities [24], [25] or potentially malicious and unwanted apps. For example, at Black Hat USA 2017, Johnson *et al.* [82], [47] gave details of a powerful backdoor present in the firmware of several models of Android smartphones, including the popular BLU R1 HD. In response to this disclosure, Amazon removed Blu products from their Prime Exclusive line-up [2]. A company named Shanghai Adups Technology Co. Ltd. was pinpointed as responsible for this incident. The same report also discussed the case of how vulnerable core system services (*e.g.*, the widely deployed MTKLogger component developed by the chipset manufacturer MediaTek) could be abused by co-located apps. The infamous Triada trojan has also been recently found embedded in the firmware of several low-cost Android smartphones [77], [66]. Other cases of malware found pre-installed include Loki (spyware and adware) and Slocker (ransomware), which were spotted in the firmware of various high-end phones [6].

Logging on Android: Two Questions

1. Are developers following Google's guidelines or does sensitive information end up in the logs?

2. Given the lack of supply chain controls, are there apps that can access the logs?

#1 : Is Sensitive Information in the Logs?

Personally Identifying Information (PII)

- Direct Identifiers
  - Email Address
  - Phone Number
  - User Name
- Indirect Identifiers
  - Android ID
  - MAC Address
  - IMEI
  - Serial Number
- User Location
  - GPS Coordinates
  - Nearby WiFi and Bluetooth devices

Logging by Default

Phone			Identifier								Proximate Data					
Make	Model	Android Version	SSID	BSSID	BT MAC	WiFi MAC	IMEI	Serial	Phone Num	Email Address	GPS	Nearby SSIDs	Nearby BSSIDs	Nearby BT MACs	Bluetooth Payloads	Read Logs
Blu	Studio Mini	9	✓	✓	✓	✓				✓		✓		✓		5
Cubot	Note 7	10	✓	✓			✓		✓	✓		✓	✓			4
Google	Pixel 3a	9	✓	✓		✓	✓		✓	✓						6
Google	Pixel 3a	12	✓	✓					✓	✓		✓	✓			6
Huawei	Nova 5T	9	✓	✓	✓	✓				✓		✓	✓			58
LG	K51	12	✓	✓	✓	✓		✓		✓						58
Motorola	G Play	10	✓	✓	✓	✓	✓	✓		✓	✓					34
Motorola	One 5G Ace	10	✓	✓	✓	✓	✓	✓	✓	✓	✓					34
Nokia	3.4	10	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	5
Nokia	3.4	12	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	22
Samsung	Galaxy A12	10	✓	✓	✓			✓		✓		✓	✓			14
Samsung	Galaxy A21S	10	✓	✓						✓						83
Samsung	Galaxy A21S	12	✓	✓						✓						95
uleFone	Note 11P	11	✓	✓	✓					✓						34
ZTE	Blade A5 2020	9	✓	✓		✓		✓		✓		✓	✓			4
Total			15	15	8	9	5	6	4	15	4	8	7	3	2	

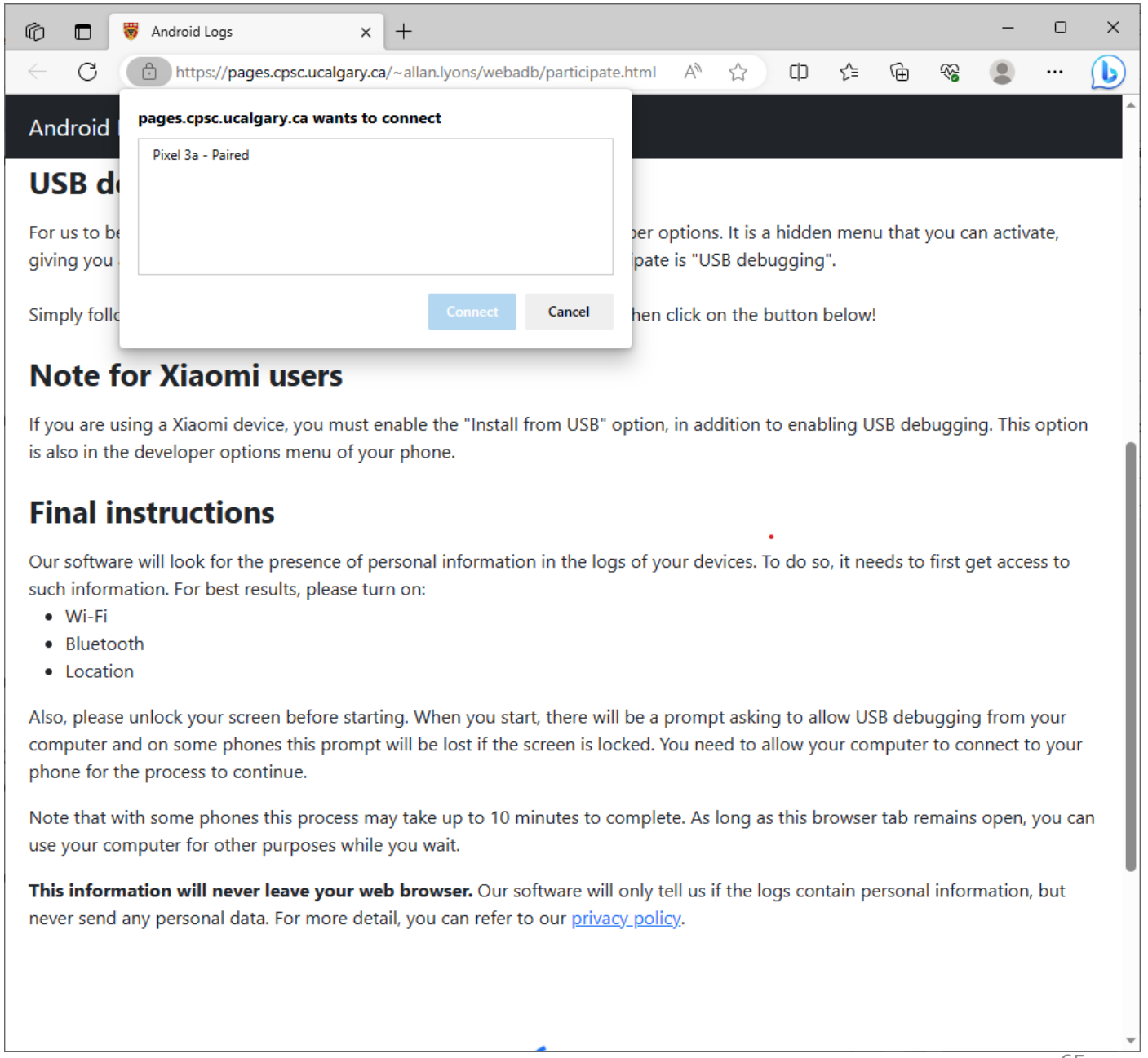
Android Logs Home Learn more Participate Privacy policy

Android Logs

How much private data is logged by your apps? Who can then access that data, and what do they do with it?
Help us find out by participating in our study!

Learn more Participate!

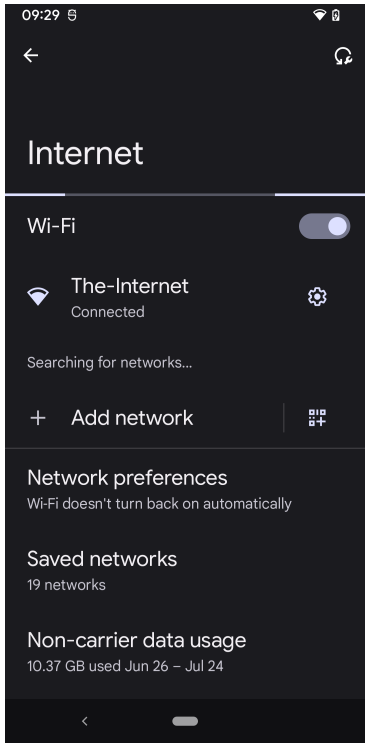
PII in the Wild Experiment



PII broadly found on phones

PII Type	PII Class	Prevalence
Email Address	Direct ID	16%
Phone Number	Direct ID	3%
Bluetooth Scan MAC	Location ID	2%
Bluetooth Scan SSID	Location ID	2%
Coarse Location	Location ID	24%
Fine Location	Location ID	22%
WiFi Router MAC	Location ID	67%
WiFi Router SSID	Location ID	68%
WiFi Scan MAC	Location ID	14%
WiFi Scan SSID	Location ID	39%
Android ID	Non-resetable ID	8%
Bluetooth MAC	Non-resetable ID	11%
IMEI	Non-resetable ID	6%
Serial Number	Non-resetable ID	4%
Bluetooth Name	Other ID	69%
WiFi Randomized MAC	Other ID	78%
Any PII Detected		**94%**

Google Pixel 3a connecting to WiFi



Google Pixel 3a Connecting to WiFi

D wpa_supplicant: wlan0: Own MAC address: aa:52:0f:bc:55:60

D wpa_supplicant: wlan0: BSS: Add new id 2 BSSID a8:70:5d:84:2a:de SSID 'ShawMobileHotspot' freq 5765 HESSID a8:70:5d:84:2a:de

I wpa_supplicant: wlan0: RX-ANQP a8:70:5d:84:2a:de 3GPP Cellular Network information

D WifiClientModeImpl[wlan0]: ConnectedMacRandomization SSID(The-Internet). setMacAddress(aa:52:0f:bc:55:60) from 02:c3:72:e5:15:17 = true

I WifiClientModeImpl[wlan0]: Connecting with aa:52:0f:bc:55:60 as the mac address

I wpa_supplicant: wlan0: Trying to associate with SSID 'The-Internet'

I wpa_supplicant: wlan0: Associated with 08:9e:08:e4:2b:a0

wpa_supplicant Logging

wpa_supplicant.c

```
wpa_dbg(wpa_s, MSG_DEBUG, "Own MAC address: " MACSTR, MAC2STR(wpa_s-
        >own_addr));
```

wpa_debug.h

```
#ifdef CONFIG_NO_STDOUT_DEBUG
#define wpa_dbg(args...) do { } while (0)
#else /* CONFIG_NO_STDOUT_DEBUG */
#define wpa_dbg(args...) wpa_msg(args)
#endif /* CONFIG_NO_STDOUT_DEBUG */
```

Xiaomi Redmi Note 9 (Android 11)

I [BIP] : [BIP NL] IPv6: *:*:*:*:*:*:*:*

I [BIP] : [BIP NL] addr state is 3, ipv4=*.*.*.*, ipv6=*:*:*:*:*:*:*:*

I WifiHAL : data: version=1, cur_rssi=-66 BSSID=12:0c:*:*:*:d9

Sample Volley Log Entry

D Volley : [919] BasicNetwork.logSlowRequests: HTTP response for request=<[ ] https://apis.netmarble.com/mobileauth/v2/players/063DFBE41A1342449E74C89BF2757786/deviceKeys/3CBCDA0D7F054EA5964CDAAD3353C651/accessToken?nmDeviceKey=d8b1df4dbf6926b2&countryCode=CA&adId=7f9e4fac-c211-498e-804c-6befc76d39530xac67c518 IMMEDIATE 3> [lifetime=445], [size=851], [rc=200], [retryCount=0]

com.netmarble.war

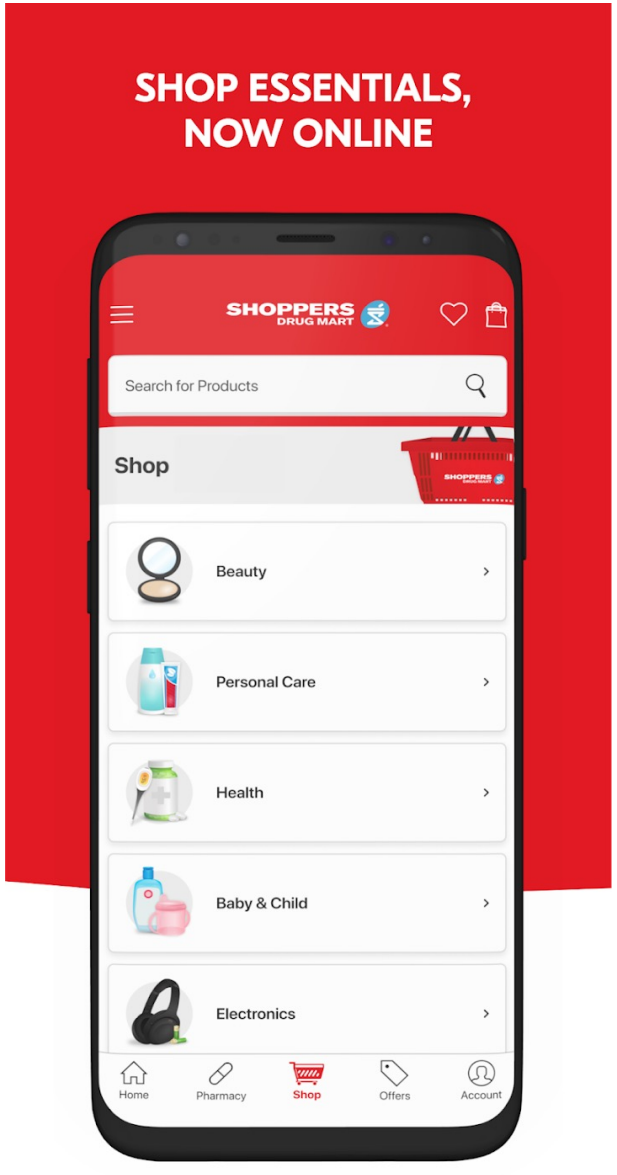
Volley Logging Code

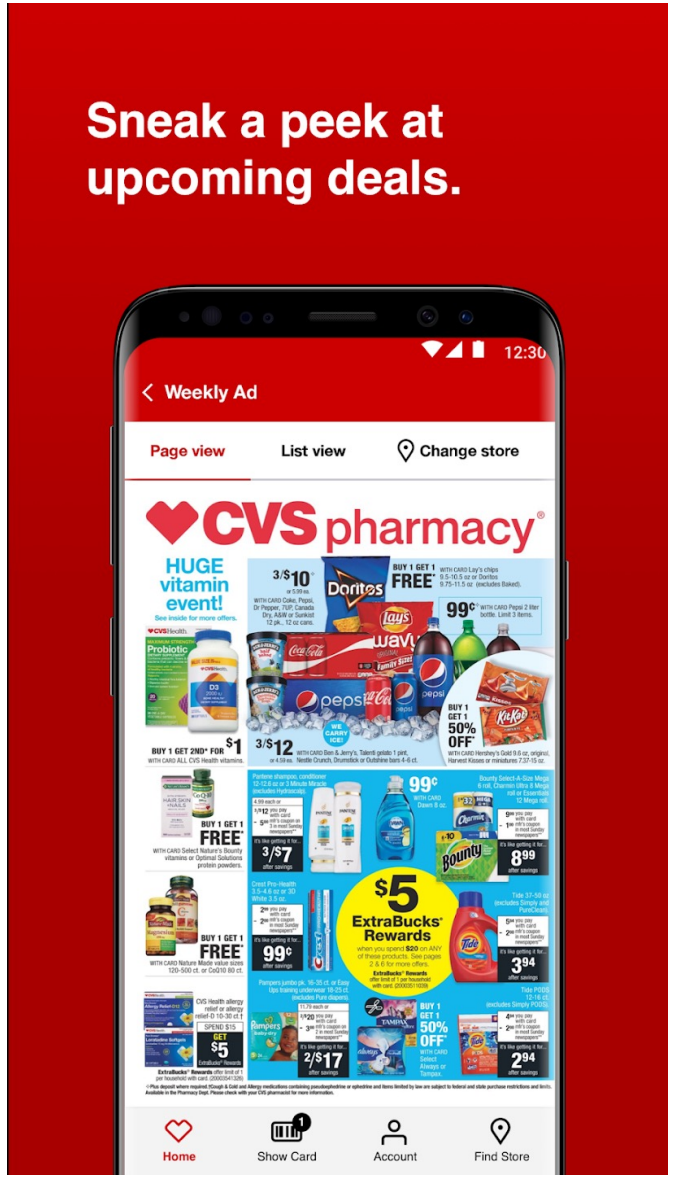
```
private static final int SLOW_REQUEST_THRESHOLD_MS = 3000;

private NetworkUtility() {}

/** Logs requests that took over SLOW_REQUEST_THRESHOLD_MS to complete. */
static void logSlowRequests(long requestLifetime, Request<?> request, byte[] responseContents, int
statusCode) {
        if (VolleyLog.DEBUG || requestLifetime > SLOW_REQUEST_THRESHOLD_MS) {
                VolleyLog.d("HTTP response for request=<%s> [lifetime=%d], [size=%s], "
                + "[rc=%d], [retryCount=%s]", request, requestLifetime,
                responseContents != null ? responseContents.length : "null",
                statusCode, request.getRetryPolicy().getCurrentRetryCount());
        }
}
```

Volley has Changed

8 core/src/main/java/com/android/volley/toolbox/NetworkUtility.java

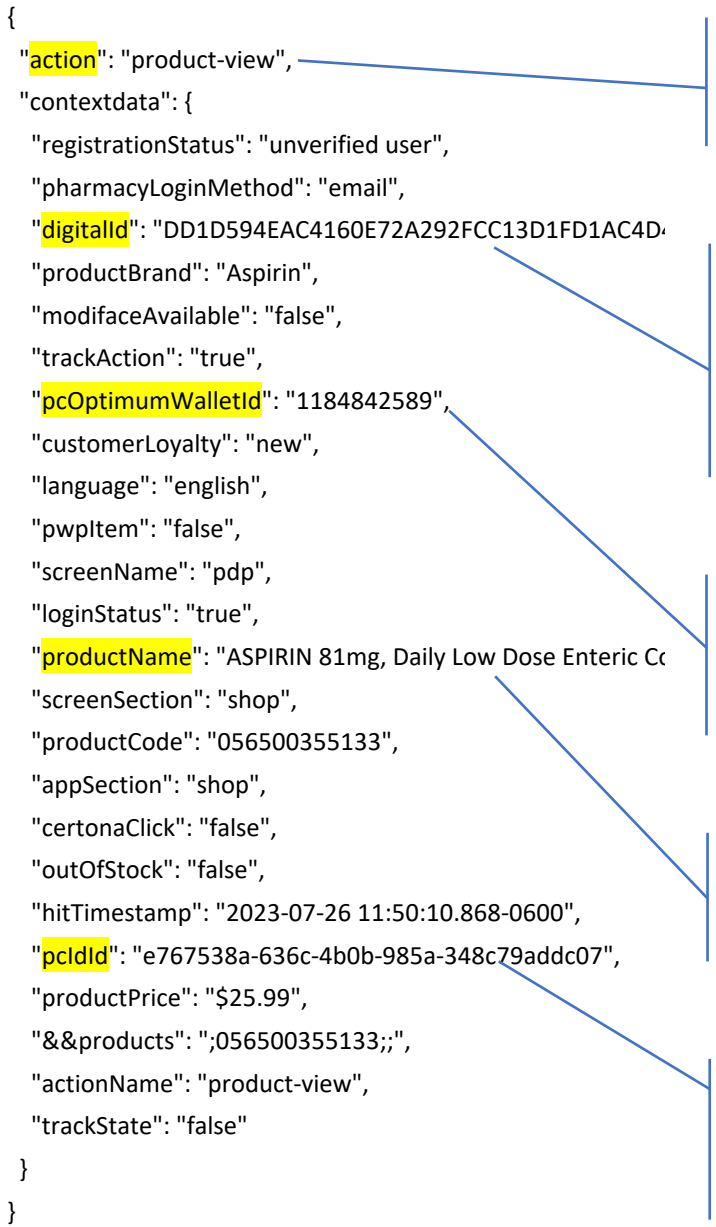
```
@@ -43,14 +43,12 @@
 * BasicAsyncNetwork}
 */
final class NetworkUtility {
-    private static final int SLOW_REQUEST_THRESHOLD_MS = 3000;
-
     private NetworkUtility() {}

-    /** Logs requests that took over SLOW_REQUEST_THRESHOLD_MS to complete. */
-    static void logSlowRequests(
+    /** Logs a summary about the request when debug logging is enabled. */
+    static void logRequestSummary(
             long requestLifetime, Request<?> request, byte[] responseContents, int statusCode) {
-        if (VolleyLog.DEBUG || requestLifetime > SLOW_REQUEST_THRESHOLD_MS) {
+        if (VolleyLog.DEBUG) {
             VolleyLog.d(
                     "HTTP response for request=<%s> [lifetime=%d], [size=%s], "
                             + "[rc=%d], [retryCount=%s]",
```


SHOP ESSENTIALS, NOW ONLINE
SHOPPERS DRUG MART
Search for Products
Shop
Beauty
Personal Care
Health
Baby & Child
Electronics
Home
Pharmacy
Shop
Offers
Account


Sneak a peek at upcoming deals.
12:30
Weekly Ad
Page view
List view
Change store
CVS pharmacy
HUGE vitamin event!
$5 ExtraBucks Rewards
Home
Show Card
Account
Find Store

Sample log entry from Shopper's App

D AdobeExperienceSDK: Rules Engine - Original EventData for Event #424:
{"action":"product-view","contextdata":{"registrationStatus":"unverified user","pharmacyLoginMethod":"email","digitalId":"DD1D594EAC4160E72A292FCC13D1FD1AC4D4EBA532953A19596C99AF57DF19AC","productBrand":"Aspirin","modifaceAvailable":"false","trackAction":"true","pcOptimumWalletId":"1184842589","customerLoyalty":"new","language":"english","pwpItem":"false","screenName":"pdp","loginStatus":"true","productName":"ASPIRIN 81mg, Daily Low Dose Enteric Coated Tablets, 180 Tablets", "screenSection":"shop","productCode":"056500355133","appSection":"shop","certonaClick":"false","outOfStock":"false","hitTimestamp":"2023-07-26 11:50:10.868-0600","pcIdId":"e767538a-636c-4b0b-985a-348c79addc07", "productPrice":"$25.99","&&products":";056500355133;;","actionName":"product-view","trackState":"false"}}



"action": "product-view"

"digitalId": "DD1D594EAC4160E72A292FCC13D1FD1AC4D4EBA532953A19596C99AF57DF19AC"

"pcOptimumWalletId": "1184842589"

"productName": "ASPIRIN 81mg, Daily Low Dose Enteric Coated Tablets, 120 Tablets"

"pcIdId": "e767538a-636c-4b0b-985a-348c79addc07"

Adobe

```
5   public c
6       ...
7       @Overr
8       public
9           supe
10          if(U
11              Mo
12              Mo
```

⚠ Using Debu
you use only

Publish your app | Android Stu

https://developer.android.com/studio/publish

Prepare your app for release

Preparing your app for release is a multistep process involving the following tasks:

- **Configure your app for release.**

  At a minimum, you need to make sure that logging is disabled and removed and that your release variant has `debuggable false` for Groovy or `isDebuggable = false` for Kotlin script set. You should also set your app's version information.

- **Build and sign a release version of your app.**

  You can use the Gradle build files with the *release* build type to build and sign a release version of your app. For more information, see Build and run your app.

- **Test the release version of your app.**

  Before you distribute your app, you should thoroughly test the release version on at least one target handset device and one target tablet device. Firebase Test Lab is useful for testing across

#2 : Are Apps Able to Access the Logs?

Do Apps Read Logs?

- Linking our field study to the dataset collected by Gamba et al.
  - 1,319 apps with READ_LOGS permission
  - 63 apps run logcat as a shell command
  - 15 of these have code to save the logs to the SD card
  - 9 apps post raw logs to the Internet

READ_LOGS Permission: What is a “**third-party**”?

“Not for use by **third-party** applications, because Log entries can contain the user's private information.”

Apps with READ_LOGS. Third-party or not?

- Apps by Mobile Network Operators like Verizon, AT&T, Telefonica
- Apps by large companies like Amazon, Baidu, Microsoft, Tencent
- Analytics services like Digital Turbine
- Utility apps such as “device cleaners”
- Parental control apps
- Anti-virus software

- Note that any SDKs used by the above inherit the permissions of the apps that include them

Mitigations

Privacy Security Best Practices

This page contains a collection of data collection guidance and recommendations to ensure that Android users have control over the handling of their data.

Logging data

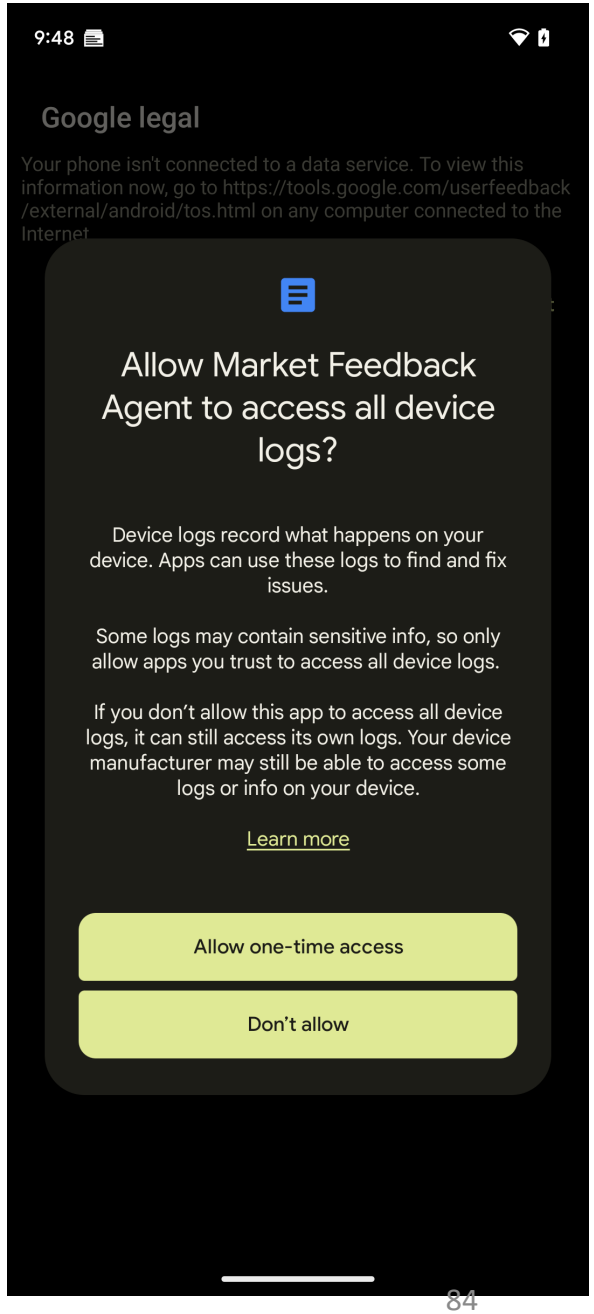
Logging data increases the risk of exposure of that data and reduces system performance. Multiple public security incidents have occurred as a result of logging sensitive user data.

- Do not log to the sdcard.
- Apps or system services should not log data provided from third-party apps that might include sensitive information.
- Apps must not log any Personally Identifiable Information (PII) as part of normal operation, unless it's absolutely necessary to provide the core functionality of the app.

CTS includes tests that check for the presence of potentially sensitive information in logs.

Recent Changes to Android

- “On Android 13, if an app tries to access all device logs for approved use cases such as app feedback or bug reporting, the system will ask you if you want to provide the app with one-time access to this more expansive set of logs.”
- Mitigation
  - If an app in the foreground with READ_LOGS requests access to the device logs, the system prompts the user to approve or deny the request.
  - An app running in the background is automatically denied unless the app
    - Shares the system UID
    - Uses a native system process (UID < APP_UID)
    - (and a few other cases listed in the documentation)



Conclusion

- Logging of potentially sensitive information is prevalent despite Google's recommendations to protect end users
  - System services log sensitive information
  - Misconfigured libraries and SDKs
  - "Debugging during deployment"

- Many preinstalled apps can read the logs

- Impact: Our work has led to a change in Android log access notification

Log: It's Big, It's Heavy, It's Filled with Personal Data!
Measuring the Logging of Sensitive Information in the Android Ecosystem

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Julien Gamba, *IMDEA Networks Institute / Universidad Carlos III de Madrid*
Austin Shawaga, *University of Calgary*
Joel Reardon, *University of Calgary / AppCensus, Inc.*
Juan Tapiador, *Universidad Carlos III de Madrid*
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Narseo Vallina-Rodríguez, *IMDEA Networks Institute / AppCensus, Inc.*

Abstract

Android offers a shared system that multiplexes all logged data from all system components, including both the operating system and the console output of apps that run on it. A security mechanism ensures that user-space apps can only read the log entries that they create, though many "privileged" apps are exempt from this restriction. This includes preloaded system apps provided by Google, the phone manufacturer, the cellular carrier, as well as those sharing the same signature. Consequently, Google advises developers to not log sensitive information to the system log.

In this work, we examined the logging of sensitive data in the Android ecosystem. Using a field study, we show that most devices log some amount of user-identifying information. We show that the logging of "activity" names can inadvertently reveal information about users through their app usage. We also tested whether different smartphones log personal identifiers by default, examined preinstalled apps that access the system logs, and analyzed the privacy policies of manufacturers that report collecting system logs.

1 Introduction

Printing diagnostics and informative output messages is fundamental to software development [45]. Meaningful, verbose logging allows one to monitor runtime behaviour and helps to quickly find and diagnose bugs without needing to replicate the issue in a debugger. Continual logging of software in production facilitates monitoring and remediation of runtime crashes. It is therefore typical that software systems log their behaviour in some manner after deployment.

At the same time, logs often contain sensitive and personal information, particularly when logs are unified across a diverse collection of software components. To that point, in 2010 Rosenberg introduced a Linux kernel patch to provide a build option to make access to the kernel ring buffer, i.e., the output of `dmesg`, effectively require root access (`CAP_SYS_ADMIN`); this option was subsequently modified to require `CAP_SYSLOG` and is now widely enabled. In deploying this patch, Rosenberg noted both the futility of attempting to sanitize thousands of `printk` statements along with the resulting loss of functional utility of these sanitized logs [53].

Analogous to Linux, the Android platform also offers a shared system log that collects all logging statements from apps, system services, and drivers [9]. Developers can write to this log using a family of logging functions, differentiated by verbosity, that provide both a log tag and message. A single system log multiplexes the output of all the log statements that occur along with metadata, which includes thread and process identifiers, a log level ("verbosity"), log tag, and timestamp.

On Android, access to the logs has never been part of the published Software Development Kit (SDK) [40], but early versions allowed full access based on requesting a permission (i.e., `READ_LOGS`). Without it, apps can only access their own log messages (but not logs from other apps or operating system components); with the permission, apps have access to *all* log data. Android 4.1 changed the `READ_LOGS` permission to become "privileged," meaning that the permission itself is only available to system apps and apps that come preinstalled (e.g., by manufacturers, carriers, etc.) [14, 40, 41].

Many such privileged apps exist. Android is an open platform that allows any manufacturer to create its own custom version of the Operating System (OS) with preinstalled software that they determine. This means that apps from the phone's manufacturer (OEM) and other key actors in the supply chain, such as Mobile Network Operators (MNOs), OEM partners, and Google, are eligible for privileged access to the system log. Gamba et al. examined preinstalled software in the Android ecosystem [35] and found a vast supply chain with many privileged third parties able to access this data. They noted that many of these apps also included additional SDKs, provided by ad networks, analytics services, or social networks, that inherit the permissions of the embedding app [34] (i.e., these third-party components can read the logs). The Android Feedback app (`com.google.android.feedback`) is an example of a privileged, preinstalled app. It can launch after another app crashes and gives the user the