Behavior-based Mobile Malware Analysis and Detection

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1 Overview

In this lab, you will learn how to use program analysis tools to analyze Mobile Apps and report any malicious activities or behaviors. The analysis includes both static and dynamic analysis. Some existing program analysis tools, such as Soot[1], FlowDroid[2] and VirusTotal[3], will be introduced. The learning objectives of this lab are listed below:

1. Understand technologies that analyze software.
2. Be able to use FlowDroid and MobSF to perform static analysis against mobile malware.
3. Be able to use VirusTotal to perform dynamic analysis against mobile malware.

2 Background

2.1 Static Code Analysis

Static code analysis is a method of examining source code before a program is run. It's done by analyzing a set of code against a set (or multiple sets) of coding rules. In contrast with dynamic analysis, which is an analysis performed on programs while they are executing, in most cases, the static analysis is performed on some version of the source code, and in the other cases, some form of the binary code[4]. Figure 1 illustrates the working process of the static analyses.

[1] https://github.com/soot-oss/soot
[2] https://github.com/secure-software-engineering/FlowDroid
[3] https://www.virustotal.com/gui/home/upload
[4] https://en.wikipedia.org/wiki/Static_program_analysis

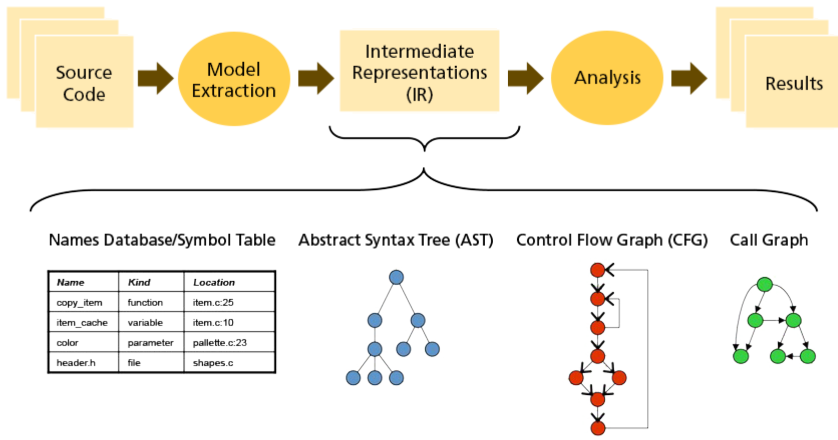


Figure 1: How Static Analysis Works.

2.2 Dynamic Analysis

Dynamic code analysis is the analysis of computer software performed by executing programs on a real or virtual processor. For dynamic program analysis to be practical, the target program must be executed with sufficient test inputs to cover almost all possible outputs. The use of software testing measures such as code coverage helps ensure that a good slice of the program's set of possible behaviors has been observed. Also, care must be taken to minimize the effect that instrumentation has on the execution (including temporal properties) of the target program. Dynamic analysis is in contrast to static program analysis. Unit tests, integration tests, system tests, and acceptance tests use dynamic testing[5]. Figure 2 illustrates the working process of the dynamic analyses.

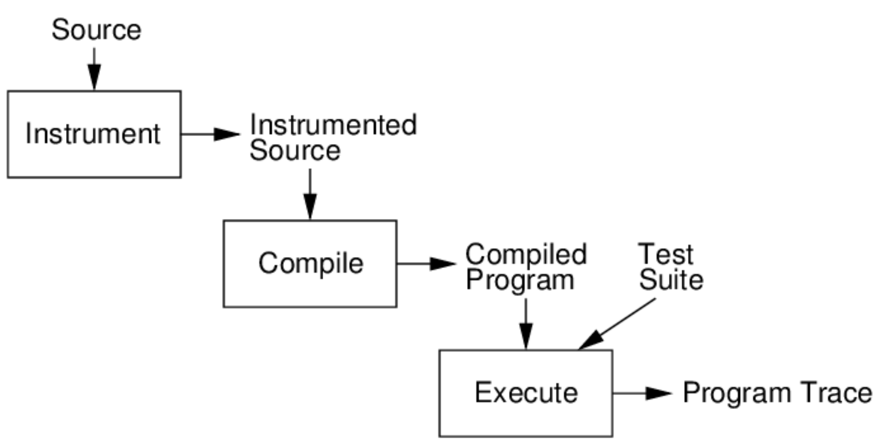


Figure 2: How Dynamic Analysis Works.

[5] https://en.wikipedia.org/wiki/Dynamic_program_analysis

2.3 FlowDroid [1]

FlowDroid[6] is a context-sensitive, flow-sensitive, field-sensitive, object-sensitive, and lifecycle-aware static analysis tool for Android applications. It is built upon Soot[7] and Heros[8]. A very precise call-graph is used to ensure flow sensitivity and context sensitivity. For the purpose of malware detection, FlowDroid statically computes data-flows in Android apps and Java programs, which is utilized to find out data leaks.

3 Task 1: Lab Set-up

In this lab, you need to use four malware samples for analysis. Their locations are listed below:

- Three malware are located under the folder `malware-analysis-lab/apks` on our pre-built Ubuntu 20.04 VM. They are: 1) `Claco.A.apk`; 2) `Dropdialer.apk`; an 3) `Obad.A.apk`.
- The fourth malware, namely `reverse_tcp.apk`, which you created in the "*Developing Mobile Malware*" lab, is located at `malware-develop-lab/volume` if you have done that lab successfully.

The environment for this lab has been pre-built in the Docker image yangzhou301/malware-analysis-lab [9], on which `/root/apks` is a shared folder mapping to `malware-analysis-lab/apks` on host.

First, run the following commands to check `malware-analysis-lab/apks` folder to see whether the `.apk` files are there (Figure 3).

```
//Make sure the malwares are there in the folder.
$ cd $HOME/malware-analysis-lab
$ ls apks
Claco.A.apk  Dropdialer.apk  Obad.A.apk
```

Figure 3: The command to check the availbilty of APKs.

You should also copy the `reverse_tcp.apk` to the `apks` folder (Figure 5).

```
//Copy the malware from the shared folder to the malware folder.
$ cp $HOME/malware-develop-lab/volume/reverse_tcp.apk $HOME/malware-analysis-lab/apks
```

Figure 4: The command to copy `reverse_tcp.apk` to the `apks` folder.

[6] https://github.com/secure-software-engineering/FlowDroid
[7] http://www.sable.mcgill.ca/soot/
[8] http://sable.github.io/heros/
[9] https://hub.docker.com/r/yangzhou301/malware-analysis-lab

Then, pull the Docker container's image and start it.

```
//Pull (download) the container for this lab.
$ docker pull yangzhou301/malware-analysis-lab

//Run the container and enable MoSF web application on port 8000.
//Remember, this is ONE line of command.
//Please type in the command, rather than COPY/PASTE it!
$ docker run --rm -it -p 8000:8000 -v $HOME/malware-analysis-lab/apks:\
/root/apks yangzhou301/malware-analysis-lab
```

Figure 5: The command to copy `reverse_tcp.apk` to the `apks` folder.

Once you start the container, you should see a screen with shell at `/root` directory as illustrated in Figure 6.

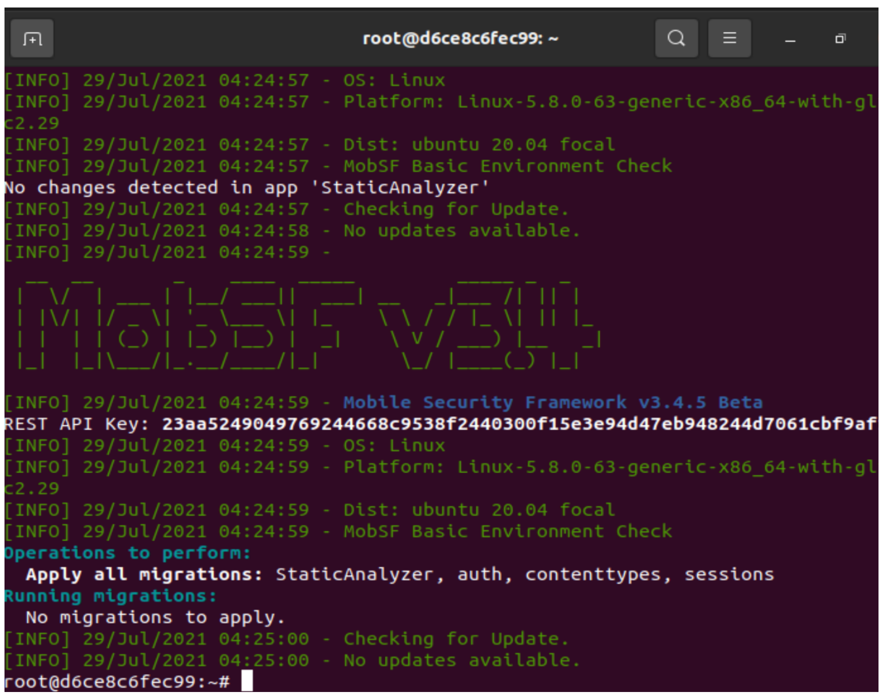


Figure 6: A screenshot of root shell in the container.

4 Task 2: Static Analysis with FlowDroid

For this task, you need to analyze an Android malware, namely `Claco.A.apk`, which steals text messages, contacts, and all SD Card files. It also automatically downloads `svchosts.exe` when the Android phone is connected to the PC in the emulation mode. The malware `svchosts.exe` will sequentially record sounds around the infected PC and upload them to remote servers.

Before running `FlowDroid` with `Claco.A.apk`, you must specify a definition file for the **sources** and **sinks**. In general, the **sources** define the statements/locations that takes a source of the sensitive data, while the **sinks** define the statements/locations that can possibly leak the sensitive data to the outside world. In this lab, you can use the `SourcesAndSinks.txt` file provided by `FlowDroid`, which targets on looking for privacy issues. Let's apply it as an example to analyze the data-flow in `Claco.A.apk` with the command in Figure 7.

```
//Run Flowdroid to perform static analysis for Claco.A.apk.
//Remember, this is ONE line of command.
//Please type in the command, rather than COPY/PASTE it!
$ java -jar soot-infoflow-cmd-jar-with-dependencies.jar -a apks/Claco.A.apk
-p $ANDROID_SDK/platforms/ -s SourcesAndSinks.txt
```

Figure 7: The command used to analyze `Claco.A.apk`.

The above command will produce a long report as the analysis result (Figure 8).

```
...
[main] INFO soot.jimple.infoflow.android.SetupApplication - Collecting callbacks and building a callgraph took 1 seconds
[main] INFO soot.jimple.infoflow.android.SetupApplication - Running data flow analysis on Claco.A.apk with 68 sources and 194
    sinks...
...
[main] INFO soot.jimple.infoflow.android.SetupApplication$InPlaceInfoflow - Callgraph construction took 0 seconds
...
[main] INFO soot.jimple.infoflow.android.SetupApplication$InPlaceInfoflow - IFDS problem with 10212 forward and 4505 backward
    edges solved in 0 seconds, processing 14 results...
[main] INFO soot.jimple.infoflow.android.SetupApplication$InPlaceInfoflow - Current memory consumption: 249 MB
[main] INFO soot.jimple.infoflow.android.SetupApplication$InPlaceInfoflow - Memory consumption after cleanup: 35 MB
[main] INFO soot.jimple.infoflow.data.pathBuilders.BatchPathBuilder - Running path reconstruction batch 1 with 5 elements
[main] INFO soot.jimple.infoflow.data.pathBuilders.ContextSensitivePathBuilder - Obtainted 5 connections between sources and sinks
...
[main] INFO soot.jimple.infoflow.android.SetupApplication$InPlaceInfoflow - The sink virtualinvoke $r7.<java.io.FileOutputStream:
    void write(byte[])>($r8) in method <smart.apps.droidcleaner.Tools: boolean GetContacts(android.content.Context)> was called
    with values from the following sources:
...
[main] INFO soot.jimple.infoflow.android.SetupApplication$InPlaceInfoflow - - r5 = interfaceinvoke $r4.<android.database.Cursor:
    java.lang.String getString(int)>($i0) in method <smart.apps.droidcleaner.Tools: boolean GetContacts(android.content.Context)
    >
...
<smart.apps.droidcleaner.Tools: boolean GetAllSMS(android.content.Context)> was called with values from the following sources:
...
[main] INFO soot.jimple.infoflow.android.SetupApplication$InPlaceInfoflow - - $r9 = interfaceinvoke $r4.<android.database.Cursor:
    java.lang.String getString(int)>($i1) in method <smart.apps.droidcleaner.Tools: boolean GetAllSMS(android.content.Context)>
[main] INFO soot.jimple.infoflow.android.SetupApplication$InPlaceInfoflow - The sink virtualinvoke $r13.<java.io.DataOutputStream:
    void write(byte[],int,int)>(r5, 0, $i0) in method <smart.apps.droidcleaner.Tools: boolean UploadFile(java.lang.String,java.
    lang.String,java.lang.String,java.lang.String,android.content.Context)> was called with values from the following sources:
[main] INFO soot.jimple.infoflow.android.SetupApplication$InPlaceInfoflow - Data flow solver took 1 seconds. Maximum memory
    consumption: 249 MB
[main] INFO soot.jimple.infoflow.android.SetupApplication - Found 11 leaks
```

Figure 8: The output report of `FlowDroid` for `Claco.A.apk`.

<u>**Deliverable 1**</u>: Run `FlowDroid` with the same source-and-sink configuration and explore the privacy issue in the malware `reverse_tcp.apk` (This is the malware you constructed in the "*Developing Mobile Malware*" lab)? Is there any data leakage? If yes, point out the lines in the outputs, which are relevant to the potential data leakage?

5 Task 2: Static Analysis with MobSF

For this task, you need to use Mobile Security Framework (MobSF)[10], an automated, all-in-one framework (Android/iOS/Windows) for mobile application pen-testing, malware analysis, security assessment, and static and dynamic analysis.

First, to use MobSF in the Ubuntu VM, you should type the following command in a terminal (Figure 9).

```
//Enable MoSF web application on port 8000.
//Remember, this is ONE line of command.
//Please type in the command, rather than COPY/PASTE it!
$ docker run --rm -it -p 8000:8000 -v $HOME/malware-analysis-lab/apks:/root/apks
yangzhou301/malware-analysis-lab
```

Figure 9: The command that connects MobSF service to port 8000.

Then, in the Ubuntu VM, open Firefox and type `http://localhost:8000/` in the address bar. If MoSF runs successfully, you should see the web interface of MobSF as Figure 10.

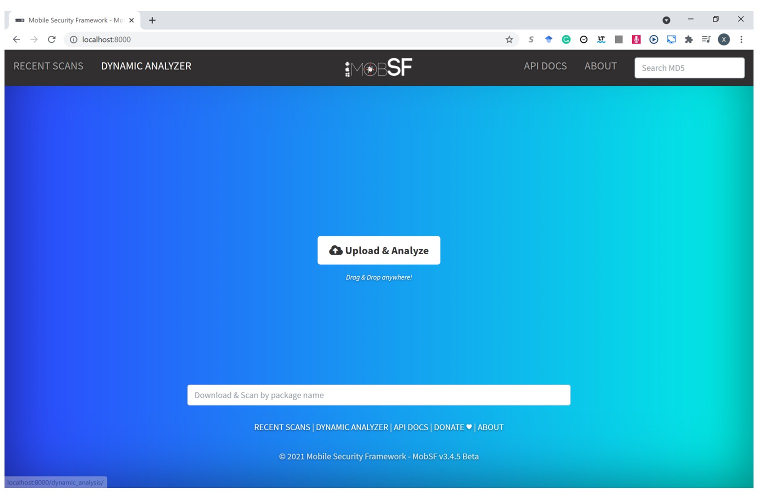


Figure 10: The interface of MobSF shown in the browser.

MobSF analyzes the mobile App through its web interface. Thus, you need to upload the `.apk` file through its web interface. In the following section, we will demonstrate how to use it to detect malware. Let's upload `Dropdialer.apk` via the web interface. Once the analysis is complete, you should see a report page as illustrated in Figure 11.

[10]https://github.com/MobSF/Mobile-Security-Framework-MobSF

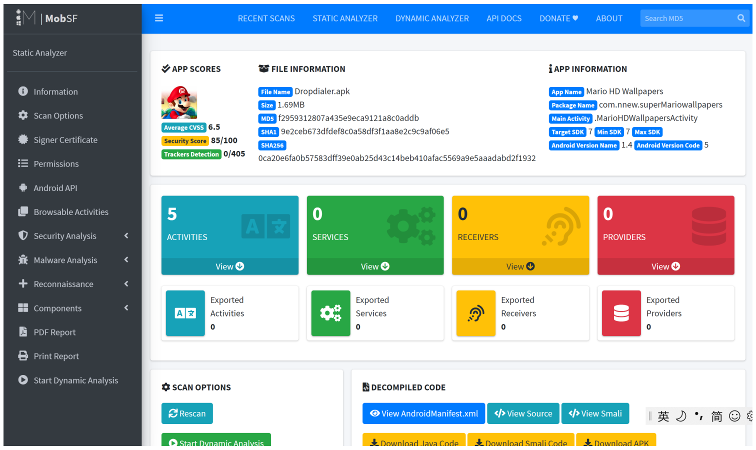
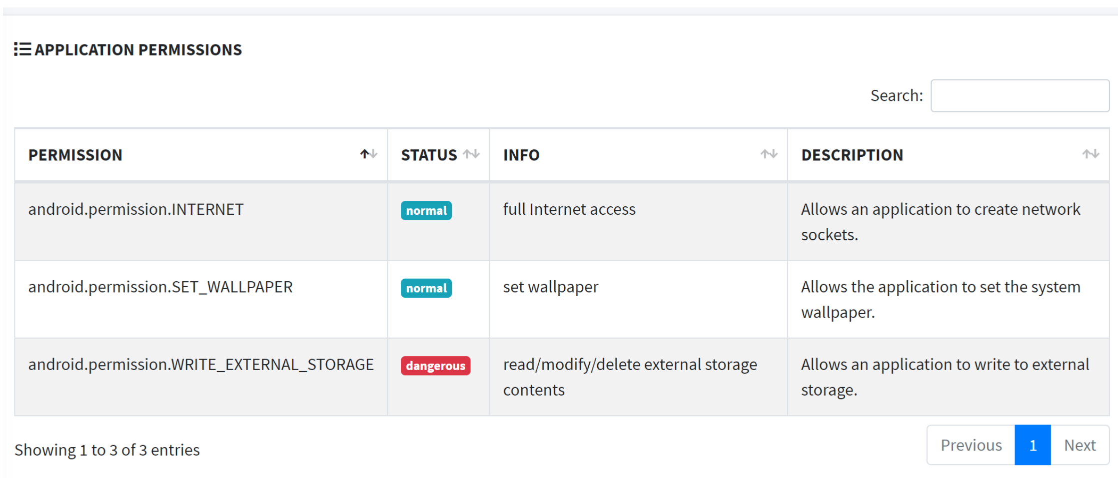


Figure 11: The analysis report of `Dropdialer.apk` generated by MobSF.

Scroll down and pay attention to the “Permission section” (Figure 12).



APPLICATION PERMISSIONS

Search:

PERMISSION	STATUS	INFO	DESCRIPTION
android.permission.INTERNET	normal	full Internet access	Allows an application to create network sockets.
android.permission.SET_WALLPAPER	normal	set wallpaper	Allows the application to set the system wallpaper.
android.permission.WRITE_EXTERNAL_STORAGE	dangerous	read/modify/delete external storage contents	Allows an application to write to external storage.

Showing 1 to 3 of 3 entries

Previous 1 Next

Figure 12: The “Permission section” of the analysis report of `Dropdialer.apk`.

Notice that it has a `WRITE_EXTERNAL_STORAGE` permission that allows the App to write **external storage**, which enables the App to download another App in the background.

Then we move to the “Code Analysis section”, which lists some potentially vulnerable codes (Figure 13).

</> CODE ANALYSIS

Search:

NO	ISSUE	SEVERITY	STANDARDS	FILES
1	The App logs information. Sensitive information should never be logged.	info	**CVSS V2:** 7.5 (high) **CWE:** CWE-532 Insertion of Sensitive Information into Log File **OWASP MASVS:** MSTG-STORAGE-3	com/nnew/superMariowallpapers/AlertActivity.java
2	App can read/write to	high	**CVSS V2:** 5.5 (medium)	com/nnew/superMariowallpapers/AlertActivity.java

Figure 13: The "Code Analysis section" of the analysis report of `Dropdialer.apk`.

The second item shows that a method of this App can write or read external storage with the default permission. For example, if you click `com/nnew/superMariowallpapers/MarioHDWallpapersActivity.java`, it will jump to the location of the vulnerable program, from which the malware can read from some downloaded `.apk` and `.txt` file (Figure 14).

```java

    public void deleteActivator() {
        startActivityForResult(new Intent("android.intent.action.DELETE", Uri.parse("package:com.activator")), 2);
    }

    public void deleteSource() {
        File file = new File(Environment.getExternalStorageDirectory() + "/download/" + "activator.apk");
        if (file.exists()) {
            file.delete();
        }
        File file2 = new File(Environment.getExternalStorageDirectory() + "/download/" + "srv.txt");
        if (file2.exists()) {
            file2.delete();
        }
    }
```

Figure 14: The code snippet of the vulnerable code in `Dropdialer.apk`.

Similarly, the "Quark Analysis" in the "Malware Analysis section" enumerates all potential malicious behaviors of this App (Figure 15).

POTENTIAL MALICIOUS BEHAVIOUR	EVIDENCE
Connect to a URL and read data from it	com/nnew/superMariowallpapers/AlertActivity.smali -> download(Ljava/lang/String;Ljava/lang/String;)V
Connect to a URL and receive input stream from the server	com/nnew/superMariowallpapers/AlertActivity.smali -> download(Ljava/lang/String;Ljava/lang/String;)V
Connect to a URL and set request method	com/nnew/superMariowallpapers/AlertActivity.smali -> download(Ljava/lang/String;Ljava/lang/String;)V

Figure 15: The "Quark Analysis section" of the analysis report of `Dropdialer.apk`.

Deliverable 2: Generate the analysis report `Dropdialer.apk` on your VM. Find out new traces to show that `Dropdialer.apk` is malware. List those new traces and justify your answer.

Deliverable 3: Analyze the `reverse_tcp.apk` (the one of the folder of this lab) with MobSF. You should answer the following questions.

1. list all possible dangerous permissions are requested by this App.
2. list all potential malicious behaviors that can be performed by this App.

6 Task 4: Dynamic Analysis with VirusTotal

In the previous task, you have learned how to analyze malware with static analysis. However, many malicious behaviors of malware remain undetected without actually running them. For this task, you should use `VirusTotal`[11], an online malware detection tool that aggregates the intelligence of many antivirus repositories, performs online scanning, and checks online behaviors of malware. More importantly, it performs *dynamic analysis* to detect malware inside Cuckoo sandbox[12].

⚠ Prerequisite

First, You should register an account on VirusTotal and log in. Otherwise, the dynamic analysis won't be functional.

For this lab, you need to analyze `Obad.A.apk`, a sophisticated malware, which

- sends SMS to premium-rate numbers;
- downloads other malicious programs and installs them on the infected device, and/or send them further via Bluetooth connection;
- controls other machines remotely from a console; and
- Exploits several unpublished vulnerabilities (dated by the year 2014).

Open the official website of VirusTotal (www.virustotal.com) as Figure 16 and upload the `Obad.A.apk` file.

[11] https://www.virustotal.com/gui/
[12] https://cuckoosandbox.org/

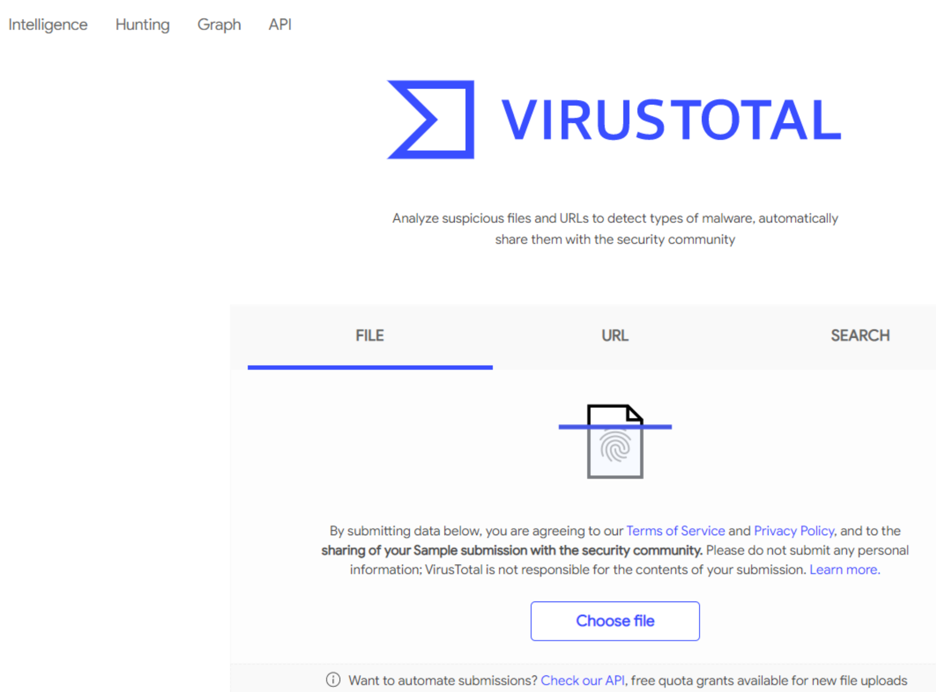


Figure 16: The web interface of `VirusTotal`.

The report should come out in a moment. Figure 17 illustrates the information and identifies the file as malware.

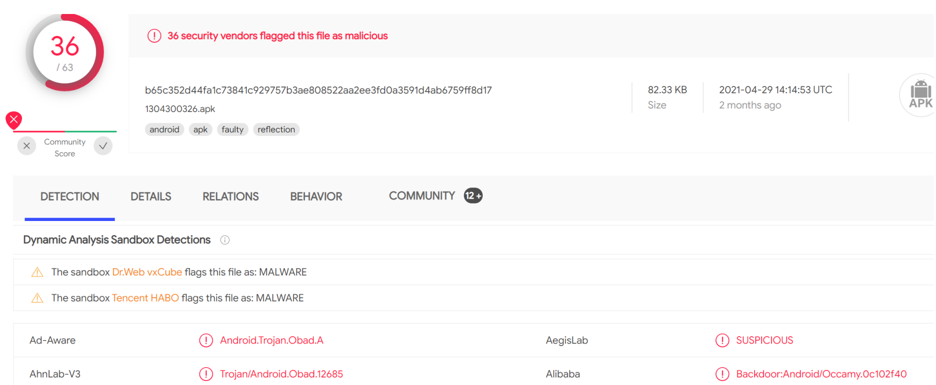


Figure 17: The output report of `VirusTotal` for `Obad.A.apk`.

Click the Details tab as Figure 18, you can read a detection report.

Contacted URLs

Scanned	Detections	URL
2015-05-19	2 / 63	http://www.androfox.com/load.php

Contacted Domains

Domain	Detections	Created	Registrar
www.google.com	1 / 86	1997-09-15	MarkMonitor Inc.
www.androfox.com	0 / 87	2018-03-20	NAMECHEAP INC
parkingpage.namecheap.com	1 / 87	2000-08-11	ENOM, INC.
mtalk4.google.com	0 / 85	1997-09-15	MarkMonitor Inc.
android.clients.google.com	0 / 86	1997-09-15	MarkMonitor Inc.

Figure 18: The Details report of `Obad.A.apk`.

Click the Relation tab as Figure 19, you can a more detailed report. In this report, you can see what domains or IP addresses this App tries to contact during its execution. It also gives a graphic summary about the files and addresses the App is related at run-time.

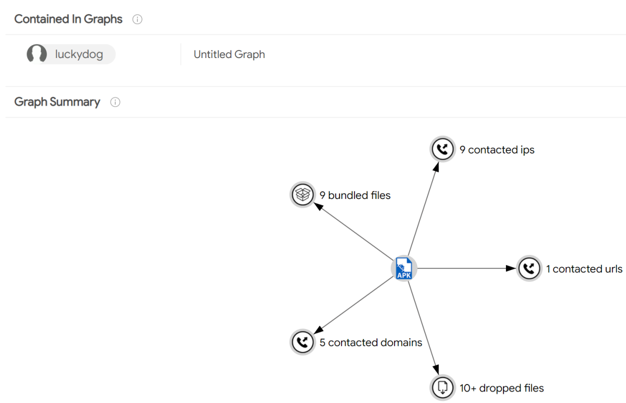


Figure 19: The Relations report of `Obad.A.apk`.

For more information about the run-time behaviors of this App, you can click the Behaviors tab as shown in Figure 20.

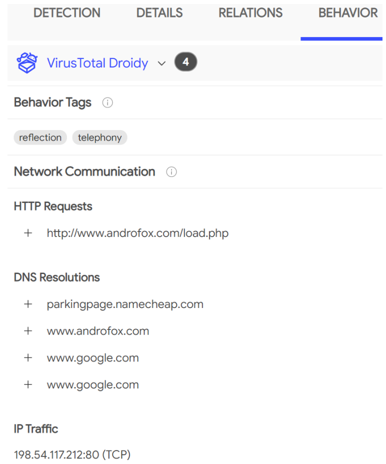


Figure 20: The Relations report of `Obad.A.apk`.

Of course, you can also read comments posted by other users in the Community panel regarding this App.

Deliverable 4: Using the similar approach as illustrated above, analyze `reverse_tcp.apk` with VirusTotal. Answer the following questions: 1) Which IP address(es) the App can contact at run-time? 2) What are other behaviors you discovered that are relevant to the attack? Would you please provide screenshot(s) to support your answer?

References

[1] S. Arzt, S. Rasthofer, C. Fritz, E. Bodden, A. Bartel, J. Klein, Y. Le Traon, D. Octeau, P. McDaniel, Flowdroid: Precise context, flow, field, object-sensitive and lifecycle-aware taint analysis for android apps, Acm Sigplan Notices 49 (6) (2014) 259–269.