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RESEARCH **Open Access**

Structural analysis of packing schemes for extracting hidden codes in mobile malware

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Abstract

In the Internet of Things service environment where all things are connected, mobile devices will become an extremely important medium linking together things with built-in heterogeneous communication functions. If a mobile device is exposed to hacking in this context, a security threat arises where all things linked to the device become targets of cyber hacking; therefore, greater emphasis will be placed on the demand for swift mobile malware detection and countermeasures. Such mobile malware applies advanced code-hiding schemes to ensure that the part of the code that executes malicious behavior is not detected by an anti-virus software. In order to detect mobile malware, we must first conduct structural analysis of their code-hiding schemes.

In this paper, we analyze the structure of the two representative Android-based code-hiding tools, Bangcle and DexProtector, and then introduce a method and procedure for extracting the hidden original code. We also present experimental results of applying these tools on sample malicious codes.

Keywords: Repackaging attack, Android app security, Mobile code hiding

1 Introduction

In the present advent of the Internet of Things (IoT) [1] era, communication functions such as Wi-Fi and Bluetooth are embedded in all things, so that real-time connection between things is made possible. While connecting various IoT devices with a single communication standard is practically very difficult, individual users already own mobile devices that fuse together multiple communication modules and companies provide a bring your own device (BYOD) work environment; hence, mobile devices will play a key role in the proliferation of IoT services.

However, in the case of mobile devices, when this coupling medium for all things is exposed to hacking, there is the threat that all the connected things will also become targets for cyber hacking. If there is a cyber attack aimed at specific connected devices, the security vulnerability of mobile devices can bring about side effects that may even have a major adverse effect on a different industry [2]. For example, in smart car service, cars connected through a mobile device can become infected with a virus and, if an infected car has problems operating, studies show that, in the worst case, major car accidents could result [3]. Consequently, in the IoT, it is a task of utmost importance and urgency to ensure that mobile devices cannot be infected easily.

Unfortunately, the number of mobile malware codes is increasing each year with evolution into various types. Recently, there has even been an emergence of ransomware, where documents in an infected device are secretly encrypted to demand payment. The majority of the mobile malware targets the Android platform. Android malware can be generally divided into two camps: those that have been designed to impersonate a normal app and those that have been designed to hide their malicious behavior. In the case where malware is designed to impersonate a normal app, it impersonates apps that users most frequently use such as apps related to the smartphone theme, finance, and games, so that a similar app is designed to secretly execute malicious behavior such as account charging and game information extraction, without the user's realization. To prevent an anti-virus from detecting such malware, attackers apply methods such as encryption, packing, and obfuscation [4] on the main code related to malicious behavior and then distribute it. To bring about speedy malware detection and response, understanding the structure of

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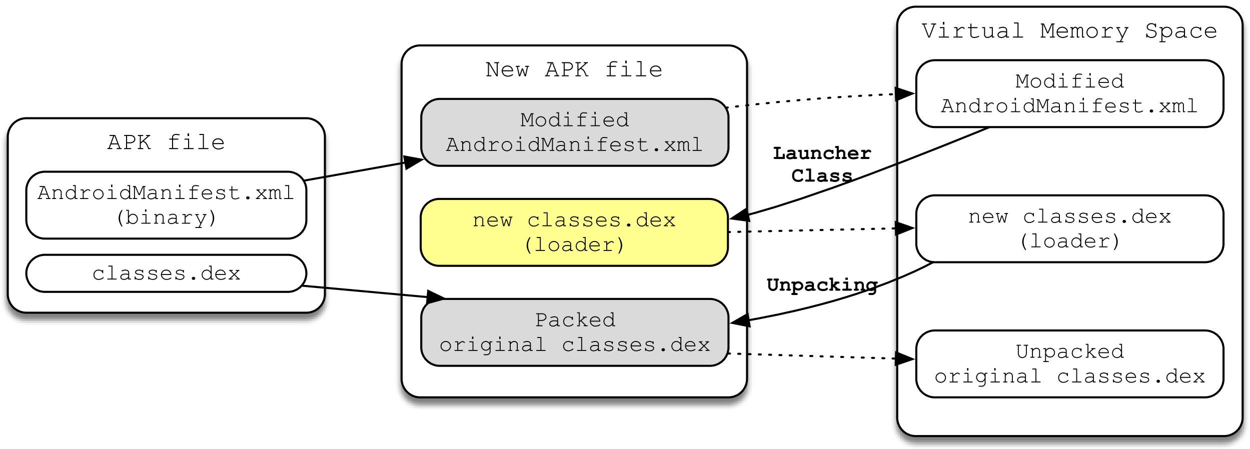

APK file
AndroidManifest.xml (binary)
classes.dex
New APK file
Modified AndroidManifest.xml
new classes.dex (loader)
Packed original classes.dex
Launcher Class
Unpacking
Virtual Memory Space
Modified AndroidManifest.xml
new classes.dex (loader)
Unpacked original classes.dex

Fig. 1 Packing and unpacking mechanisms

such code-hiding methods in order to extract the original code related to malicious behavior must first be achieved.

Thus, in this paper, we analyze the fundamentals behind the main code-hiding schemes used by mobile malware and, by running tests, empirically present methods for extracting the original code hidden in the malware through reverse engineering analysis. The tests target the malware that applies the main code-hiding tools, Bangcle [5] and DexProtector [6], and we analyze in detail the method of extracting the actual code responsible for malicious behavior from the packed Android application package (APK) files generated by these two analysis tools.

This paper is organized as follows. Section 2 presents background knowledge. Sections 3 and 4 describe the process of extracting the original code by conducting reverse engineering analysis of the structures of Bangcle's packing scheme and DexProtector's class encryption scheme. Section 5 presents results from experiments using sample apps, and Section 6 draws conclusions.

2 Related works

2.1 Repackaging attacks

The cause of various problems, including malware distribution in the Android environment is as follows. The Android platform, also labeled the Android Open

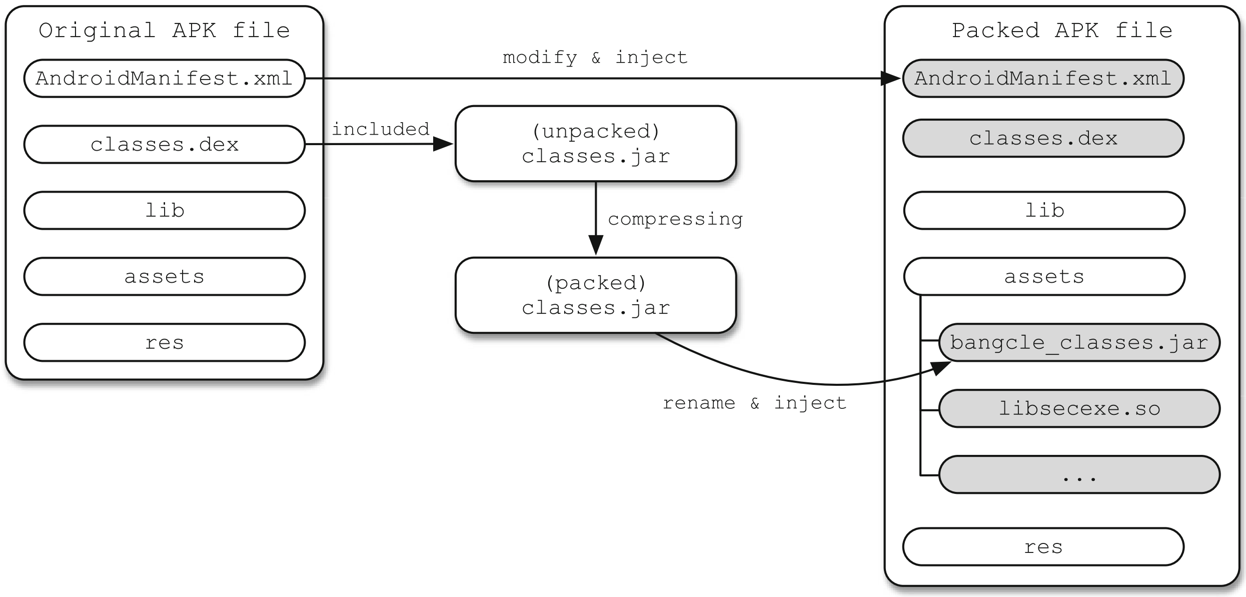


Fig. 2 Structure of an APK file packed by Bangcle

Table 1 List of files added by Bangcle

assets/bangcle_classes.jar
assets/bangcleplugin/collector.apk
assets/bangcleplugin/container.apk
assets/bangcleplugin/dgc
assets/com.msec.login
assets/com.msec.login.art
assets/com.msec.login.L
assets/com.msec.login.x86
assets/libsecexe.so
assets/libsecexe.x86.so
assets/libsecmain.so
assets/libsecmain.x86.so
assets/meta-data/manifest.mf
assets/meta-data/rsa.pub
assets/meta-data/rsa.sig

Source Project (AOSP) [7], promotes broad openness. While Androids possess a high market share for the smartphones because of this, various security problems have arisen owing to the app structure and signing method devised to provide this openness [8].

Android apps are, by default, built using the Java language and are generated in the APK file format [9, 10]. Because at this level in app development the developer distributes code by self-signing using jarsigner, an attacker can distribute code by re-signing using the attacker's private key rather than the developer's signature [11]. An attacker can use this point of weakness to insert attack code into a normal app, repackage it, and then distribute it. This is called a repackaging attack [12, 13].

2.2 Mobile code packing

Packing is a method used when one wishes to hide the code's structure before the code is run. Code packed by techniques such as encryption and compression is not revealed until execution; then, at each run time, the packed code is unpacked through dynamic loading and executed. Code exposure is minimized through static analysis. Such packing methods are used mainly so that malware such as viruses or worms are not detected by an anti-virus; however, recently, normal programs have also utilized this method in the area of copyright protection to protect important code logic [14].

Generally, when using packing, the original code exists in its packed state, so a loader that unpacks packing code is added and the control flow is also adjusted so that the loader is run first. When a packed app is run, the loader is run first, so that the app loads once the packed code is unpacked before running the original code (Fig. 1). Such packing schemes have the advantage of minimizing modifications to the original code compared to a code obfuscation scheme.

Table 2 Classes added and used by Bangcle

Classes	Description
ACall	Interfacing with libraries
ApplicationWrapper	Entry point of the packed app
FirstApplication	Loading the original app
MyClassLoader	Loading the original app
Util	Other utilities

```
public static void runAll(Context ctx) {
    ...
    checkX86(ctx);
    CopyBinaryFile(ctx);
    createChildProcess(cox);
    tryDo(ctx);
    runPkg(ctx, ctx.getPackageName());
}
```

Fig. 3 Source code decompiled from `Util` classes

2.3 Mobile code reverse engineering

Reverse engineering methods for mobile code can be grouped roughly into static analysis methods or dynamic analysis methods. In static analysis, the method uses a disassembler or decompiler. Disassemblers targeting the Android execution file, called Dalvik Executable (DEX), include *baksmali* [15], *dedexer* [16], and *apktoolkit* [17], and using these programs, the DEX file is converted into a smali file [18], so that Dalvik virtual machine (DVM) bytecode [19] can be analyzed in units of commands. For decompilers, dex2jar [20], jad.jeb [21], etc. have been made public, and they also provide the function of restoring a DEX file into Java source code. Static analysis of the app is done through APK extraction using ADB, DEX conversion to JAR using *dex2jar*, and JAR file analysis using a Java decompiler while static analysis of *so* library is carried out using IDA [22] with Hex-Ray. We can investigate which functions and libraries are used through static analysis.

Dynamic analysis enables accurate observation of parameters and return values of variables and functions that are difficult to identify using static analysis, thus allowing effective analysis of the app. The main Android dynamic analysis tools are DroidScope [23], AppUse [24], and DroidBOX [25], but these run in sandbox-based emulator form. When an app is run in the emulator, it either analyzes the commands executed in the DVM or analyzes the APIs being used and provides the user with activity information needed for app analysis. Furthermore, IDA

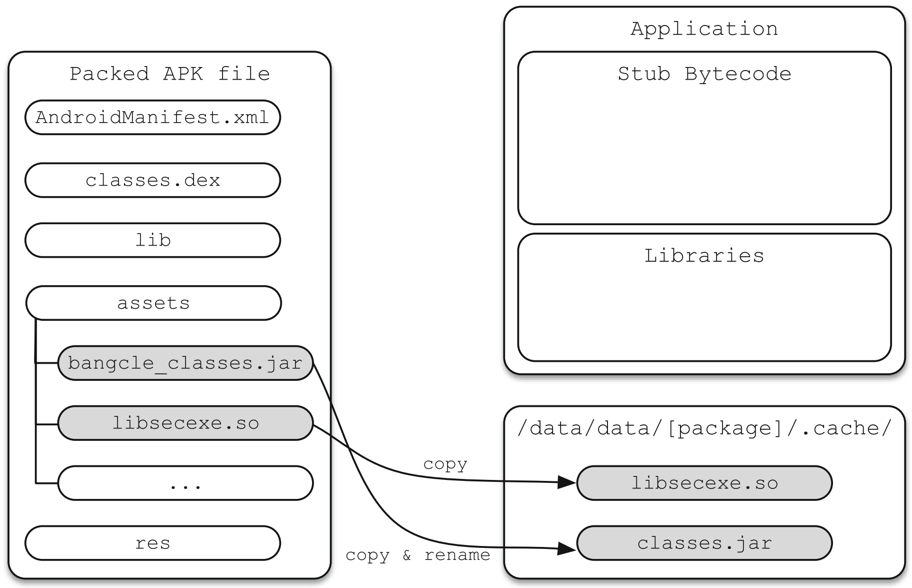


Fig. 4 Copying procedure when the `CopyBinaryFile` method is invoked

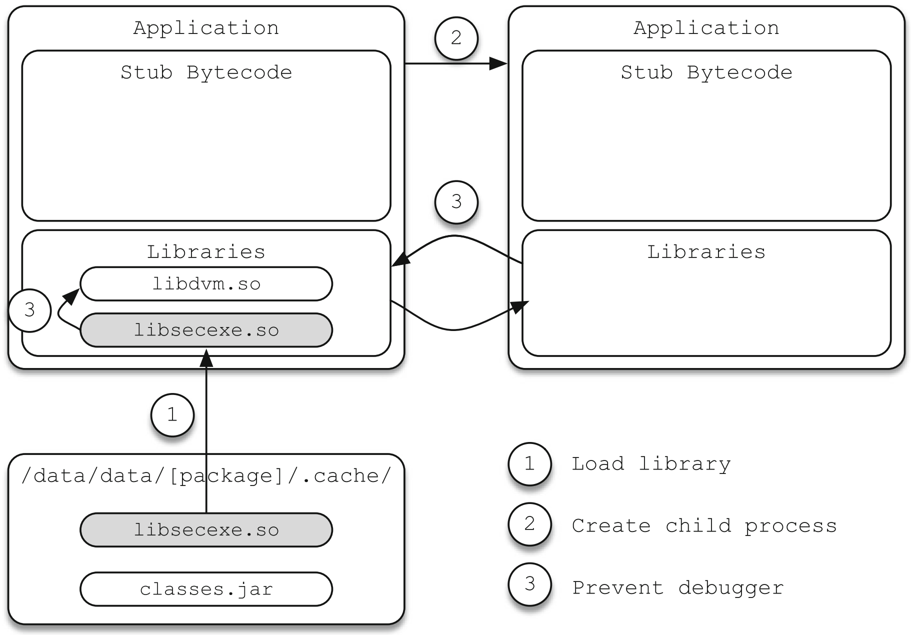


Fig. 5 Processing steps of the `createChildProcess` method

```
I/dalvikvm( 2582): Debugger is active
I/WindowState( 248): WIN DEATH: Window{41926a68 com.msec.login/
com.msec.login/.MainActivity}
I/ActivityManager( 248): Process com.msec.login (pid 2582) has died.
W/ActivityManager( 248): Force removing ActivityRecord{42c46518 u0
com.msec.login/.MainActivity t3}: app died, no saved state
```

Fig. 6 Target app process is terminated when being attached to NetBeans

```
D/dalvikvm(10750): Trying to load lib /data/data/com.msec.login/.cache/libsecexe.so
D/dalvikvm(10750): Added shared lib /data/data/com.msec.login/.cache/libsecexe.so
I/ActivityManager( 248): Process com.msec.login (pid 10750) has died.
W/ActivityManager( 248): Force removing ActivityRecord{41842938 u0
com.msec.login/.MainActivity t4}: app died, no saved state
I/WindowState( 248): WIN DEATH: Window{42c8b0e8 com.msec.login/
com.msec.login/.MainActivity}
```

Fig. 7 Target app process is terminated when being attached to IDA

and GDB [26] are used not only for static analysis but also frequently for dynamic analysis.

3 Structural analysis on Bangcle

3.1 Packing

Bangcle is a packing tool that provides anti-reverse engineering functions such as anti-debugging [27], anti-tampering, anti-decompilation, and anti-runtime injection for mobile code using execution code compression [28]. To examine the functions provided by this tool, we examine the packing process for a sample app that has a simple log-in function shown in Fig. 2. The areas colored in gray in the illustration denote files that have been newly added or changed by Bangcle.

First, using just *classes.dex* from the original APK file, another *classes.jar* in the APK file format is generated. Compressing this *(unpacked) classes.jar* file, the file is generated under the same file name *(packed) classes.jar*. Then, this *classes.jar* file is renamed to *bangcle_classes.jar* and saved in the packed APK file's assets folder. Additionally, files such as *libsecexe.so* which provide decompression and anti-analysis functions for the *bangcle_classes.jar* file are also stored together in the assets folder. The list of added files is shown in Table 1.

After packing the original *classes.dex*, a separate *classes.dex* file is newly generated and added to the packed APK. In addition, the *AndroidManifest.xml* file is also updated with information regarding the newly generated *classes.dex* file. Table 2 shows the class information included in the newly generated *classes.dex* file. The `ACall` class manages the interface with library files, and the `ApplicationWrapper` class monitors the control flow using the entry point of the compressed app. The `FirstApplication` class and `MyClassLoader` class are used to load the original app into memory. The `Util` class carries out overhead operations needed to execute *libsecexe.so* and calls functions from *libsecexe.so* to perform unpacking, anti-debugging, anti-tampering, and anti-runtime injection functions.

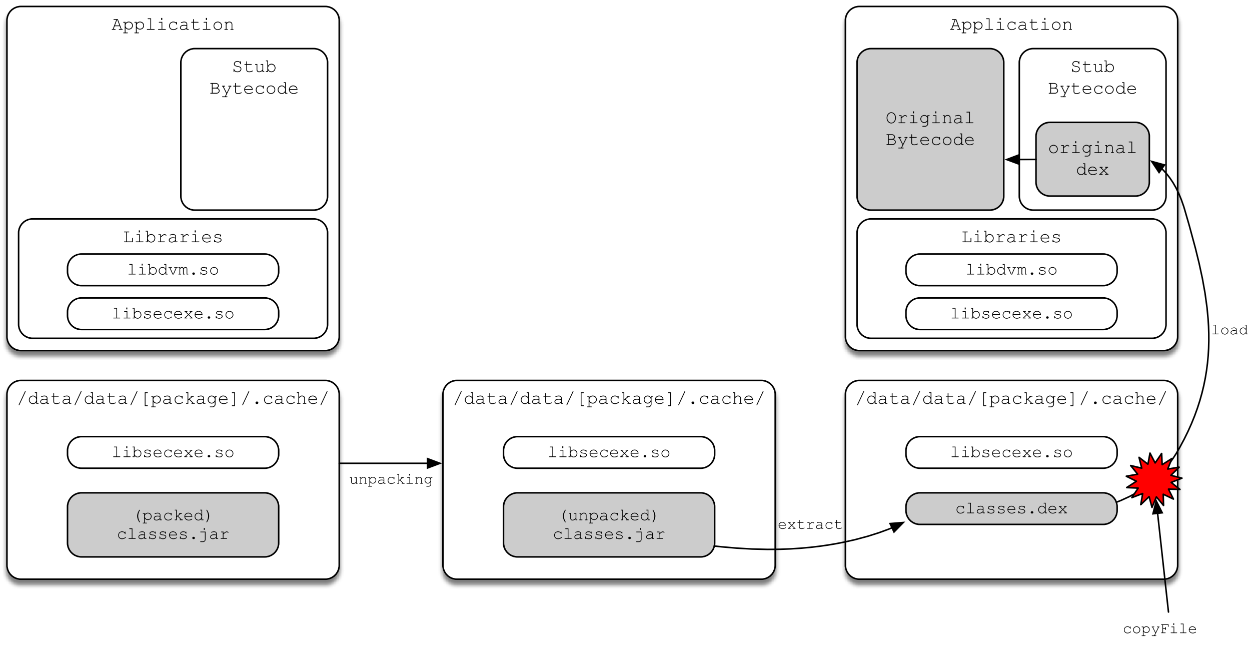


Fig. 8 Modified unpacking procedure for extracting the original *classes.dex*

```
public static void runAll(Context ctx) {
    ...
    checkX86(ctx);
    CopyBinaryFile(ctx);
    createChildProcess(cox);
    tryDo(ctx);
    copyFile(ctx);
    runPkg(ctx, ctx.getPackageName());
}
```

Fig. 9 Modified code to extract the original *classes.dex*

3.2 Unpacking

Figure 3 examines the primary logic of the code inserted by Bangcle to execute the packed APK. This code is the Java code obtained by disassembling the `Util` class.

The operation process of the primary methods is as follows. First, the `checkX86` method identifies whether the CPU of the device running the app is x86-based or ARM-based. If it is an x86-based CPU, the *libsecexe.x86* file is copied to a temporary folder, whereas if it is an ARM-based CPU, the *libsecexe.so* file is copied to a temporary folder. `CopyBinaryFile` takes the *bangcle_classes.jar* file in the assets folder of the compressed APK file, copies it to the temporary folder `/data/data/[package_name]/.cache/`, and renames it as *classes.jar* (Fig. 4). As a method that provides anti-debugging-related functions, `createChildProcess` is explained in more detail in the next section. `tryDo` restores the *(packed) classes.jar* file copied to the temporary folder into the *(unpacked) classes.jar* file that includes the original *classes.dex*. `runPkg` loads the original *classes.dex* in the *(unpacked) classes.jar* file into memory and executes it. After the original *classes.dex* has been loaded, the *(unpacked) classes.jar* file is recompressed into the *(packed) classes.jar* and saved in the temporary folder.[1]

3.3 Anti-debugging

The method `createChildProcess` generates a child process, so that Java debug wire protocol (JDWP) and a native debugger cannot run. As shown in Fig. 5, first, the *libsecexe.so* file copied to the temporary folder is loaded into memory. After the file is loaded into memory, the method used to prevent native and/or managed code debuggers is applied.

Both Figs. 6 and 7 show that the app instantly terminates as soon as connection of the NetBeans and IDA debuggers to the packed APK is attempted.

In this way, because the anti-debugging function is already applied with Bangcle, analysis methods that use existing debuggers do not work, and a different method must be used for analysis.

3.4 Code extraction

As explained in Section 3.2, when the packed APK is executed, the *bangcle_classes.jar* file is renamed to *classes.jar* and copied to the temporary folder along with files such as *libsecexe.so*. The *classes.jar* saved in the temporary folder at this time is packed, so we cannot analyze it. However, as shown in Fig. 8, if we find the point when the *(packed) classes.jar* file is temporarily restored to the *(unpacked) classes.jar* and copy that file to the data folder, we can extract the original *classes.dex*.

Figure 9 shows a section of `Util.java` modified to copy the *(unpacked) classes.jar* file into the data folder, namely, if the `copyFile` method is added in order to copy the file between the `tryDo` method and `runPkg` method, we can procure the *(unpacked) classes.jar* with the original *classes.dex* included.

If the *classes.dex* file obtained in this way is converted into smali code using the *baksmali* tool, we can observe the code in its original state as in Fig. 10. Thus, we see that Bangcle's packing function can be neutralized in this manner.

4 Structural analysis on DexProtector

4.1 Encryption

DexProtector is a program used for anti-reverse engineering for Androids. The main functions provided by DexProtector are class encryption, tamper detection, code and data hiding, etc. In this paper, we set out to examine

```
.prologue
.line 7
const-string v0, "MSEC"

invoke-virtual {p1, v0}, Ljava/lang/String;->equals(Ljava/lang/Object;)Z

move-result v0

if-eqz v0, :cond_12

const-string v0, "1234"

invoke-virtual {p2, v0}, Ljava/lang/String;->equals(Ljava/lang/Object;)Z
```

Fig. 10 Smali code disassembled from the extracted *classes.dex*

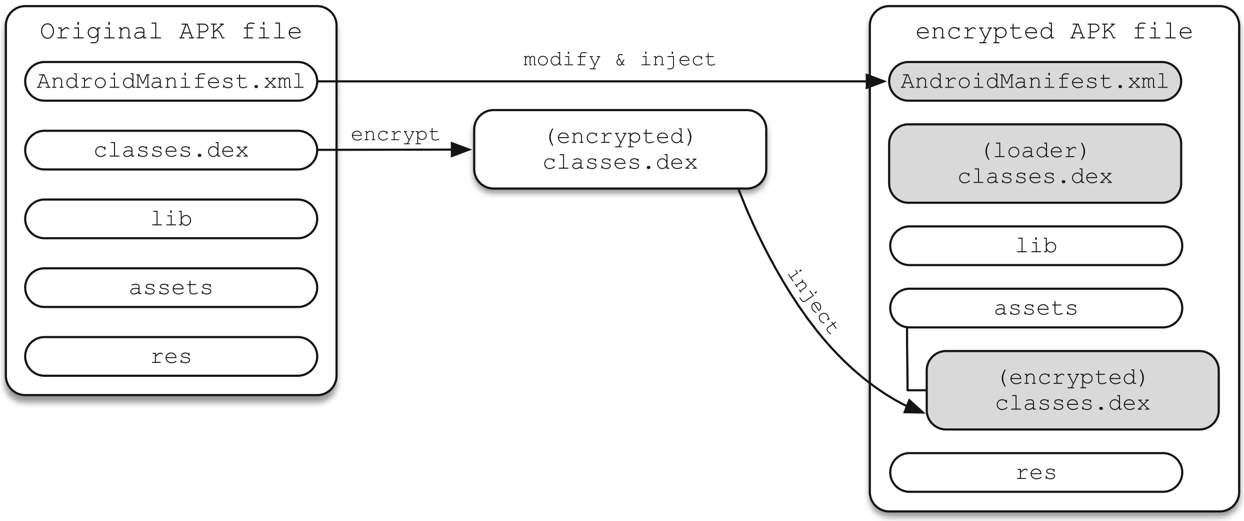


Fig. 11 Class encryption procedure of DexProtector

the potential for reverse engineering analysis focusing on the class encryption function in the various DexProtector functions. Figure 11 shows the class encryption process of DexProtector.

First, the *classes.dex* of the original APK file is encrypted to generate the identically named *(encrypted) classes.dex* and save it in the assets folder. During this time, both the *classes.dex* file for decrypting and executing the *(encrypted) classes.dex* file and the *AndroidManifest.xml* file updated with the modified file information are saved, and the encrypted APK file is generated.

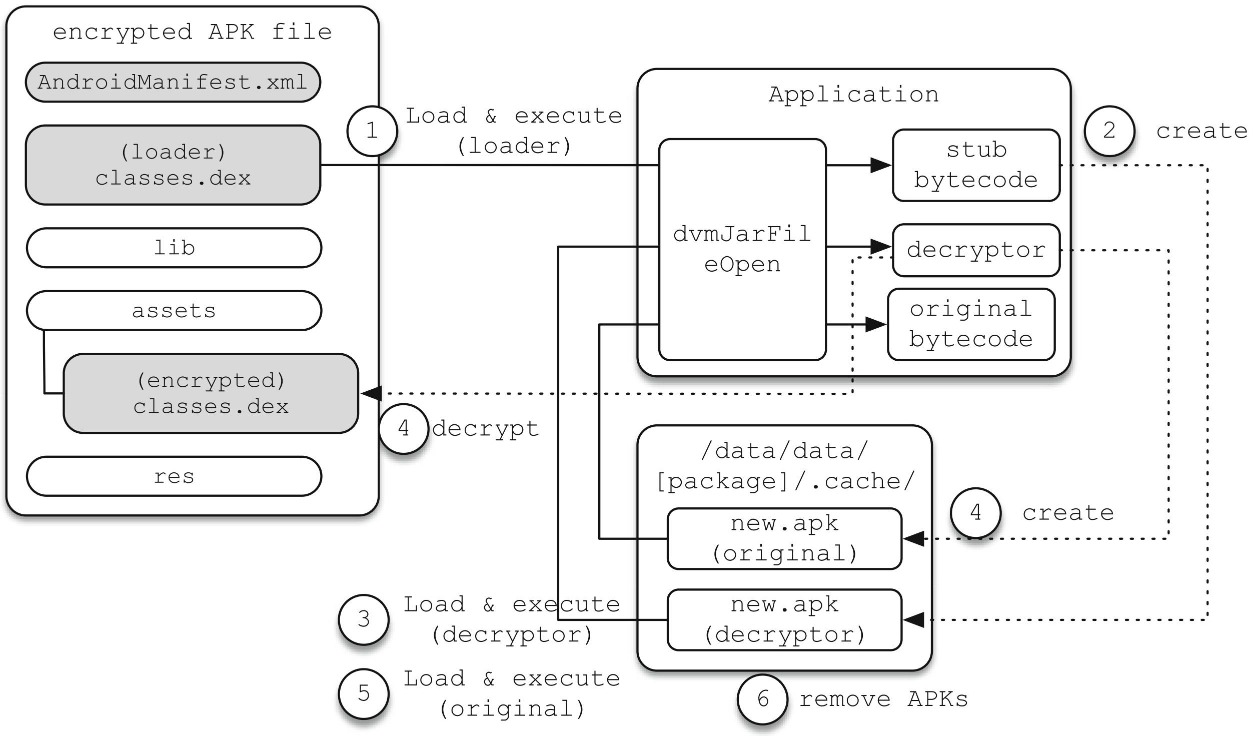


Fig. 12 DexProtector class decryption procedure

```
<application
    android:debuggable="true"
    android:icon="@drawable/app_notes"
    android:label="@string/app_name"
    android:name=".Application">
        ...
</application>
```

Fig. 13 Modifying *AndroidManifest.xml* for enabling debugger attachment

4.2 Decryption

When the encrypted APK file is executed, the *(loader) classes.dex* file is executed first. The *(loader) classes.dex* file generates the decryptor APK file in the `/data/data/[package_name]/.cache` folder, and, using the generated decryptor APK file, the decryptor is run. The executed decryptor decrypts the *(encrypted) classes.dex* file saved in the assets folder of the encrypted APK file and saves the original APK file in the `/data/data/[package_name]/.cache` folder. Afterwards, the restored original APK file is actually executed. After being executed, the original APK file saved in the `/data/data/[package_name]/.cache` folder is deleted. Figure 12 shows the DexProtector class decryption procedure.

4.3 Code extraction

Because apps with DexProtector have the anti-debugging function applied by default, debugging at the smali code level can be done using IDA. Therefore, to debug an app at the smali code level, the debuggable property in the *AndroidManifest.xml* file must be forcibly modified to true, as shown in Fig. 13.

In this paper, the objective is to obtain the decrypted classes by reverse engineering the encrypted classes. If the APK is simply repackaged and executed, the original app is terminated before MainActivity is executed and the log is outputted, as seen in Fig. 14. By analyzing the *log* file, we confirmed that the first generated *new.apk* file was loaded properly and the second generated *new.apk* file failed to open because it was not in a zip file format.

In the case of normal execution, the *new.apk* file is generated twice and then loaded. However, when the application is executed normally, the *new.apk* cannot be found because the *new.apk* file is deleted after loading. Therefore, to incapacitate DexProtector's class encryption scheme, the *new.apk* file which is generated in real time must be obtained before deletion.

To open the *new.apk* file, we must first set a breakpoint for the `Application` class that is executed for the first time the app is executed by using the smali code level debugger. Then, we set breakpoints such as the `dvmJarFileOpen` function from *libdvm.so* by using native code-level debugger. Afterwards, when the app is rerun, after a *new.apk* file is generated, the app freezes at the assigned breakpoint. If we obtain the first generated *new.apk* file and decompile it using the JEB decompiler, we can observe the unpack function, etc., as in Fig. 15. The `unpack` function uses the application's hash value as a decryption key to decrypt the packed `classes.dex`. Because hash values change when the application is repackaged, the second *new.apk* is not generated correctly. Thus, to obtain the second *new.apk* file (without repackaging), one must connect the debugger and obtain the file before `MainActivity` is executed.

Because Android apps are generated initially from the early Zygote process, we go about attempting to debug during the Zygote process. Using the follow-fork-mode child option in the debugger, we debug the child process generated by Zygote.

The `dvmJarFileOpen` function [29] is immediately called to load the file type compressed by the functions in the *libdvm.so* library file (see Fig. 16). The `dvmJarFileOpen` function that is called first is a function for loading the installed APK file. The `dvmJarFileOpen` function that is called second is a function for loading the first *new.apk* file generated. The `dvmJarFileOpen` function called afterwards is a function for loading the second *new.apk* file, which includes the decrypted logic.

Figure 17 shows the result of obtaining and disassembling the second *new.apk* file generated in the installed app's data folder before the last `dvmJarFileOpen` function is called. Because the encrypted class was already decrypted, hereafter, there are no constraints on disassembling and conducting reverse analysis. Figure 18 shows one of methods to obtain the original code from DexProtector.

```
D/dalvikvm( 5124): DexOpt: --- BEGIN 'new.apk' (bootstrap=0) ---
D/dalvikvm( 5138): DexOpt: load 7ms, verify+opt 4ms, 103460 bytes
D/dalvikvm( 5124): DexOpt: --- END 'new.apk' (success) ---
D/dalvikvm( 5124): Dex prep '/data/data/com.example.msec/app_dex/new.apk': unzip in 0ms, rewrite 82ms
D/dalvikvm( 5124): Zip: EOCD not found, /data/data/com.example.msec/app_dex/new.apk is not zip
```

Fig. 14 Log output when running the repackaged app

```
static void unpack(Context arg21, File arg22, File arg23) {
    FileOutputStream v15_2;
    FileOutputStream v16;
    Context v0 = arg21;
    File v1 = arg22;
    File v2 = arg23;
    int v4 = v0.getPackageManager().getPackageInfo(v0.getPackageName(), 64).signatures[0].hashCode();
    int[] v5 = new int[][v4, v4, v4, v4];
    int[] v6 = new int[][-1220469515, -462801895, 895405498, 1374636159];
    byte[] v7 = new byte[8192];
    InputStream v9 = v0.getAssets().open("classes.dex");
    try {
        v16 = new FileOutputStream(v1);
    }
```

Fig. 15 Java code decompiled from the first *new.apk* file

```
[New process 1482]
[Switching to LWP 1482]

Breakpoint 1, 0x407908be in dvmJarFileOpen(char const*, char const*, JarFile**,
bool) () from /system/lib/libdvm.so
(gdb) set follow-fork-mode parent
(gdb) c
Continuing.

Breakpoint 1, 0x407908be in dvmJarFileOpen(char const*, char const*, JarFile**,
bool) () from /system/lib/libdvm.so
(gdb)
Continuing

Breakpoint 1, 0x407908be in dvmJarFileOpen(char const*, char const*, JarFile**,
bool) () from /system/lib/libdvm.so
(gdb)
Continuing
```

Fig. 16 Debugging process to obtain the second *new.apk* file

```
# virtual methods
.method public secretMethod()Z
    .locals 3

    const-string v1, "msec.ssu.ac.kr"

    iget-object v0, p0, Lcom/example/msec/SecretClass;

    const v2, 0x7f080002

    invoke-virtual {v0, v2}, Lcom/example/msec/MainActivity

    mov-result-object v0
```

Fig. 17 Smali code disassembled from the second *new.apk* file

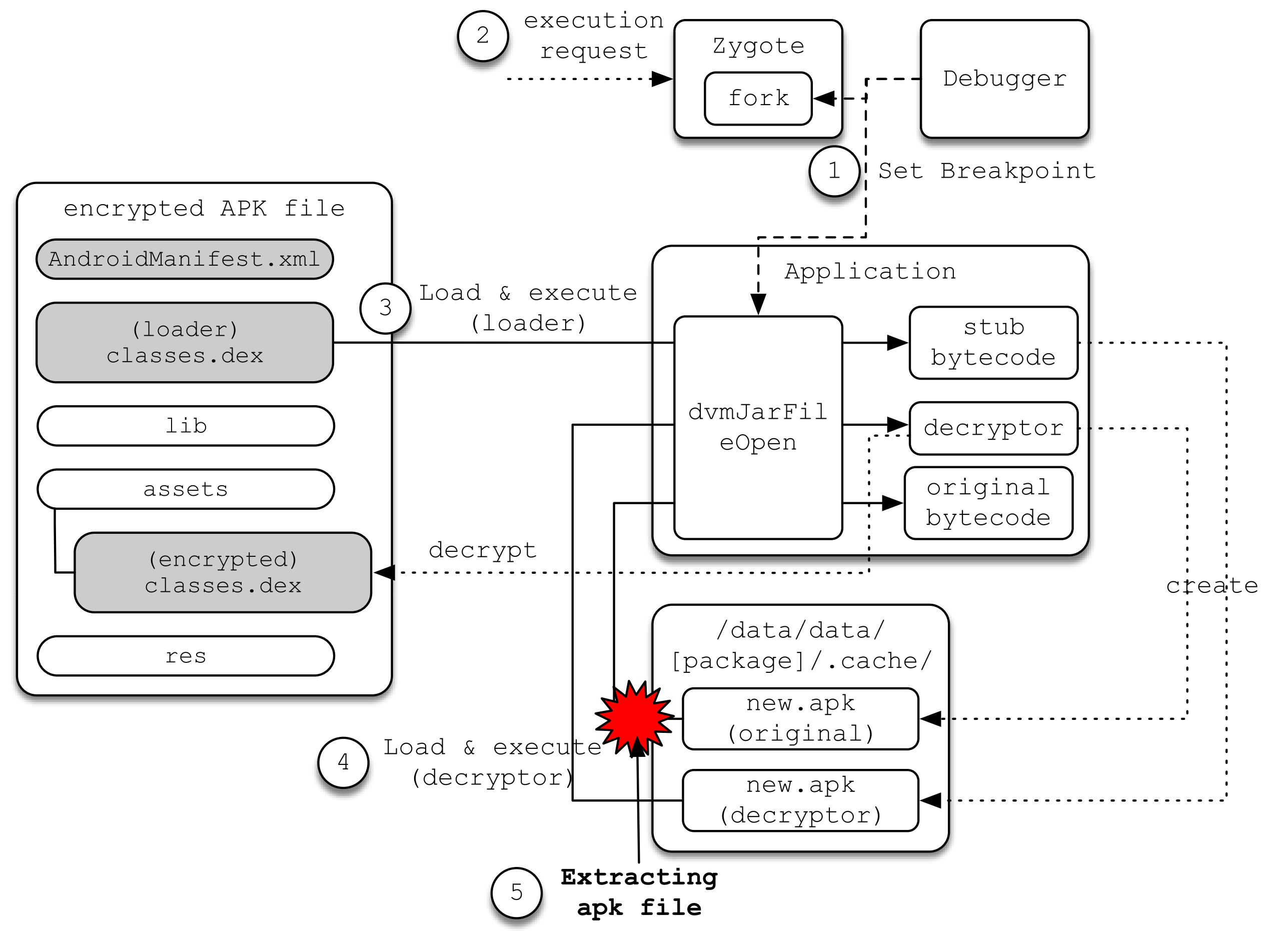


Fig. 18 Process used to obtain the original class from the APK file with class encryption

5 Experiments

In this section, we describe experimental results for determining whether code extraction schemes can be used successfully for analyzing malware samples that apply Bangcle and DexProtector.

5.1 Target app selection

We first obtained the target malware apps for the experiment from Contagio [30] and VirusShare [31] and distinguished them according to whether the apps applied Bangcle or DexProtector.

Table 3 The analysis results on packed and unpacked applications with various analysis engines

Analysis engine	Packed application	Unpacked application
AVG	Android/Deng.MAO	Android/Deng.GNV
Alibaba	A.L.Rog.Tgcmbwlbehlb	A.W.Rog.ModelAd
CAT-QuickHeal	Android.SecApk.A (PUP)	Android.Dowgin.AM (AdWare)
ESET-NOD32	Secapk.E potentially unsafe	AdDisplay.Dowgin.Rpotentially unwanted
Fortinet	Adware/Secapk!Android	Adware/Secapk!Android
Ikarus	AdWare.AndroidOS.Secapk	PUA.AndroidOS.Dowgin
Kaspersky	not-a-virus:HEUR: AdWare.AndroidOS.Mmaro.a	HEUR:Trojan-Downloader. AndroidOS.Agent.az
NANO-Antivirus	Trojan.Android.Dowgin.dtznya	Trojan.Android.Dowgin.dtznya
Qihoo-360	Adware.Android.Gen	Adware.Android.Gen
Sophos	Andr/PornClk-AB	Android Dowgin (PUA)

First, in the case of determining Bangcle, when decompiling the APK file, if package names such as *com.secapk.wrapper*, *com.secneo.guard*, and *com.bangcle.protect* are included or if *libexec.so*, *libmain.so*, *bangcle _classes.jar*, etc. are found in the assets folder, Bangcle was determined to have been applied. In the case of DexProtector, because it is difficult to determine its use with only the results generated from decompiling the file, the `Application` class is included. It was determined that DexProtector is applied based on the log record showing whether, when executed, the `DexOpt` process optimizes an identical named apk file twice.

Based on the above criteria, we were able to determine seven malware apps that applied Bangcle and one malware app that applied DexProtector, thus selecting a total of eight apps as the subjects for our experiment.

5.2 Experimental setup

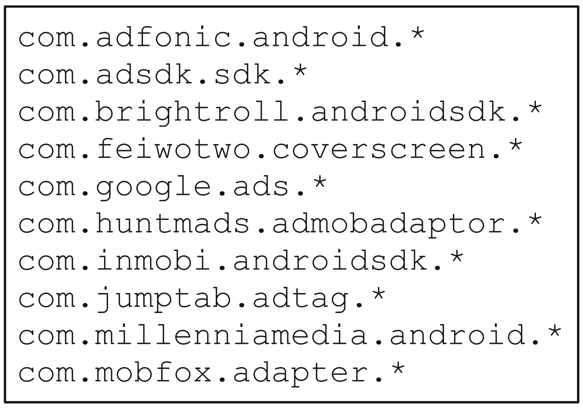
To extract code from malware that applied Bangcle and DexProtector, we experimented in the environment described as follows. Because an app using Bangcle only needs to be repackaged to be executed, we ran the app on an Android version 4.4.4 device that had not been rooted. We determined that the Bangcle version information was given by the numbers assigned with the `VERSION_NAME` variables in the `Util` class. Because a debugger needs to be used for apps that have applied DexProtector, we used a rooted device to obtain higher privileges than the app process. For the debugger, we used a GDB built for ARM use. Finally, for decompiling and repackaging, we used *apktool* version 2.0.3.

5.3 Experimental results

The analyzed apps were applied with various versions of Bangcle, from 1.0 to 8.5.12. However, all of the versions were able to extract *the original codes*. Likewise, it was possible to extract the original codes from DexProtector.

Table 3 shows the experimental results on packed and unpacked applications using well-known analysis engines. In the case of the packed applications, most of the analysis engines recognize that Bangcle has been used but do not check their behaviors in details. On the other hand, most of them are able to figure out the unpacked application's behavior and thus determine it is an adware.

Also, we observed that the unpacked applications include various library related to advertisement as shown in Fig. 19. Therefore, we can understand the exact behavior of the applications by obtaining unseen information from the unpacked applications.



```
com.adfonic.android.*
com.adsdk.sdk.*
com.brightroll.androidsdk.*
com.feiwotwo.coverscreen.*
com.google.ads.*
com.huntmads.admobadaptor.*
com.inmobi.androidsdk.*
com.jumptab.adtag.*
com.millenniamedia.android.*
com.mobfox.adapter.*
```

Fig. 19 Advertisement libraries included in the application

6 Conclusions

In this paper, we present the experimental results of a reverse engineering analysis conducted regarding code-hiding methods applied in Android-based malware. As code-hiding tools in the experiment, we used Bangcle, the most commonly used packer in the Android market, and DexProtector, the highest-performing binary code protector, as subjects. Through structural analysis, we were able to identify characteristics and fundamentals of the shielding method for each tool and were successful in extracting the original code that causes malicious behavior from all of the tested malicious apps. We predict that such an analysis method will be used as a foundational technique to quickly detect and counteract mobile malware, which is the core security risk factor in the proliferation of IoT service.

It should be noted that, if the shielding methods analyzed in this paper are conversely used to protect code in normal apps, they could be used to act on the apps' weaknesses. Therefore, further investigation is required on secure code-hiding methods to prevent such reverse engineering.

Endnote

[1]Note that we speculate that the reason for recompression after loading the original *classes.dex* is to prevent reverse engineering analysis of the folder saved in the temporary folder.

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Competing interests
The authors declare that they have no competing interests.

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