A peek under the Blue Coat

ProxySG internals

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AIRBUS GROUP

Outline

Outline

What? Why?

Blue Coat ProxySG?

- enterprise (Web) proxy
- one of the most deployed in big companies
- lots of complex features:
  - URL categorization (WebSense and others)
  - video streaming / instant messaging specific handling
  - MAPI and SMB proxy / cache / prefetcher
  - etc.
- runs proprietary SGOS

Why research ProxySG?

- widely used in Airbus Group
- interesting target for malicious actors: log bypass, Internet exposed, MITM, etc.
- no known previous research: unknown security level
  - security bulletins: mostly OpenSSL and Web administration interface bugs

Research

Study objectives:

- assess the global security level
- write recommendations for secure deployment
- be prepared for forensics in case of a compromised ProxySG

Why publish?

- first public info but surely not first research
- foster research $\Longrightarrow$ better security

Today's presentation:

- raw technical results, as a starting point for research
- goes from low level (FS) to high level, following our approach
- applies to all ProxySG models and 6.x versions *up to Q1 2015*

Getting started

Running ProxySG:

- hardware: commodity x86 CPUs, HDD, etc.
- VMware appliances

Common versions:

- 5.5: older version, EOL Aug 2014
- 6.2: previous *long term release*, EOL Oct 2015
- 6.5: latest *long term release*, recommended by BC

To get a first look, we need to access the filesystem:

- 6.? ($\geq$ 6.4): small FAT32 partition containing proprietary BCFS image
- older versions: fully proprietary disk partitionning/data (no FAT32)

Outline

On disk data: intro

Hardware

Basic architecture: 3 disks (or more)

- small CompactFlash or SSD for OS (FAT32)
- 2 or more drives for data (proprietary FS)

Filesystems

- static, *read-only* FS for OS (**BCFS**):
  - OS files
  - low level (static) configuration: kernel options, resource limits
- *cache engine* FS based on hash tables (**CEFS**) (Patent US7539818)
- *registry* in CEFS for settings

Remarks

- unknowns:
  - CEFS structures
  - log storage format
- on-disk partition structures are very complex
- today: only static FS (BCFS) for OS files

System disk organization (BIOS mode)

Files on FAT32 partition

```
/sgos/boot/systems/system1
/sgos/boot/cmpnts/starter.si
/sgos/boot/cmpnts/boot.exe
/sgos/boot/meta.txt
/sgos/fbr.con
```

Both *starter.si* and *system1* use BCFS

bootloader: *starter.si*

- 6 MiB
- basic SGOS (UP kernel, drivers, no application)
- looks up available systems
- displays GRUB-like boot menu

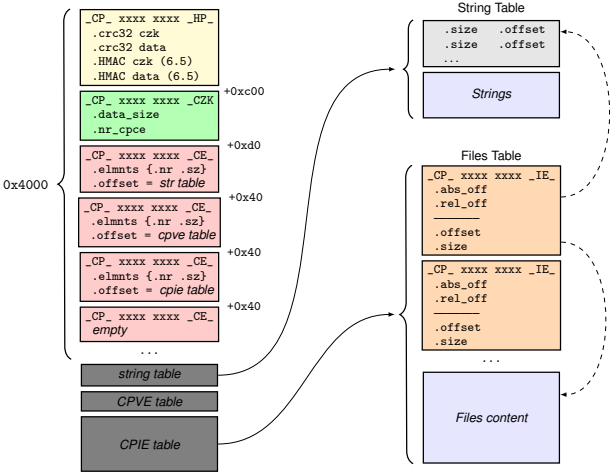
Real OS: *system1*

- 210 MiB
- full blown OS:
  - SMP kernel
  - Web UI
  - actual applications
  - etc.

Boot sequence (BIOS)

1. BIOS
2. MBR
3. boot sector of active partition
4. *boot.exe*, found by hardcoded sector number
5. *kernel.exe*, first file entry in *starter.si* FS
6. kernel starts *sequencer.exe*, second entry in *starter.si*
7. *sequencer.exe* parses the *main.cfg* script and starts the necessary drivers
8. *main.cfg* finally launches *starter.exe* which displays the boot menu
9. *starter.exe* loads the selected system

BCFS (read-only FS) format



How to extract?

1. read CPCE entries, note offsets for strings table and files table
2. parse files table (CPIE) linearly
3. get file name from strings table

How to modify?

1. cannot increase file size
2. fix CRC and HMAC

System image configuration variables (CPVE)

- offset and size specified by 3rd `_CP_ _CE_` entry
- modifying the variable implies fixing CRC/HMAC and reboot
- variable names can be found in *sequencer.exe*

Structure

```
struct cpve_entry {
    uint32_t magic1; /* _CP_ */
    uint64_t unk;
    uint32_t magic2; /* _VE_ */
    uint16_t number;
    uint16_t section;
    uint32_t unk2;
    uint64_t value; }
```

Known variables (*section*, *number*: *description*)

Section 4, `kernel`:

- 4,0: `flags`:
  - 0x8: GDB monitor enabled
  - 0x200: int3 at OS startup
  - 0x400: kernel debug logs enabled
- 4,1: `arch_flags`
  - 1: activate *Write Protect* in `cr0`
- 4,3: `console_speed` (in bauds)

Cache Engine FS (CEFS): writable storage

- hash-table object storage with disk backend
- mostly used for cache data:
  - web content
  - CIFS files
  - MAPI mails
  - etc.
- *regular* files are also supported, with prefix `/legacy/cache_engine/`

Some files (paths straight from the code, no typo)

```
.../persistent/replicated/authorized_keys
.../persistent/replicated/volatile//config/v9/registry/registry.xml
.../transient//snmp.log
.../persistent/replicated/licensing_certificate
```

Registry: settings storage

- tree structure used for all settings
- entries are referenced by strings like “config:Authenticator:local_users”
- on-disk storage: xml file on writable CEFS

URLs (admin rights needed)

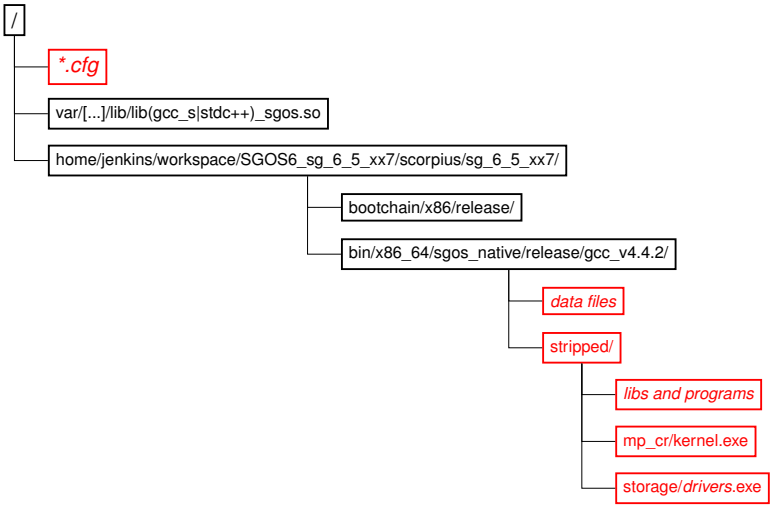
```
/registry/show
/registry/registry.html
/registry/registry.xml
/registry/debug
```

Interesting CLI extensions (cf slide 24)

```
reg-set
reg-delete
reg-list
reg-trace
```

Outline

OS Filesystem organization



ELF files: kernel, libs, programs

Everything interesting is located in `.../stripped/`:

- `.exe`, `.exe.so` and `.so` extensions (version 5 was using PE files)
- 32 or 64 bits ELF files, depending on model (RAM size?)
- *everything* in C++, compiled with g++ with custom *sgos* target
- lots of unit tests
- more than 2600 source files referenced
- everything is stripped, but lots of external symbols
- heavy template use: AMI::Config_Data::Config_Data(AMI::Storage_Class, AMI::String_Ref const&, AMI::Shared_Ptr<AMI::Installed_Systems const> const&, AMI::Shared_Ptr<AMI::Config_General const> const&, AMI::Shared_Ptr<AMI::Shell const> const&, AMI::Shared_Ptr<AMI::SSL const> const&, AMI::Shared_Ptr<AMI::SMTP_Data const> const&, AMI::Shared_Ptr<AMI::BC_Threat_Protection const> const&, AMI::Shared_Ptr<AMI::Banner_Settings const> const&, AMI::Shared_Ptr<AMI::Policy_Settings const> const&, AMI::Shared_Ptr<AMI::Statistics_Export_Settings const> const&)

"custom" ABI in 32 bits (probably gcc called with `-mregparm`):

- EAX, EDX, ECX, stack

in 64 bits, standard SysV ABI:

- RDI, RSI, RDX, RCX, R8, R9, stack

Known code?

Interesting open source libraries (version numbers from 6.5 release, Aug 2014):

- BGET: memory allocator (first dev in 1972!)
- NET-SNMP 5.4.2.1 (2008-10-31)
- newlib: libc
- expat 1.95.2: XML parser (2001!)
- libxml2 2.7.7-82143f4 (2010-11-04)
- OpenSSH 6.3 (2013-09-13)
- OpenSSL 1.0.1e (2013-02-11)
- zlib 1.2.3 (2005-07-18)

Blue Coat states that they backport fixes regularly (without necessarily changing the version string).

Outline

Kernel

The kernel in practice

- kernel access partially abstracted in `libknl_api.so`
- small (~800 KiB), basic primitives:
  - interrupt/exception handling
  - semaphores/locks
  - message passing
  - drivers
- `ds:1014h` points to a “TEB”-like structure

Some syscalls

```
Nop
Suicide
Enable_event_logging
Register_worker_address
Symbol_address
Processor_voltage
Semaphore_signal_all
Grow_stack
```

Kernel: syscall

32 bits

- `call dword ptr ds:1018h`
- parameters in structure pointed by `eax`

```
kernel_req      struc
    field_0         dd ?
    return_code     dd ?
    return_code2    dd ?
    arg0            dd ?
    arg1            dd ?
    arg2            dd ?
    arg3            dd ?
    sys_num         dd ?
kernel_req      ends
```

64 bits

- `call [ds:0FFFFFF8000000020h]`
- parameters in structure pointed by `rdi`

```
knl_req64       struc
    field_0         dq ?
    retcode         dq ?
    arg0            dq ?
    arg1            dq ?
    arg2            dq ?
    arg3            dq ?
    sysnum          dq ?
    field_38        dq ?
knl_req64       ends
```

Memory organization

Back to the 90s

- protected mode
- **everything** in *ring 0* (mentioned in US7539818 patent ;)

ELF mapping: at boot, once and for all

```
Unpacking executables...
    Unpacking sequencer.exe elapsed time: 0s, 0ms, 326us
    Unpacking ata.exe elapsed time: 0s, 0ms, 413us
[...]
Relocating executables...
    Relocating sequencer.exe elapsed time: 0s, 2ms, 356us
    Relocating ata.exe elapsed time: 0s, 0ms, 559us
10 executables relocated; total unpack and reloc time 0s, 20ms, 550us
```

Outline

Making things easier: our tools

IDA plugins:

- automatically comment function with source filename (from debug logs)
- automatically rename functions from debug log strings
- automated syscall recognition (with syscall name, parameters)
- CLI structures dumper to list all CLI commands

BCFS: FUSE tool to mount system images:

- file access: read/write (without size change)
- CPVE access: read/write
- automatic CRC/HMAC calculation

Tools are internal PoCs and are not going to be released.

Getting more info: useful tricks

Enable debug info, by modifying BCFS (physical access or RCE needed):

- kernel "*printk*": CPVE 4,0 |= 0x400
- debug mode: set `customer_release` to 0 in `main_cr.cfg`

230+ CLI extensions in debug mode:

- list with ".", access with ".extension"
- examples: `cfg`, `policy`, `cag`, `mgmt`, etc.

Example commands

- `.mgmt show-adv-urls`
- `.svc ashowstate`
- `.<ext> logaddmask all` then `.<ext> logshow`
- `.policy dbgtraceon`

CLI extension example

```
ProxySG VA 1818181818>.cag
.cag extension usage
commands:
  logshow       : display contents of the debug log
  logaddmask    : add a mask to the debug log
  logsubmask    : remove a mask from the debug log
  log2console   : toggling logging to the console
  logreset      : reset the CAG debug log
  gzip-allow    : determine if gzip allowed in responses
ProxySG VA 1818181818>enable
Enable Password:
ProxySG VA 1818181818#_
```

GDB

Kernel includes GDB stub! But finding how to activate it took me weeks :(

- CPVE 4,0 |= 0x8
- multiplexed on COM1 with console
- send 0x18, 0x14 on COM port to activate
- (non-standard) text paging is handled server-side, patch client or use `monitor util height 1000000`

GDB `monitor` extensions (kernel side)

```
Current debug extensions:
 name knl, Function 0x1261500
 name util, Function 0x1028786E0
 name scorpius, Function 0x1028487E0
```

Some `knl` extensions

- `processes`: display all active processes.
- `pd`: display the contents of a process descriptor.
- `images`: display details of loaded ELF files.

Practical understanding: HTTP parsing

Goal: find function for HTTP response parsing

- activate HTTP debug mode at `https://x.x.x.x:8082/HTTP/debug`
- make request through proxy
- get log
- read interesting function name
- look for function in `libhttp.exe.so`

Example log (simplified, most recent first):

```
HTTP CW 95B72F20: Parse_request called. beg=57DE3000 end=57DE30DC length=220
HTTP CW 95B72F20: Parse_request
HTTP CW 95B72F20: Should_tunnel_on_error
HTTP CW 95B72F20: Read_request
HTTP CW 95B72F20 POLICY: Evaluating PE_POLICY_CHECKPOINT_NEW_CONNECTION
HTTP CW 95B72F20: Transaction_startup
HTTP CW 95B72F20: Init_state
```

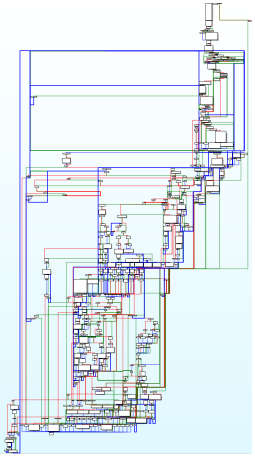
Going deeper: Hell

Locating the code is the easy part.
Problems:

- **HUGE** functions (16 KiB!, see CFG)
- C++ everywhere
- IDA struggles with calling convention
- threads, everywhere!

Dynamic debugging howto:

- find image base using `monitor knl image libhttp.exe.so` in GDB
- relocate binary in IDA
- set breakpoint in Proxy SG CLI: `conf t; debug; breakpoint-set 0 B X <ADDR>`
- break and connect!

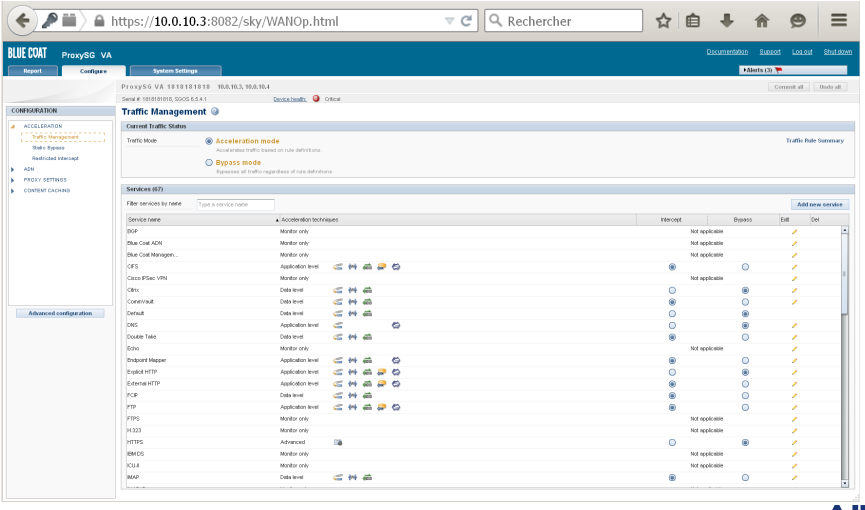


Outline

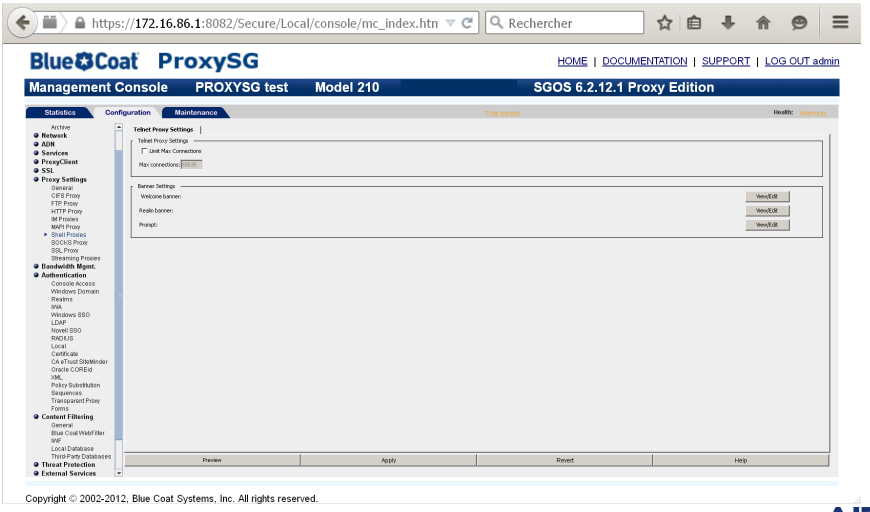
Application security

- authentication:
  - local passwords are hashed with FreeBSD MD5 crypt (1), Blowfish supported
  - dozens of schemes supported: LDAP, AD, etc.
- default protocols: only HTTPS and SSH
- read-only or admin accounts
- OS trust:
  - PKCS7 signed updates (SHA-512/RSA-2048)
  - local images:
    - $<$ 6.5: CRC only
    - $\geq$ 6.5: HMAC SHA-1
- crypto:
  - openssl
  - critical random data is generated securely

Administration interface (Flash)



Administration interface (Java)



Administration interface

- actually *POST*s CLI commands, in an *enable* shell
- restricted commands for *read-only* users
- Java interface specifics:
  - also uses a kind for RPC mechanism (`/Secure/Local/console/pod`)
  - also implements its own HTTPS “client”

Request (simplified)

```
POST /Secure/Local/console/install_upload_action/cli_post_setup.txt
Host: 10.0.10.3:8082
Authorization: Basic YWRtaW46dGVzdA==
[...]
Cookie: bcsi.logout=0; BCSI_MC=605032960:1

---------------7d518638300904
Content-Disposition: form-data; name="file"

show version
---------------7d518638300904-
```

Response data

```
ProxySG VA 1818181818#(config)show version
Version: SGOS 6.4.1.2 MACH5 Edition
Release id: 90192
UI Version: 6.4.1.2 Build: 90192
Serial number: XXXXXXXXXX
NIC 0 MAC: 000FF9B6006F
There were 0 errors and 0 warnings
```

System-level security

BAD

- no stack canaries
- no ASLR
- everything in ring0
- kernel callgate at a fixed address

GOOD

- NX enabled on most platforms since 6.2. 300/600 support added in 6.5.7.1 and 6.2.16.3
- BGET heap: asserts check for meta-data coherence (*unlink* attacks impossible)
- read-only FS for binaries makes it (way) harder to backdoor OS
- physical access (or code exec) is needed to change system image as updates are signed

Exploitability

Facilitating exploits

- previous slide :)
- vtables everywhere
- only C++ code => more memory corruption bugs (vs script/safer languages)

Hurdles

- no second chance (*ring0*)
- no ASLR but mapping different for each version
- custom payload needed
- guard pages

Outline

Conclusion

Findings

- unusual, entirely proprietary OS design
- no user/kernel isolation or exploit hardening (historical for performance?)
- no vulnerabilities found (I didn't look for them!)...
- ...but Blue Coat release notes document plenty of fixes for "software restarts"

Recommendations

- use a dedicated (V)LAN for administration
- monitor the event log
- investigate reboots
- physically protect appliances
- use secure passwords (of course!)

Evolutions in ProxySG

Security enhancements in recent versions

- NX support for 300/600 added in 6.5.7.1 and 6.2.16.3
- bootchain and system image validation (hashes published by Blue Coat)
- *Secure boot* in pre-release, available in a future release
- debug (GDB, CLI extensions) support removed

We are currently discussing further security enhancements, such as user/supervisor separation, with Blue Coat. Release timing and platform support are still under discussion.

End

Questions?

Thanks!

- Stéphane D. for his work on BCFS and the tikz figures :)
- Stéphane L. and AGI for giving me the opportunity to work on Blue Coat

Outline

8 Backup slides

System disk organization (UEFI mode)

Files on FAT32 partition

```
/sgos/boot/systems/diag.si
/sgos/boot/systems/system.si
/sgos/boot/meta.txt
/sgos/fbr.con
/EFI/BOOT/BOOTx64.EFI
/EFI/BOOT/osloader.si
```

.si files use BCFS

New: UEFI

- `BOOTx64.EFI` replaces `starter.si`
- `osloader.si` contains a copy of `BOOTx64.EFI`

New: `diag`

Linux diagnostic system:

- check hardware health
- interesting `cli` binary, with symbols :)

Boot sequence (UEFI)

1. UEFI
2. BOOTx64.EFI
3. desired system is selected
4. *prekernel.exe* is started, first file entry in *system.si* FS
5. *prekernel.exe* setups GDT, IDT, etc. and starts *kernel.exe* (2nd entry)
6. kernel starts *sequencer.exe*, (3rd entry)
7. *sequencer.exe* parses the *main_cr.cfg* script
8. *main_cr.cfg* includes *main_common.cfg* which starts everything

Way simpler than BIOS boot.