Recent Advances in Single Packet Authorization

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Agenda

- Design tradeoffs in PK/SPA systems
- fwknop-2.0
- Security aspects of fwknop development
- SPA in the Amazon Cloud
- The future of Single Packet Authorization
- Demo

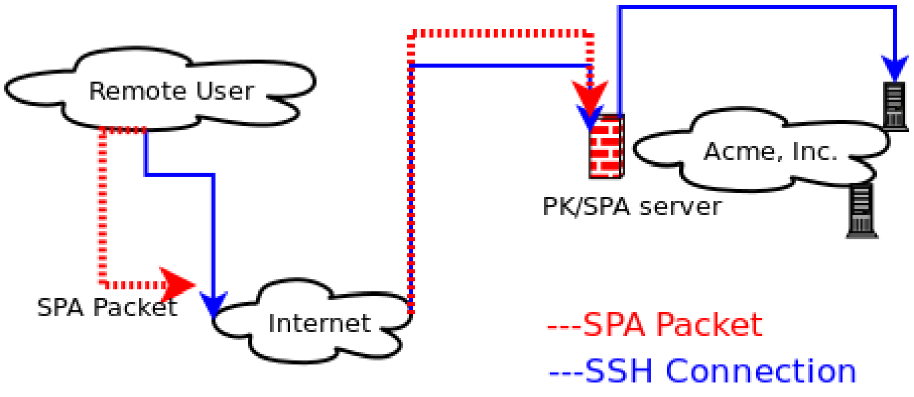
PK/SPA Common Goals

- Firewall default-drop stance for protected services
- Passive collection of authentication information
- Firewall policies dynamically reconfigured for temporary authenticated access

- **Consequences:**
  - Makes scanning for vulnerable services impractical
  - Fundamentally changes the server side exploit model
  - Reduces visible attack surface

Typical Work Flow

- User wants SSH access behind PK/SPA firewall
- User executes PK/SPA client
- Firewall is reconfigured to allow SSH connections from the specified IP
- PK/SPA packet(s) passively monitored
- PK/SPA packet(s) never acknowledged in any way
- SSHD cannot be scanned for
- *Think beyond SSHD*



This is where the similarities in PK/SPA systems end...

About 40 PK/SPA implementations:

http://www.portknocking.org/

fwknop Design Goals

- **Firewall default drop stance for protected services**
- **Passive collection of authentication information**
- **Support for Symmetric and Asymmetric ciphers**
- **Encrypted and non-replayable SPA packets**
  - Do not want anything that trusts an IP in the network layer header
- **Server portable to embedded systems**
  - Do not want a heavyweight interpreted language (this is a trade off)
- **Server portable to different firewall architectures and router ACL languages**
  - Make sophisticated use of NAT
- **Client portable to everything from Cygwin to the iPhone**
  - Do not want to require raw socket manipulation of packet headers or admin privileges
- **Library implementation of SPA protocol for greater portability and integration possibilities**

fwknop-2.0

- Completely re-written in C
- fwknopd supports iptables, ipfw, and pf
- SPA protocol library implementation 'libfko'
  - perl and python bindings
- FORCE_NAT mode transparently NAT's authenticated connections
- iPhone and Android clients

```
$ git clone http://www.cipherdyne.org/git/fwknop.git
```

fwknop-2.0 Dependencies

```
$ ldd server/.libs/fwknopd
        linux-vdso.so.1 =>  (0x00007fffe8d98000)
        libfko.so.0 => /usr/lib/libfko.so.0 (0x00007f822850f000)
        libpcap.so.0.8 => /usr/lib/libpcap.so.0.8 (0x00007f82282d8000)
        libc.so.6 => /lib/libc.so.6 (0x00007f8227f53000)
        libgpgme.so.11 => /usr/lib/libgpgme.so.11 (0x00007f8227d1e000)    ← optional
        libgpg-error.so.0 => /lib/libgpg-error.so.0 (0x00007f8227b1a000)  ← optional
        /lib64/ld-linux-x86-64.so.2 (0x00007f8228947000)
```

Old Perl Dependencies

- Digest::SHA
- Net::Pcap
- Crypt::CBC
- GnuPG::Interface
- Unix::Syslog
- Net::IPv4Addr
- MIME::Base64
- IPTables::Parse
- IPTables::ChainMgr

Acquiring SPA Data?

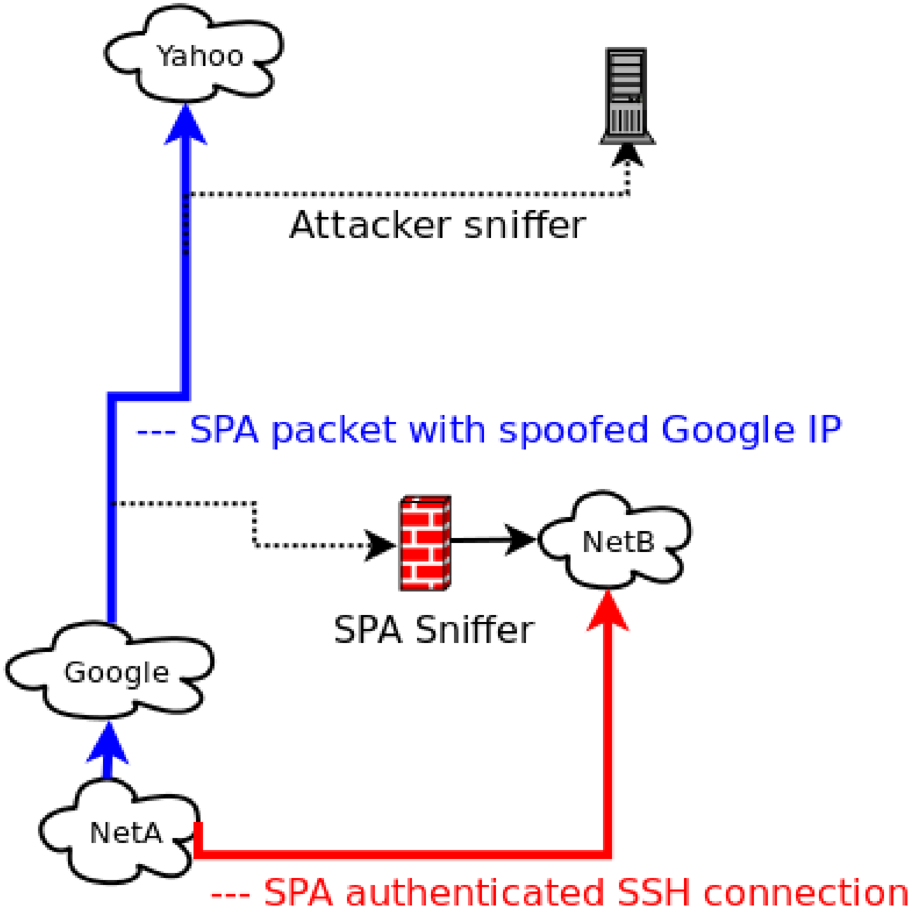
- fwknop runs libpcap + lightweight crypto layer
- Allows design goals to be achieved
- *Every* PK/SPA system must acquire data in *some* way
- This is about attack surface reduction in server-side software – changes the exploit model
- What do exploit frameworks do about sniffers?

Metasploit: Exploitation of pcap-Based Software

- Snort
  - Back Orifice preprocessor buffer overflow
  - DCE/RPC preprocessor buffer overflow
- Wireshark
  - LWRES dissector stack-based buffer overflow
  - packet-dect.c stack overflow
  - A few others...
- Exploits generally rely on complex code that is layered above libpcap – National Vulnerability Database (NVD) searches confirm this
- Network exploitation of non-pcap userspace software requires access to talk up the remote networking stack – kernel drivers and other kernel code is a different story

Things Are Not Always As They Seem...

- User gains access to NetB from NetA
- Attacker: Which system to attack?
- SPA server can be anywhere on the routing path of an SPA packet – not just the SPA destination IP
- SPA packet source IP can be spoofed too
- Neither the SPA source nor destination IP matters


Yahoo
Attacker sniffer
--- SPA packet with spoofed Google IP
NetB
SPA Sniffer
Google
NetA
--- SPA authenticated SSH connection

fwknop: Security-Focused Development

Security Aspects of fwknop Development

- Usage of run time memory checkers (valgrind)
- Usage of static analyzers (splint, wishlist: Coverity – *expensive*!)
- Usage of compile time security options
- Automated testing
  - Automated function coverage support
  - Automated valgrind usage and flagged function comparisons
- SPA protocol review
- Fuzzing (TODO)

Test Suite

- All major SPA functionality is tested/validated
- Compilation warning checks
- Security aspects of compiled binaries are verified (`hardening-check` from Kees Cook)
- `--enable-valgrind` mode
- `--diff` mode across test runs
- `fwknop-2.0/test/test-fwknop.pl`

Test Suite:

```
# ./test-fwknop.pl
[build security] [client] Position Independent Executable (PIE).....pass (3)
[build security] [client] stack protected binary....................pass (4)
[build security] [client] fortify source functions..................pass (5)
[build security] [client] read-only relocations.....................pass (6)
[build security] [client] immediate binding.........................pass (7)
[build security] [server] Position Independent Executable (PIE).....pass (8)
[build security] [server] stack protected binary....................pass (9)
[build security] [server] fortify source functions..................pass (10)
[build security] [server] read-only relocations.....................pass (11)
[build security] [server] immediate binding.........................pass (12)
```

- This is enabled via:
  - gcc … -fstack-protector-all -fstack-protector -fPIE -pie -D_FORTIFY_SOURCE=2 -Wl,-z,relro -Wl,-z,now

Test Suite: Rijndael SPA Cycle

```
# ./test-fwknop.pl

[Rijndael SPA] [client+server] complete cycle (tcp/22
ssh)..........pass (43)

# head output/43_fwknopd.test

Fri May 10 19:01:34 2012 CMD: LD_LIBRARY_PATH=../lib/.libs
../server/.libs/fwknopd -c conf/default_fwknopd.conf -a
conf/default_access.conf -d run/digest.cache -p run/fwknopd.pid -i lo
--foreground --verbose —verbose

process_spa_request() CMD: '/sbin/iptables -t filter -A FWKNOP_INPUT
-p 6 -s 127.0.0.2 --dport 22 -m comment --comment _exp_1328904099 -j
ACCEPT 2>&1' (res: 0, err: )

Added Rule to FWKNOP_INPUT for 127.0.0.2, tcp/22 expires at 1328914099

...
```

Test Suite: Bug Hunting with Valgrind

- Development cycle becomes:

  ```
  # ./test-fwknop.pl --enable-valgrind
  ```

  - Code code code...

  ```
  # ./test-fwknop.pl --enable-valgrind
  # ./test-fwknop.pl --diff
  ```

  - Look for new errors reported by valgrind and fix

  ```
  $ git add … , git commit
  ```

Example: crypto_update Branch

```
# ./test-fwknop.pl --include "appended" --enable-valgrind

[+] Starting the fwknop test suite...

    args: --include appended --enable-valgrind

    Saved results from previous run to: output.last/

[Rijndael SPA] [client+server] appended data to SPA pkt.............pass (1)
[GnuPG (GPG) SPA] [client+server] appended data to SPA pkt..........pass (2)
```

What Does Valgrind Say?

```
# ./test-fwknop.pl --diff
+Conditional jump or move depends on uninitialised value(s)
+   at 0x48384D6: rij_decrypt (cipher_funcs.c:263)
+   by 0x483A34A: fko_decrypt_spa_data (fko_encryption.c:158)
+   by 0x483AE9B: fko_new_with_data (fko_funcs.c:210)
+   by 0x10CC29: incoming_spa (incoming_spa.c:245)
+   by 0x10DB40: process_packet (process_packet.c:200)
+   by 0x4861E63: ??? (in /usr/lib/i386-linux-gnu/libpcap.so.1.1.1)
+   by 0x4864667: pcap_dispatch (in /usr/lib/i386-linux-gnu/libpcap.so.1.1.1)
+   by 0x10D607: pcap_capture (pcap_capture.c:223)
+   by 0x10A668: main (fwknopd.c:299)
+ Uninitialised value was created by a heap allocation
+   at 0x482BE68: malloc (in /usr/lib/valgrind/vgpreload_memcheck-x86-linux.so)
+   by 0x483A317: fko_decrypt_spa_data (fko_encryption.c:154)
+   by 0x483AE9B: fko_new_with_data (fko_funcs.c:210)
+   by 0x10CC29: incoming_spa (incoming_spa.c:245)
+   by 0x10DB40: process_packet (process_packet.c:200)
+   by 0x4861E63: ??? (in /usr/lib/i386-linux-gnu/libpcap.so.1.1.1)
+   by 0x4864667: pcap_dispatch (in /usr/lib/i386-linux-gnu/libpcap.so.1.1.1)
+   by 0x10D607: pcap_capture (pcap_capture.c:223)
+   by 0x10A668: main (fwknopd.c:299)
```

The Fix

```
diff --git a/lib/fko_encryption.c b/lib/fko_encryption.c
index 5f1788a..af43a87 100644
--- a/lib/fko_encryption.c
+++ b/lib/fko_encryption.c
@@ -139,6 +139,15 @@ _rijndael_decrypt(fko_ctx_t ctx, const char *dec_key, int encryption_mode)

     cipher_len = b64_decode(ctx->encrypted_msg, cipher);

+    /* Since we're using AES, make sure the incoming data is a multiple of
+     * the blocksize
+    */
+    if((cipher_len % RIJNDAEL_BLOCKSIZE) != 0)
+    {
+        free(cipher);
+        return(FKO_ERROR_INVALID_DATA);
+    }
+
     /* Create a bucket for the plaintext data and decrypt the message
      * data into it.
     */
```

Coming Soon: HMAC Support

- HMAC-SHA256 coming in fwknop-2.2
  - $\text{HMAC}(K,m) = H((K \oplus \text{opad}) \| H((K \oplus \text{ipad}) \| m))$
  - SPA encrypted message = $m \| \text{HMAC}$
  - K != encryption key

- fwknop uses the encrypt-then-authenticate paradigm
  - SSH uses encrypt-and-MAC
  - SSL uses MAC-then-encrypt
  - IPSEC uses encrypt-then-MAC ← *provably INT-CTXT and IND-CCA2 secure*

Why HMAC?

- In encrypt-then-authenticate mode:
  - Protection against things like the Vaudenay attack against SSL: http://www.iacr.org/cryptodb/archive/2002/EUROCRYPT/2850/2850.pdf
  - Can ignore bogus (inauthentic) data faster
  - Further reduction in potential attack surface
    - Can discard data *without running any decryption code*
    - libgpgme functions protected by more simplistic HMAC layer

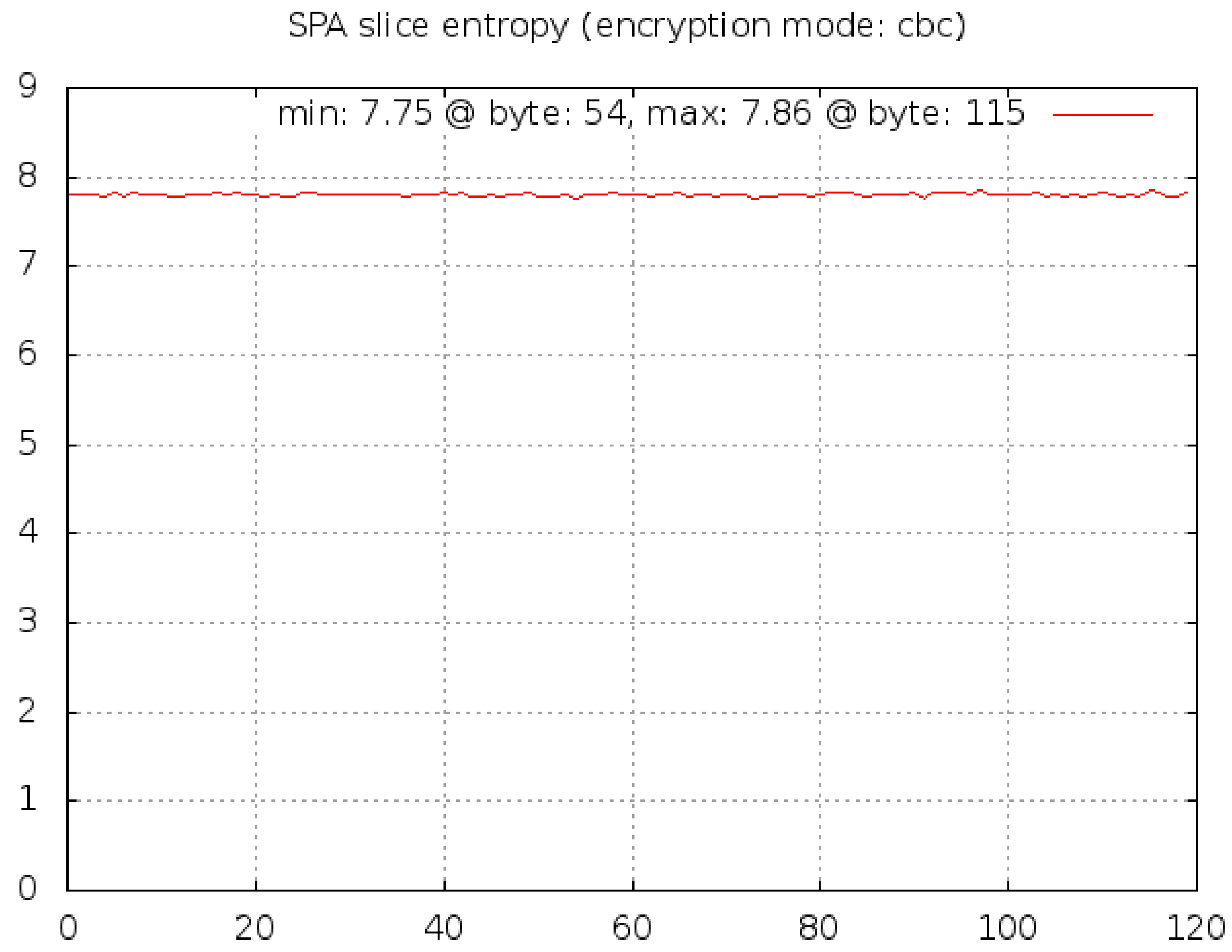
http://www.daemonology.net/blog/2009-06-24-encrypt-then-mac.html

Cross-Packet Ciphertext Entropy

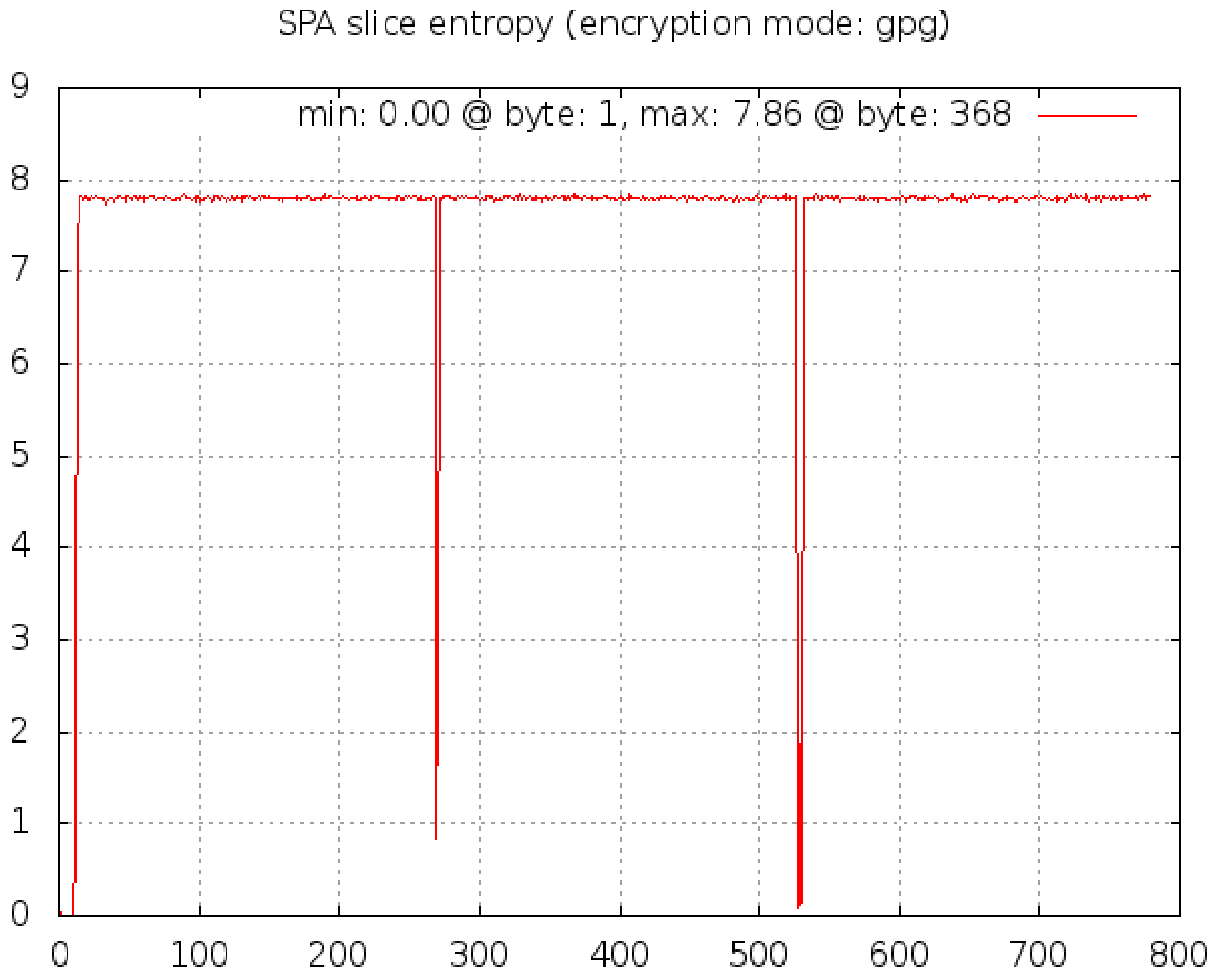
- Strategy: generate lots of SPA packets, then measure total entropy at each byte position in slices
- We expect high levels of entropy if the usage of random data and encryption is done properly
- `extras/spa-entropy/spa-entropy.pl`

```
$ ./spa-entropy.pl -f spa_pkts.out -r -c 1000
--base64-decode
```

1,000 SPA Packets - Rijndael CBC Mode



1,000 SPA Packets - GnuPG ElGamal Cipher



How Good is /dev/urandom?

```
$ dd if=/dev/urandom count=1000 | ent
1000+0 records in
1000+0 records out
512000 bytes (512 kB) copied, 0.128497 s, 4.0 MB/s
Entropy = 7.999625 bits per byte.

Optimum compression would reduce the size
of this 512000 byte file by 0 percent.

Chi square distribution for 512000 samples is 265.77, and randomly
would exceed this value 50.00 percent of the times.

Arithmetic mean value of data bytes is 127.5076 (127.5 = random).
Monte Carlo value for Pi is 3.138715386 (error 0.09 percent).
Serial correlation coefficient is -0.001293 (totally uncorrelated = 0.0).
```

SPA in the Amazon Cloud

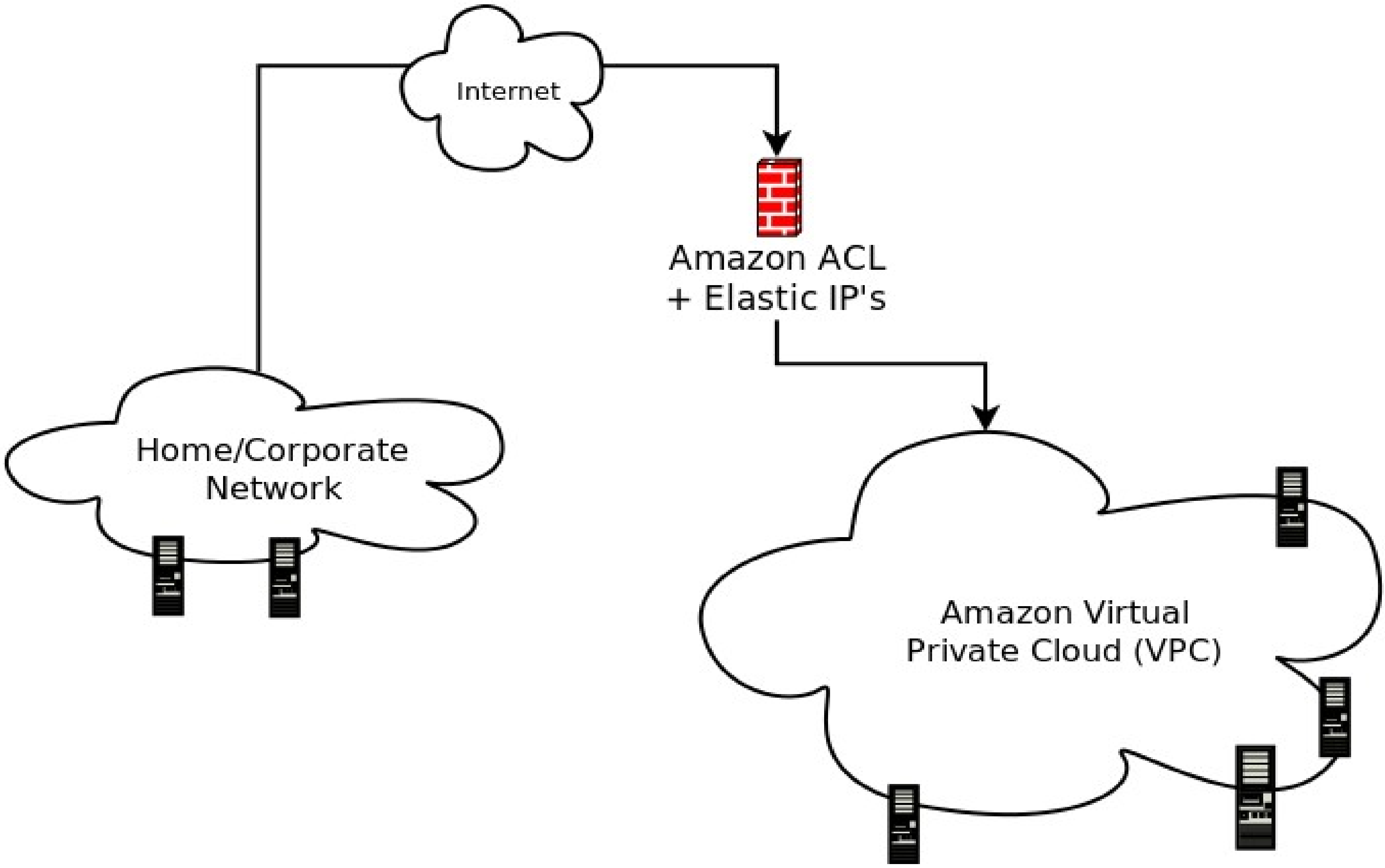
http://aws.amazon.com/

Amazon Web Services (AWS)

- AWS provides massive infrastructure for cheap on-demand costs
- Notable usages of AWS:
  - 42nd fastest supercomputer built in EC2: http://www.wired.com/wiredenterprise/2011/12/nonexistent-supercomputer/
  - Debian Openssl key debacle:

    http://trailofbits.files.wordpress.com/2008/07/hope-08-openssl.pdf
- We deploy SPA on Elastic Compute Cloud (EC2) and Virtual Private Cloud (VPC) networks

Amazon VPC Networks



The Perfect SPA Use Case

- Microsoft RDP vulnerability earlier this year (CVE-2012-0002)
- Full remote code execution potential, although Metasploit has a DoS module
- Problem: fwknop does not support a Windows firewall

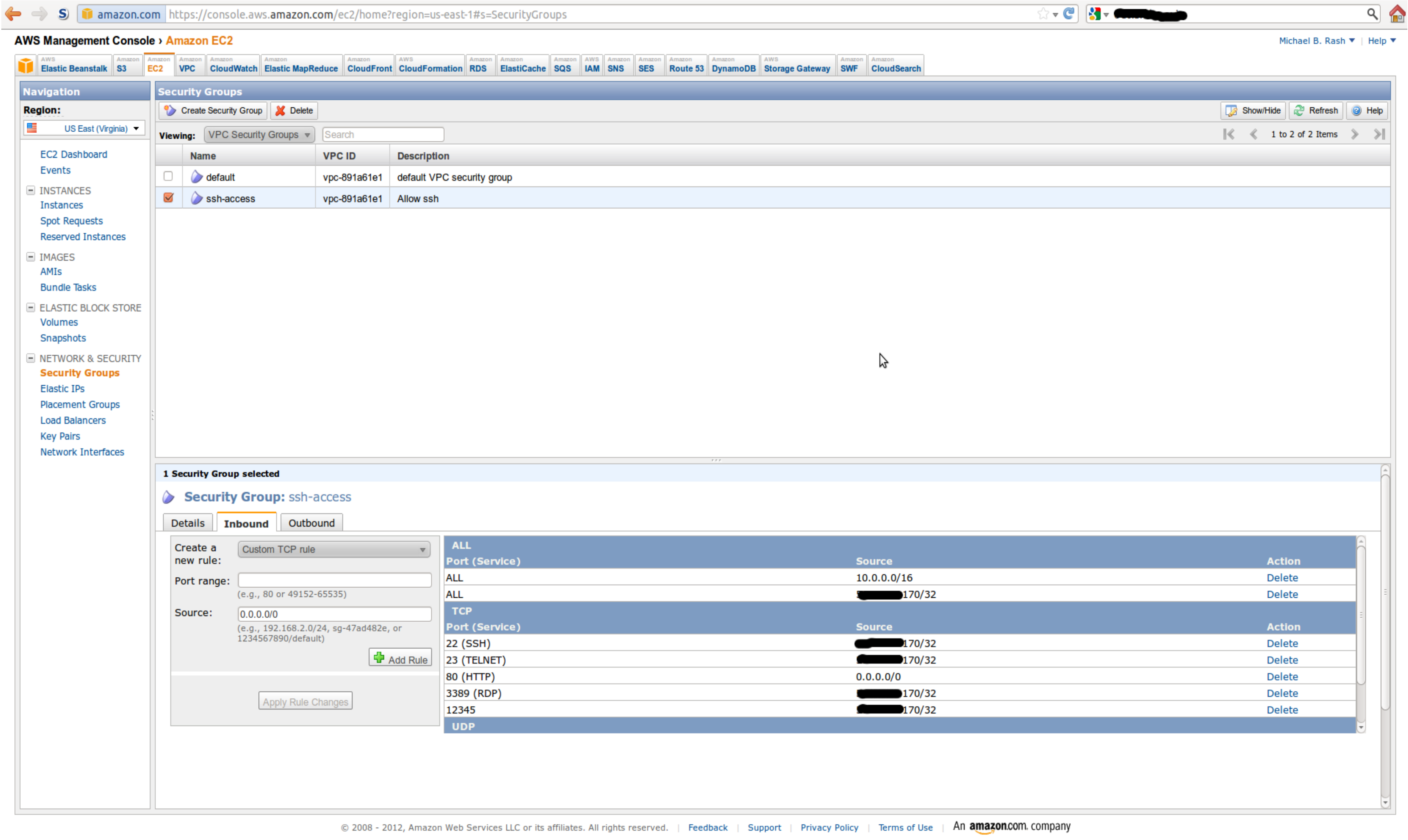
SPA + NAT = Secure RDP Access

- Use an internal Ubuntu AWS image as a jump host
- fwknopd is deployed on the Ubuntu system

- ***Any*** VPC system is accessible ***through*** the Ubuntu system via SPA + NAT
- Only one Amazon Elastic IP is required
  - Changes the normal Amazon NAT+Elastic IP association model

- iptables+SPA extends Amazon's filtering capabilities – SPA not integrated into AWS border controls

VPC Filtering Policy



amazon.com https://console.aws.amazon.com/ec2/home?region=us-east-1#s=SecurityGroups

[redacted]

AWS Management Console › Amazon EC2

Michael B. Rash ▾ | Help ▾

Navigation

Region: US East (Virginia) ▾

- EC2 Dashboard
- Events
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- ELASTIC BLOCK STORE
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  - Security Groups
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  - Placement Groups
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  - Key Pairs
  - Network Interfaces

Security Groups

Viewing: VPC Security Groups ▾ Search

1 to 2 of 2 Items

	Name	VPC ID	Description
□	default	vpc-891a61e1	default VPC security group
☑	ssh-access	vpc-891a61e1	Allow ssh

1 Security Group selected

Security Group: ssh-access

Create a new rule: Custom TCP rule ▾

Port range:

(e.g., 80 or 49152-65535)

Source: 0.0.0.0/0

(e.g., 192.168.2.0/24, sg-47ad482e, or 1234567890/default)

Port (Service)	Source	Action
ALL		
ALL	10.0.0.0/16	Delete
ALL	[redacted]170/32	Delete
TCP		
22 (SSH)	[redacted]170/32	Delete
23 (TELNET)	[redacted]170/32	Delete
80 (HTTP)	0.0.0.0/0	Delete
3389 (RDP)	[redacted]170/32	Delete
12345	[redacted]170/32	Delete
UDP		

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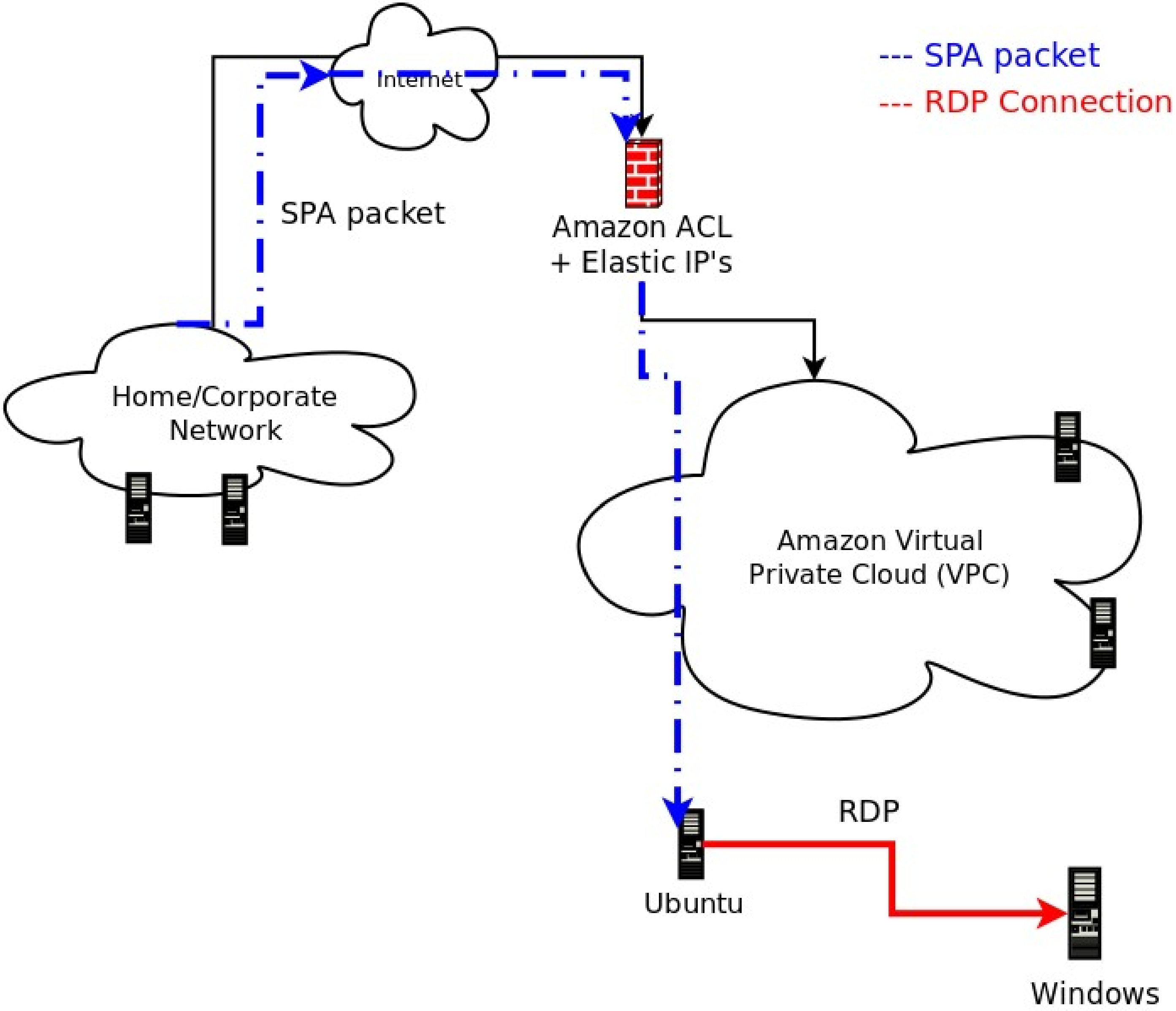
SPA + NAT = RDP Access



fwknop Client Command Line

- Ubuntu IP: 10.0.0.171
- Windows Server IP: 10.0.0.79
- External Elastic IP: 107.21.55.55

```
$ fwknop -A tcp/80 -N 10.0.0.79,3389 -R -D
107.21.55.55 --server-port 53
```

```
$ rdesktop -u Administrator 107.21.55.55:80
```

fwknopd Configuration

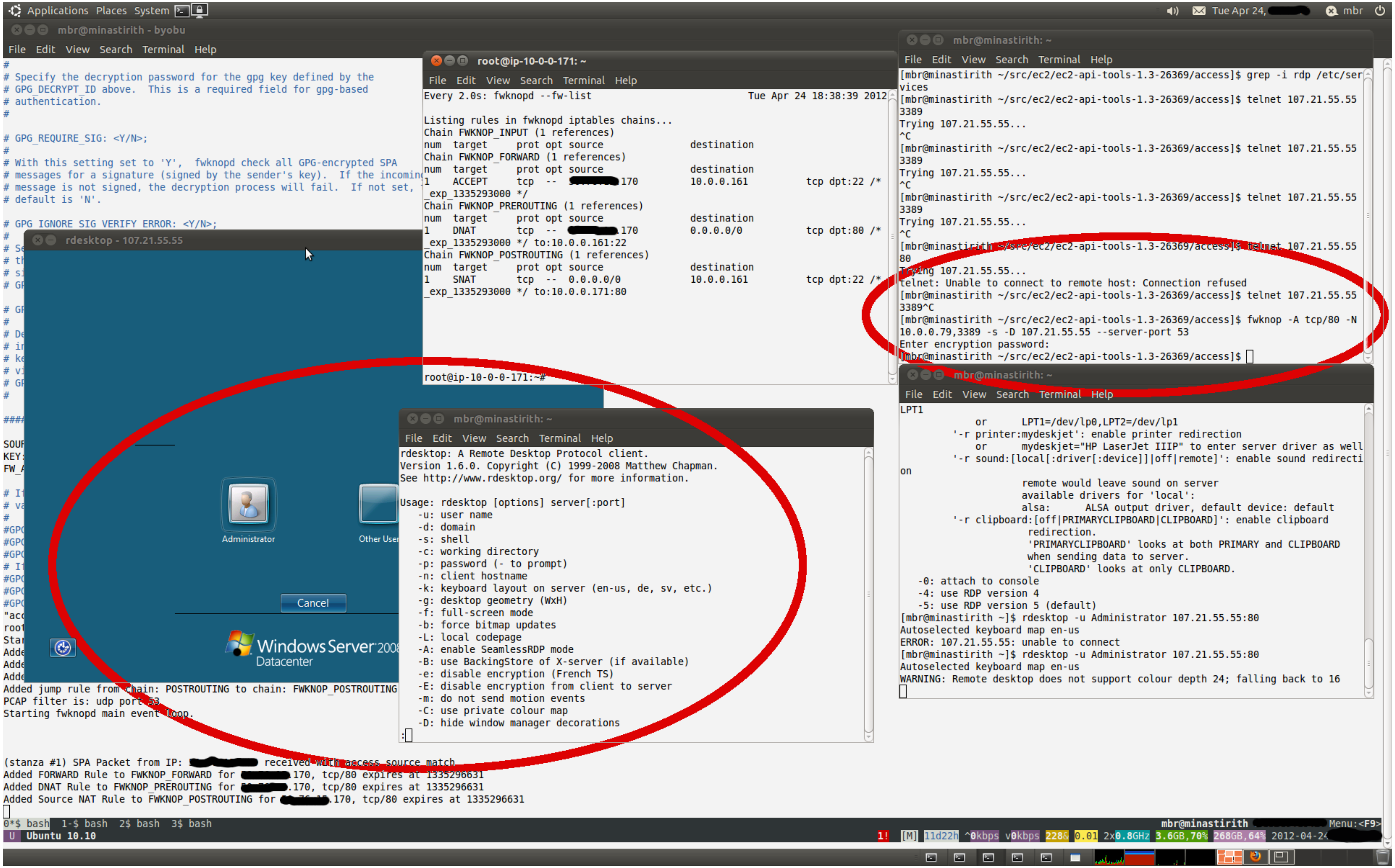
- Need NAT to work through the Ubuntu system, so in `fwknopd.conf`:

```
ENABLE_IPT_FORWARDING     Y;
```

- The Windows host is not associated with an Elastic IP, so we want return traffic to go back through the Ubuntu host
- The Windows host only sees an RDP connection from the Ubuntu host – not from its true source over the Internet

```
ENABLE_IPT_SNAT     Y;
SNAT_TRANSLATE_IP   <ubuntu IP>
```

SPA NAT Access to RDP



```
#
# Specify the decryption password for the gpg key defined by the
# GPG_DECRYPT_ID above.  This is a required field for gpg-based
# authentication.
#

# GPG_REQUIRE_SIG: <Y/N>;
#
# With this setting set to 'Y',  fwknopd check all GPG-encrypted SPA
# messages for a signature (signed by the sender's key).  If the incoming
# message is not signed, the decryption process will fail.  If not set,
# default is 'N'.

# GPG_IGNORE_SIG_VERIFY_ERROR: <Y/N>;
#
# Se
# th
# si
# GP

# GP
#
# De
# in
# ke
# vi
# GP
#

####

SOUR
KEY:
FW_A

# It
# va
#
#GP
#GP
#GP
# It
#GP
#GP
#GP
"acc
root
Star
Adde
Adde
Adde
Added jump rule from chain: POSTROUTING to chain: FWKNOP_POSTROUTING
PCAP filter is: udp port 53
Starting fwknopd main event loop.


(stanza #1) SPA Packet from IP: [redacted] received with access source match
Added FORWARD Rule to FWKNOP_FORWARD for [redacted].170, tcp/80 expires at 1335296631
Added DNAT Rule to FWKNOP_PREROUTING for [redacted].170, tcp/80 expires at 1335296631
Added Source NAT Rule to FWKNOP_POSTROUTING for [redacted].170, tcp/80 expires at 1335296631

0*$ bash  1-$ bash  2$ bash  3$ bash
 U  Ubuntu 10.10
```

```
Every 2.0s: fwknopd --fw-list                                     Tue Apr 24 18:38:39 2012

Listing rules in fwknopd iptables chains...
Chain FWKNOP_INPUT (1 references)
num  target     prot opt source               destination
Chain FWKNOP_FORWARD (1 references)
num  target     prot opt source               destination
1    ACCEPT     tcp  --  [redacted]170        10.0.0.161          tcp dpt:22 /*
_exp_1335293000 */
Chain FWKNOP_PREROUTING (1 references)
num  target     prot opt source               destination
1    DNAT       tcp  --  [redacted].170       0.0.0.0/0           tcp dpt:80 /*
_exp_1335293000 */ to:10.0.0.161:22
Chain FWKNOP_POSTROUTING (1 references)
num  target     prot opt source               destination
1    SNAT       tcp  --  0.0.0.0/0            10.0.0.161          tcp dpt:22 /*
_exp_1335293000 */ to:10.0.0.171:80



root@ip-10-0-0-171:~#
```

```
[mbr@minastirith ~/src/ec2/ec2-api-tools-1.3-26369/access]$ grep -i rdp /etc/ser
vices
[mbr@minastirith ~/src/ec2/ec2-api-tools-1.3-26369/access]$ telnet 107.21.55.55
3389
Trying 107.21.55.55...
^C
[mbr@minastirith ~/src/ec2/ec2-api-tools-1.3-26369/access]$ telnet 107.21.55.55
3389
Trying 107.21.55.55...
^C
[mbr@minastirith ~/src/ec2/ec2-api-tools-1.3-26369/access]$ telnet 107.21.55.55
3389
Trying 107.21.55.55...
^C
[mbr@minastirith ~/src/ec2/ec2-api-tools-1.3-26369/access]$ telnet 107.21.55.55
80
Trying 107.21.55.55...
telnet: Unable to connect to remote host: Connection refused
[mbr@minastirith ~/src/ec2/ec2-api-tools-1.3-26369/access]$ telnet 107.21.55.55
3389^C
[mbr@minastirith ~/src/ec2/ec2-api-tools-1.3-26369/access]$ fwknop -A tcp/80 -N
10.0.0.79,3389 -s -D 107.21.55.55 --server-port 53
Enter encryption password:
[mbr@minastirith ~/src/ec2/ec2-api-tools-1.3-26369/access]$
```

```
rdesktop: A Remote Desktop Protocol client.
Version 1.6.0. Copyright (C) 1999-2008 Matthew Chapman.
See http://www.rdesktop.org/ for more information.

Usage: rdesktop [options] server[:port]
   -u: user name
   -d: domain
   -s: shell
   -c: working directory
   -p: password (- to prompt)
   -n: client hostname
   -k: keyboard layout on server (en-us, de, sv, etc.)
   -g: desktop geometry (WxH)
   -f: full-screen mode
   -b: force bitmap updates
   -L: local codepage
   -A: enable SeamlessRDP mode
   -B: use BackingStore of X-server (if available)
   -e: disable encryption (French TS)
   -E: disable encryption from client to server
   -m: do not send motion events
   -C: use private colour map
   -D: hide window manager decorations
:
```

```
LPT1
            or      LPT1=/dev/lp0,LPT2=/dev/lp1
         '-r printer:mydeskjet': enable printer redirection
            or      mydeskjet="HP LaserJet IIIP" to enter server driver as well
         '-r sound:[local[:driver[:device]]|off|remote]': enable sound redirecti
on
                    remote would leave sound on server
                    available drivers for 'local':
                    alsa:      ALSA output driver, default device: default
         '-r clipboard:[off|PRIMARYCLIPBOARD|CLIPBOARD]': enable clipboard
                     redirection.
                     'PRIMARYCLIPBOARD' looks at both PRIMARY and CLIPBOARD
                     when sending data to server.
                     'CLIPBOARD' looks at only CLIPBOARD.
   -0: attach to console
   -4: use RDP version 4
   -5: use RDP version 5 (default)
[mbr@minastirith ~]$ rdesktop -u Administrator 107.21.55.55:80
Autoselected keyboard map en-us
ERROR: 107.21.55.55: unable to connect
[mbr@minastirith ~]$ rdesktop -u Administrator 107.21.55.55:80
Autoselected keyboard map en-us
WARNING: Remote desktop does not support colour depth 24; falling back to 16
```

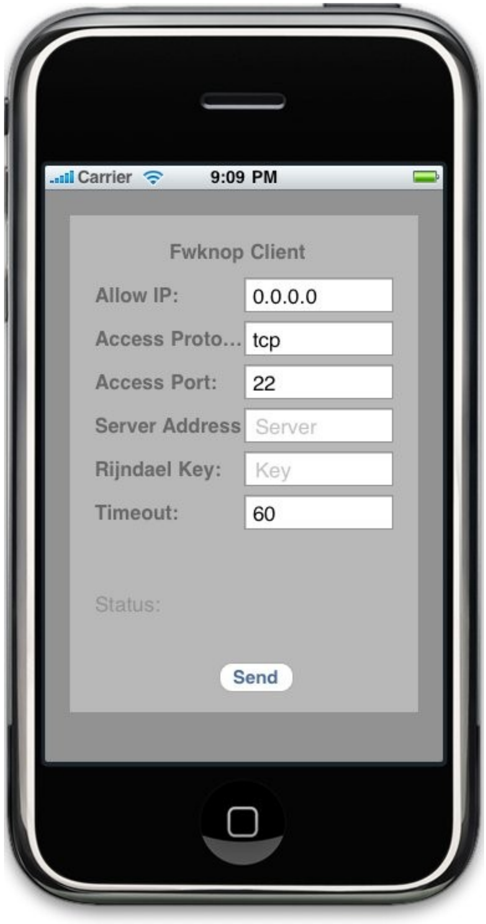
```
mbr@minastirith [redacted] Menu:<F9>
1!  [M] 11d22h ^0kbps v0kbps 228& 0.01 2x0.8GHz 3.6GB,70% 268GB,64% 2012-04-24[redacted]
```

The Future of Single Packet Authorization

The Future of SPA

- Mandatory Access Control support via SELinux and/or AppArmor
- Supported iPhone client (we are looking for a maintainer – please email me if interested)
- Further cloud computing extensions and integration points
- Packed binary protocol
- Tunneling mode extensions (DNS, HTTP, SMTP, Tor)

iPhone + Android fwknop Clients



Fwknop Client

Allow IP: 0.0.0.0

Access Proto... tcp

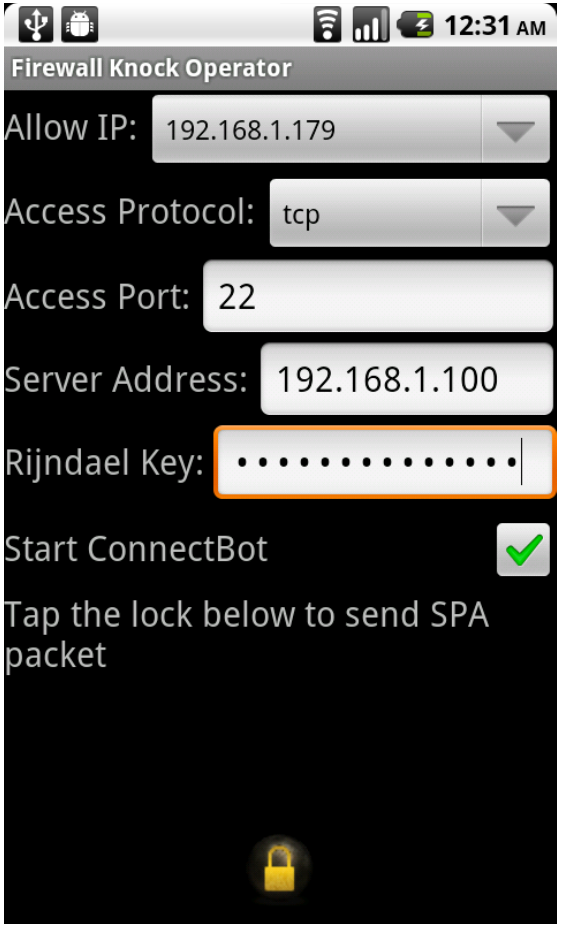
Access Port: 22

Server Address: Server

Rijndael Key: Key

Timeout: 60

Status:



Firewall Knock Operator

Allow IP: 192.168.1.179

Access Protocol: tcp

Access Port: 22

Server Address: 192.168.1.100

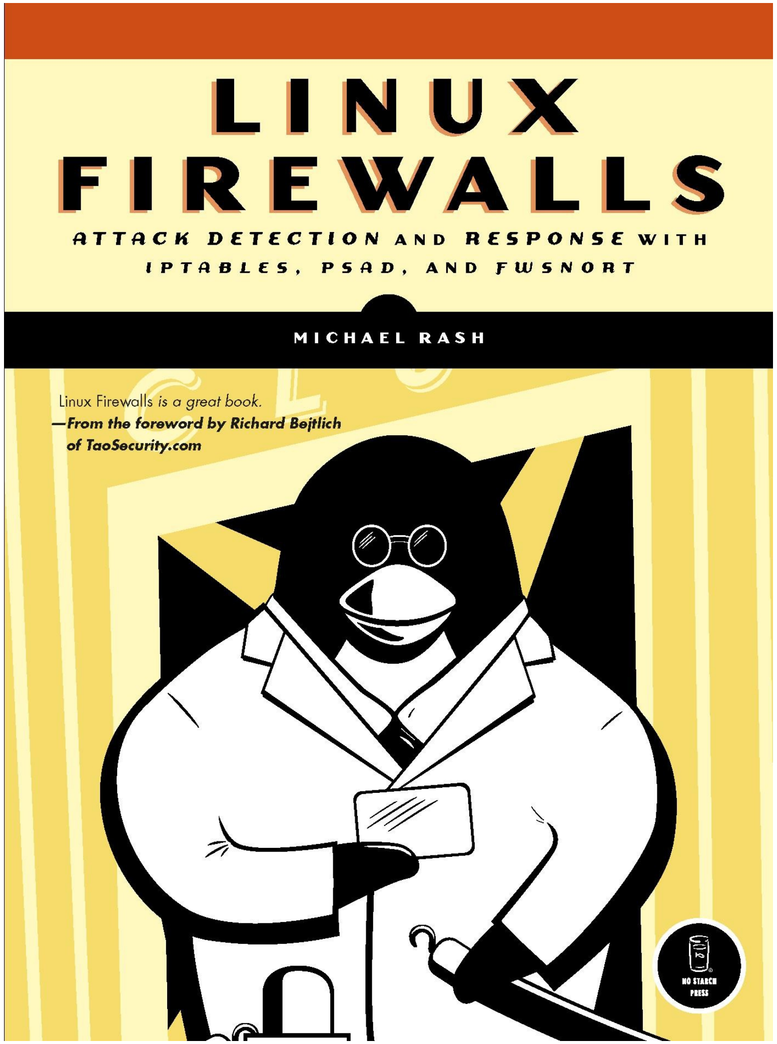
Rijndael Key: ••••••••••••••

Start ConnectBot ☑

Tap the lock below to send SPA packet

Demo...

Linux Firewalls 2nd Edition
Input Please...



LINUX FIREWALLS

ATTACK DETECTION AND RESPONSE WITH IPTABLES, PSAD, AND FWSNORT

MICHAEL RASH

Linux Firewalls is a great book.

—From the foreword by Richard Bejtlich of TaoSecurity.com

Questions?

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http://www.cipherdyne.org/fwknop/