Secure Shell: SSH

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Let’s move up the stack and look at ssh
Partly a tool, partly an application
We’ll discuss the original version of the protocol
Features of SSH

- Encrypted login and shell connection
- Easy, drop-in replacement for rlogin, rsh, rcp
- Multiple means of authentication
- Interesting case study in deployability
Simple Login Sequence

- Client contacts server
- Server sends its public RSA “host” key (at least 1024 bits), an RSA “server” key (768 bits), and a list of ciphers
  (The server key is changed hourly)
- The client authenticates the server
- The client generates a session key and encrypts it using both the host and server key
- The server decrypts it and uses it for traffic encryption
- The client authenticates to the host
The Server’s Two Keys

- Why are two keys used?
- The longer key is for authentication: only the genuine host will be able to decrypt it
- The shorter key provides an approximation to perfect forward secrecy: if the host is compromised more than one hour after the session starts, there’s no way for the attacker to recover it and read old sessions
- But why not use Diffie-Hellman? Speed? 768-bit RSA is faster than 1024-bit Diffie-Hellman, and computers were slower then. Actually, it’s because Tatu Ylönen, the author, was an inspired amateur in 1995...
How does the client authenticate the server?

More precisely, why should it trust the server’s key?

Note well: the server is sending a key, not a certificate — no one is vouching for the key.

The first time a key is received, the user is prompted about whether or not to accept it.

The result is cached in a “known hosts” file.
$ ssh foo
The authenticity of host 'foo (192.168.77.222)' can't be established.
Are you sure you want to continue connecting (yes/no)?
Warning: Permanently added 'foo (RSA)' to the list of known hosts.
An Attack?

$ ssh foo

WARNING: REMOTE HOST IDENTIFICATION HAS CHANGED!
IT IS POSSIBLE THAT SOMEONE IS DOING SOMETHING NASTY!
Someone could be eavesdropping on you right now (man-in-the-middle attack)!
It is also possible that the RSA host key has just been changed.
The fingerprint for the RSA key sent by the remote host is
Please contact your system administrator.
Add correct host key in /home/smb/.ssh/known_hosts to get rid of this message.
Offending key in /home/smb/.ssh/known_hosts:86
RSA host key for foo has changed and you have requested strict checking.
Host key verification failed.
What is the Security Guarantee?

- We don’t know that the key is correct
- We do know that the key is the same as it was last time
- The vulnerability is on the initial login only
- But — users must be taught what to do about that message...
What Should Users Do?

- The system administrator can populate a system-wide known hosts file
- System administrators can publish a digitally-signed list of their hosts’ keys (see http://www.psg.com/ssh-keys.html
- Users can check a piece of paper or ask each other
- Do people actually do this?
- Note: MITM attacks against ssh have been seen in the wild...
The server transmits a list of ciphers at the start

The client picks one

What if an attacker substituted a list containing only weak or cracked ciphers?

This is known as a *rollback* or *downgrade* attack

Solution: after starting the encryption, send an authenticated list of the algorithms you originally proposed
Client Authentication

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How does the client authenticate itself to the host?

Many possible ways — in fact, very many possible ways...

We’ll look at just a few
Password Authentication

- Simplest form: ordinary username and password
- The password is protected from eavesdropping
- There is no protection against brute-force password guessing
Password Guessing Attacks on SSH

00:01:36  foo sshd: Invalid user duane from 206.231.8.119
00:01:37  foo sshd: Invalid user murray from 206.231.8.119
00:01:38  foo sshd: Invalid user kovic from 206.231.8.119
00:01:39  foo sshd: Invalid user mitchell from 206.231.8.119
00:01:40  foo sshd: Invalid user nance from 206.231.8.119
00:01:41  foo sshd: Invalid user liberty from 206.231.8.119
00:01:42  foo sshd: Invalid user alan from 206.231.8.119
00:01:43  foo sshd: Invalid user wilfe from 206.231.8.119
00:01:45  foo sshd: Invalid user ruthy from 206.231.8.119
00:01:46  foo sshd: Invalid user oriana from 206.231.8.119
00:01:47  foo sshd: Invalid user mauzone from 206.231.8.119
00:01:48  foo sshd: Invalid user leopold from 206.231.8.119
Public Key Authentication

- Client has a public/private key pair, and sends the public key to the server.
- Server encrypts a 256-bit random number with that key.
- Client decrypts it and sends back an MD5 hash of the random number.
Trust the Client's Key

- Again, this is a simple key, not a certificate.
- There is a per-client list of *authorized keys*.
- If the client’s key is in that list, it’s accepted (provided, of course, that the challenge/response works).
Host-Based Authentication

- The client’s host can have a public/private key pair
- If this host is listed in an authorized hosts file, the userid is simply accepted
- Note: this is only useful if the two machines are under common administration and are secure against insider attacks
Storing Private Keys

- How are private keys stored?
- If a private key is compromised, all security bets are off
- Note: must cope with NFS-mounted home directories
All private key files must be read-protected

But if users store their keys under their home directories and use NFS, someone can eavesdrop on the NFS traffic

Solution: encrypt the private key with some symmetric cipher; prompt the user for a passphrase as needed
Too Many Prompts!

- If people use ssh heavily, they’ll be prompted for passwords constantly
- Solution: `ssh agent`
- Run a process that prompts for the passphrase once, decrypts the keys in memory, and performs the public key operations on behalf of the *proper* ssh client
- How do we secure that channel?
Securing the SSH Agent

- All communications to it are via a Unix-domain socket, which lives in the file system
- Not all systems enforce file permissions on Unix-domain sockets, since they’re seen as communications channels rather than as files
- But — all systems verify permissions on containing directories
- Put the socket in a protected directory; use shell environment variables to pass the location to clients
Using SSH Agent

$ set|grep SSH
SSH_AGENT_PID=363
SSH_AUTH_SOCK=/tmp/ssh-00000418aa/agent.418

$ ls -la /tmp/ssh-00000418aa
total 8
drwx------ 2 smb wheel 20 Oct 11 03:15 .
drwxrwxrwt 4 root wheel 260 Oct 12 00:13 ..
srwxr-xr-x 1 smb wheel 0 Oct 10 20:57 agent.418
Connection-Forwarding

Secure Shell: SSH
Client Authentication

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X11 Forwarding
Authenticating X11 Connections
X11 Forwarding Cookie Change
The Risks of X11 Forwarding

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Connection-Forwarding

- Ssh can forward TCP connections from the local machine to the remote, or vice-versa
- Can be used to access resources through an ssh firewall
- Talking to an internal POP3 server:
  
  ```
  ssh -L 110:mbox:110 firewall
  ```
  followed by (in another window)
  ```
  telnet 127.0.0.1 110
  ```
- Or, of course, configure your mailer to talk to 127.0.0.1
- Can forward remote connections to the local machine, too
Violating Security Policy with SSH

- Policy 1: ssh to the firewall is the only inbound service allowed
- Policy 2: all ssh connections must be authenticated by a SecurID token

Violation:

```bash
capture -L 2222:insidehost:22
```

Counts port 2222 on some outside machine to port 22 — ssh — on some inside server

To log in without using a SecurID token, just connect to 2222 on that outside machine

Similar violations can be initiated from the inside, if outbound ssh is permitted
Forwarding the Authentication Agent

- Alice uses `ssh-agent` to log in to host Foo. From Foo, she logs in to Bar. How does she authenticate?
- She could have a separate private/public key bar stored on Foo, and use it to log in to Bar.
- Alternatively, she could use a special form of connection-forwarding to forward access to the authentication agent.
- Note: the private key itself is not transmitted; all cryptographic operations are still done by the same agent process.
$ ssh-add -l
b132$ ssh berkshire
NetBSD 4.99.3 (BERKSHIRE) #0: Sun Sep 24 16:30:08 EDT 2015
b129$ ssh-add -l
b130$ set|grep SSH
SSH_AUTH_SOCK=/tmp/ssh-00028833aa/agent.28833
SSH_CLIENT=’192.168.2.79 65051 22’
SSH_CONNECTION=’192.168.2.79 65051 192.168.2.163 22’
SSH_TTY=/dev/ttyp4
Suppose that host Foo is insecure

An attacker with root privileges on Foo can contact Alice’s authentication agent

It is thus possible for the attacker to log in as Alice anywhere that key is accepted

Never do connection-forwarding to an insecure machine
Ssh can be used to forward X11 window system connections, too

How X11 works: with X11, the X server controls the keyboard, screen, and mouse

X applications open a connection — via Unix-domain sockets or TCP — to the server

The environment variable DISPLAY tells the application what to do

How is this connection authenticated?
Authenticating X11 Connections

- Some people don’t — so attackers can read the screen, and send synthetic keypress and mouse events. Oops...
- Can be done with odd Kerberos facilities
- Normal way: use “magic cookie” mode — the application has to read a (secret) value from a file, and send that to the X server
X11 Forwarding

- The remote sshd generates a new, random cookie and stores it in that file for applications.
- It sets DISPLAY to point to itself.
- When an X11 application attempts to connect to the X server, it actually connects to sshd and sends that magic cookie.
- The sshd server verifies the cookie, and forwards the connection over the ssh channel to the client.
- The client replaces the remote cookie with the local one, and contacts the local X server.
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X Server

SSH

SSHD

xterm

xterm

The Risks of X11 Forwarding
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The Risks of X11 Forwarding

- Again, assume that Foo is insecure and is penetrated
- An attacker can read the cookie, connect to Alice’s X server, and read the screen, send events, etc.
- Moral: don’t forward X11 to an insecure machine
Deployability
Why Did SSH Succeed?

- No infrastructure needed
- No PKI, no CAs, no central server
- A site could deploy SSH on as many or as few machines as needed
Usability

- It was a drop-in replacement for rlogin
- It could even be configured with the same host-based trust model
- It required little in the way of user training
- It provided some nice features, such as connection- and X11-forwarding, compression, etc.
Security

- It defended against real attacks
- It provided extra functionality not in other packages, such as connection-forwarding
- It included add-ons such as scp
- It ran on more Unix variants than its competitors did
Limitations

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Limitations
SSH Doesn’t Solve All Problems
Compromised Hosts
Ssh Worms
Conclusions
SSH Doesn’t Solve All Problems

- Cryptographic mistakes (i.e., using a CRC instead of MD5)
- Compromised hosts
- Password-guessing
- Deliberate user misbehavior
- Ssh worms
Compromised Hosts

- The ssh and ss hd commands can be Trojaned, and used to steal passwords
- X11 and authentication agent forwarding can be captured by the bad guys
The known host file indicates connectivity patterns

More importantly, it tends to indicate trust patterns

An attacker who has compromised your machine can not only use your ssh keys, but can also look at the known hosts list to see where you’ve connected via ssh

Transitive trust patterns help the attack spread

(Byw, studies suggest that many users don’t encrypt their private keys... )
A professional cryptographer would have designed a system around certificates issued by properly-isolated and secured CAs.

In a very real sense, that would have been more secure — and it would likely have been undeployable.

We got more real security from a partially-secure implementation that better matched deployment patterns.