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

Secure Shell: SSH
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Features of SSH
Simple Login Sequence
The Server's Two Keys
Authenticating the Server
Sample Initial Login
An Attack?
What is the Security Guarantee?
What Should Users Do?
A List of Ciphers
Client Authentication
Connection-Forwarding
Deployability
Limitations

- 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. . .

Authenticating the Server

- 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

Sample Initial Login

```
$ ssh foo
The authenticity of host ’foo (192.168.77.222)’ can
RSA key fingerprint is cf:26:92:6c:01:c1:05:c7:51:de
Are you sure you want to continue connecting (yes/no
Warning: Permanently added ’foo (RSA) to the list of
```

An Attack?

Secure Shell: SSH
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```
$ 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
f1:68:d8:0d:0a:1b:78:2c:48:3a:aa:1b:4a:8c:cb:ca.
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?

Secure Shell: SSH
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- 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. . .

A List of Ciphers

- 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

Client Authentication

- 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
00:01:37 foo sshd: Invalid user murray from 206.231.
00:01:38 foo sshd: Invalid user kovic from 206.231.8
00:01:39 foo sshd: Invalid user mitchell from 206.23
00:01:40 foo sshd: Invalid user nance from 206.231.8
00:01:41 foo sshd: Invalid user liberty from 206.231
00:01:42 foo sshd: Invalid user alan from 206.231.8.
00:01:43 foo sshd: Invalid user wilfe from 206.231.8
00:01:45 foo sshd: Invalid user ruthy from 206.231.8
00:01:46 foo sshd: Invalid user oriana from 206.231.
00:01:47 foo sshd: Invalid user mauzone from 206.231
00:01:48 foo sshd: Invalid user leopold from 206.231
```

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

Trusting 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

The Minimum

- 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

Secure Shell: SSH
Client Authentication
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Password Authentication
Password Guessing Attacks on SSH
Public Key Authentication
Trusting the Client's Key
Host-Based Authentication
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The Minimum
Too Many Prompts!
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Using SSH Agent
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```
$ 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.41
```

Connection-Forwarding

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

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Client Authentication
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Violating Security Policy with SSH
Forwarding the Authentication Agent
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The Risks of Agent Forwarding
X11 Forwarding
Authenticating X11 Connections
X11 Forwarding
Cookie Change
The Risks of X11 Forwarding
Deployability
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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:

  ```
       ssh -L 2222:insidehost:22
  firewall
  ```
- Connects 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 use `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

Forwarding the Authentication Agent

```
$ ssh-add -l
1024 7c:01:66:d8:4b:3d:bc:36:1e:97:92:8e:48:d5:0f:37
b132$ ssh berkshire
NetBSD 4.99.3 (BERKSHIRE) #0: Sun Sep 24 16:30:08 ED

b129$ ssh-add -l
1024 7c:01:66:d8:4b:3d:bc:36:1e:97:92:8e:48:d5:0f:37
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
```

The Risks of Agent Forwarding

- 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

X11 Forwarding

- 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?

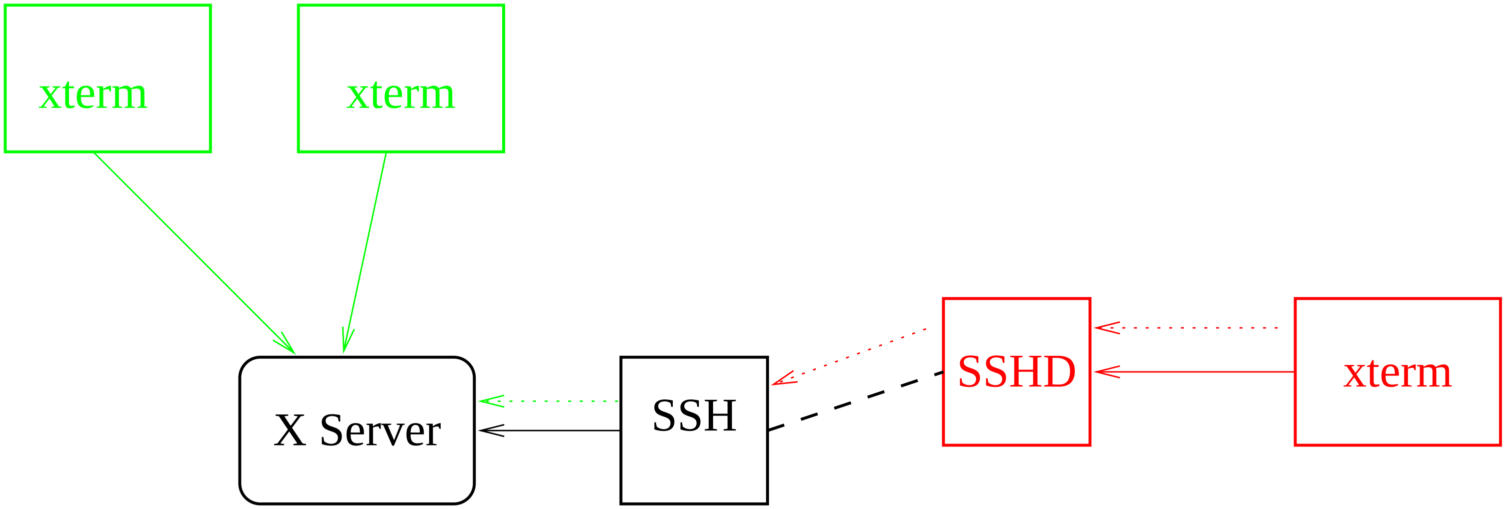
Authenticating X11 Connections

- 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

Cookie Change



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

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 sshd commands can be Trojaned, and used to steal passwords
- X11 and authentication agent forwarding can be captured by the bad guys

Ssh Worms

- 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
- (Btw, studies suggest that many users don't encrypt their private keys. . .)

Conclusions

- 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