What's new in OpenSSH?

Damien Miller <djm@openssh.com>

EuroBSDCon 2011

Introduction

- OpenSSH is approaching 12 years old
- Still adding features
- We don't do “big splash” releases, so you may not have heard of what has been developed recently
- Let's fix that...

What's new?

- PKCS#11 support
- sftp extensions
- SSH protocol 1 deprecation
- Certificate authentication
- Elliptic Curve cryptography
- Sandboxed pre-auth privilege separation

PKCS#11

- PKCS#11 is a standard for cryptographic tokens
  - Smartcards
  - Hardware Security Modules (HSM)
- Key storage in PKCS#11 devices appeared in 5.4
  - Deprecating the old opensc/libsectok smartcard code
- Smartcards can store authentication and CA keys

Match – example: use a smarcard key

```
ssh -I /opt/lib/mycard-pkcs11.so user@host
```

ssh(1) will dlopen() the specified PKCS#11 provider and use it to enumerate and use keys on the device it supports

Match - example: smartcard w/ agent

```
# add keys
ssh-add -s /opt/lib/mycard-pkcs11.so

# remove keys
ssh-add -e /opt/lib/mycard-pkcs11.so
```

Pretty simple :)

PKCS#11 – future work

- Currently, using a token means trying *all* its keys
  - Granular control would be nice
  - We can to some extent using IdentityFile in ssh(1), but this isn't obvious
- Allow host keys to be stored in PKCS#11
  - Root compromise != persistent hostkey theft
- Add support for certificates (mentioned later)

sftp extensions

- The sftp protocol as OpenSSH implements is actually “sftp v.3”, or more verbosely “draft-ietf-secsh-filexfer-02.txt”
- sftp is a good example of how consensus standards development can produce bad protocols
- Original versions had an elegant simplicity
  - Basically the Unix file API as protocol methods
  - Open file => handle
  - Read from handle => data
  - Reminiscent of 9p from Plan 9

sftp extensions

- Later versions (up to v.6) accreted features
  - “Text mode” files to better support Windows
  - “Record mode” files to better support OpenVMS
  - MIME types, Win32ish ACLs, byte-range locking
- We think that we already have a do-everything network filesystem protocol in NFS, we don't need another
- So we stopped implementing features after sftp v.3
- This was unfortunate for people who needed new features

sftp extensions

- Fortunately, the sftp protocol is extensible
- In the initial protocol “hello” message, client and server can advertise extensions that they support
- When the protocol is established, named extension methods can be used
  - E.g. “statvfs@openssh.com”
  - Downside: named extensions are more bandwidth hungry than numbered protocol methods.

sftp extensions

- We have added a number of extensions already:
  - posix-rename@openssh.com
    - Standard sftp v.3 uses a link()+rm() raceless rename
    - Use as “rename” via sftp(1) in OpenSSH >= 4.8
  - statvfs@openssh.com, fstatvfs@openssh.com
    - Use as “df” via sftp(1) in OpenSSH >= 5.1
  - hardlink@openssh.com
    - Use as “ln” via sftp(1) in OpenSSH >= 5.7

sftp extensions

- More to come:
  - user/group names for files
    - sftp v.3 only support numeric uid/gid
  - fsync() file handle method
  - O_NOFOLLOW open mode
- Some of these are very useful for user-space filesystems that use the sftp protocol
  - (though it is inherently racy)

Deprecation of SSHv1

- We recently completed a staged deprecation of SSHv1

- Why?
  - SSHv1 lacks many features of SSHv2
  - SSHv1 offers no viable extension mechanism
  - SSHv1 suffers from a number of unfixable cryptographic weaknesses

SSHv1 – CORE-SDI “SSH insertion attack”

- Found by CORE SDI in 1998
- Fundamental problem is SSHv1's use of CRC as a integrity code
  - CRC is linear; changes in its input lead to predictable changes in its output
- CORE SDI figured out how to inject data by calculating how to reconstruct a valid CRC
- Attack cannot be prevented, but can be probabilistically detected
  - Detection code was buggy too!
    - Twice!

SSHv1 – Use of MD5 in the protocol

- SSHv1 uses MD5 for key derivation and RSA public key authentication
- No way to specify a different algorithm
- MD5 is broken as a cryptographic hash
  - Attackable for the RSA authentication case?

SSHv1 – downgrade attack

- If a client and server support SSHv1 and SSHv2, a man-in-the-middle may silently downgrade their connection to SSHv1

- SSH advertises supported versions in initial banner:
  - e.g. "`SSH-1.99-OpenSSH_5.8`"
  - SSHv2 checks banners, SSHv1 does not

- Attacker can modify banners, force use of SSHv1
  - Attack vulnerable code or protocol components.

SSHv1 – even more crypto badness

- Not-quite PFS (ephemeral host key)
- Probably vulnerable to CPNI-957037 "Plaintext Recovery Attack Against SSH", Information Security Group at Royal Holloway, U. London, November 2008
- Weak private key file format

SSHv1 - weaknesses

- We deprecated it in two steps
  - 4.7 – new server installations no longer enable SSHv1
  - 5.4 – client must be explicitly configured to use SSHv1

- Quite a few people still liked SSHv1 because of speed
  - It's easy to be fast when you are insecure :)
  - Why is SSHv2 slower? MAC and key exchange
  - We implemented a fast MAC (umac-64) and now a fast key exchange (ECDH)

Certificate authentication for OpenSSH

- A new, very lightweight certificate format (not X.509)
- Released in OpenSSH-5.4, improved in OpenSSH-5.6
- Design goals: simplicity, modest flexibility, minimal attack surface

Why (another certificate format)

"We have OpenPGP and X.509, why reinvent the wheel?"

- OpenSSH will not accept complex certificate decoding in the pre-authentication path:
  - PGP and X.509 (especially) are syntactically and semantically complex
  - Too much attack surface in the pre-authentication phase
  - Bitter experience has taught us not to trust ASN.1

Differences from X.509

X.509	OpenSSH
hierarchical CA structure	no hierarchy (maybe later)
complex identity structure	identity is just a string
multi-purpose	SSH auth only
identity bound by key owner	identity bound by CA
complex encoding	simple encoding
infinitely extensible	extensible enough (we hope)

OpenSSH certificate contents

So, what is in an OpenSSH certificate?

```
Nonce
Public key (DSA or RSA)
Certificate type (User or Host)
Key identifier
List of valid principals
Validity time range
Critical options
Extensions
Reserved field (currently ignored)
CA key
Signature
```

Critical options and extensions

Options that limit or affect certificate validity or use. May be "critical" or not. Critical options cause the server to refuse authorisation if it the option is unrecognised

Present options are basically a mapping of `.ssh/authorized_keys` options into the certificate:

Critical	Non-critical
`force-command`	`permit-X11-forwarding`
`source-address`	`permit-agent-forwarding`
	`permit-user-rc`
	`permit-pty`
	`permit-port-forwarding`

Generally, options that *grant* privilege are non-critical as ignoring them does not yield security surprises.

Certificate encoding

- The certificate is encoded using SSH-style wire primitives and signed using SSH-style RSA/DSA signatures
  - Very little new code.
  - Minimises incremental attack surface
- Fixed format: all fields must be present (though some subfields may be empty) and must appear in order.
- Certificates are extensible using new critical options, extensions, new types (in addition to user/host), or the currently-ignored "reserved" field.

Certificate integration - User auth

User authentication can be trusted CA keys listed in `~/.ssh/authorized_keys` or via a sshd-wide trust anchor specified in `sshd_config's` *TrustedCAKeys* option

Principal names in the cert must match the local account name in the case of `authorized_keys`. A `principals="..."` key option allows some indirection here.

For certs signed by *TrustedCAKeys*, an optional *AuthorizedPrincipalsFile* (e.g. `~/.ssh/authorized_principals`) allows listing of certificate principals to accept.

Certificate integration - host auth

CAs trusted to sign host certificates must be listed in a *known_hosts* file (either the system `/etc/ssh/known_hosts`, or the per-user `~/.ssh/known_hosts`)

Trust of host CA's can be restricted to a specific list of domain wildcards:

```
@cert-authority  localhost,*.mindrot.org,*.djm.net.au ssh-rsa AAAAB3Nz...
```

Fallback: If a host presents a cert from an unrecognised CA, then it is treated as a raw public key for authentication purposes (normal key learning rules apply)

Certificate integration - CA operations

CA operations are built into *ssh-keygen*:

```
# Create a keypair
$ ssh-keygen -qt ecdsa -C '' -f ~/.ssh/id_ecdsa -N ''

# (on the CA) sign the public key to create a user cert
$ sudo ssh-keygen -s /etc/ssh/ssh_ca_key \
    -I "djm" -n djm,shared-nethack \
    -O source-address=10.0.0.0/8 \
    -O force-command=/usr/bin/nethack \
    -O permit-pty \
    -V -1d:+52w1d id_ecdsa.pub \
    -z 314159265
Signed user key id_ecdsa-cert.pub: id "djm" serial 314159265 for
djm,shared-nethack valid from 2011-02-10T14:28:00 to 2012-02-
09T14:28:00
```

Certificates - Revocation

- Revocation story is kind of weak at present.
- Emphasis is on making certs short-lived rather than revocation
- User authentication keys can be revoked using a flat file of public keys. Host keys are revoked in known_hosts.
- Revoked keys print a scary warning on use:

```
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@       WARNING: REVOKED HOST KEY DETECTED!               @
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
The RSA-CERT host key for localhost is marked as revoked.
This could mean that a stolen key is being used to
impersonate this host.
```

- Can do an OCSP-like protocol if necessary in the future. (patches welcome)

Certificates - Future plans

- Write a HOWTO-style document
- Improve revocation
  - Compact CRL format
  - Maybe an OCSP-like protocol
- Ability to store OpenSSH certs in X.509 certs for smartcard use
  - OCTET-STRING certificate extension under an OID IETF allocated to the OpenSSH project
- Combined OpenSSH and X.509 CA tool: sign CSR and OpenSSH pubkey in a single operation
- Maybe implement chained certificates

Elliptic curve cryptography

- OpenSSH 5.7 introduced Elliptic Curve Cryptographic key exchange and public key types
  - Key Exchange is ECDH
  - New public key type is ECDSA

- Implemented according to RFC5656 “Elliptic Curve Algorithm Integration in the Secure Shell Transport Layer” by Douglas Stebila

What is ECC?

- Elliptic Curve Cryptography (ECC) is public-key cryptography calculated using Elliptic Curves over finite fields
    - Contrast with traditional public key algorithms that usually calculate in a finite integer group

- Elliptic curves over finite fields provide an algebraic group structure in which the discrete logarithm problem is "hard"
    - Discrete Log problem (DLP): Given g^x, find x
    - Solving the DLP is more difficult in curve fields than in prime fields, so key lengths can be shorter

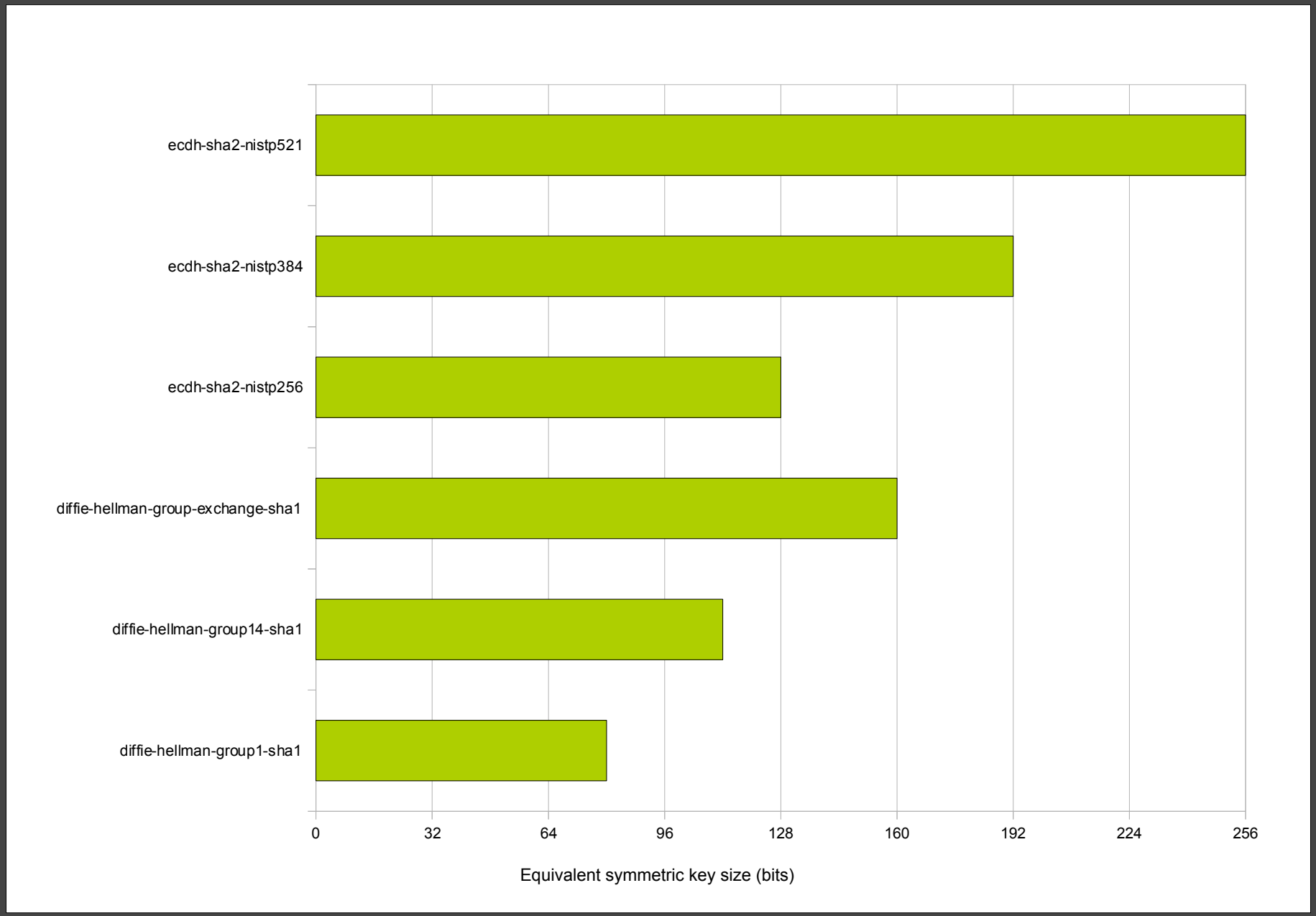
What is ECC?

- Since the DLP is hard, DLP-dependent cryptosystems work
  - DSA => ECDSA
  - DH => ECDA
  - ECRSA isn't common since RSA doesn't rely on the DLP
- Since key lengths are shorted, ECC-based algorithms are usually faster for a given security level
- More introductory information at:
  - http://wikipedia.org/wiki/Elliptic_curve_cryptography
  - http://imperialviolet.org/2010/04/ecc.html

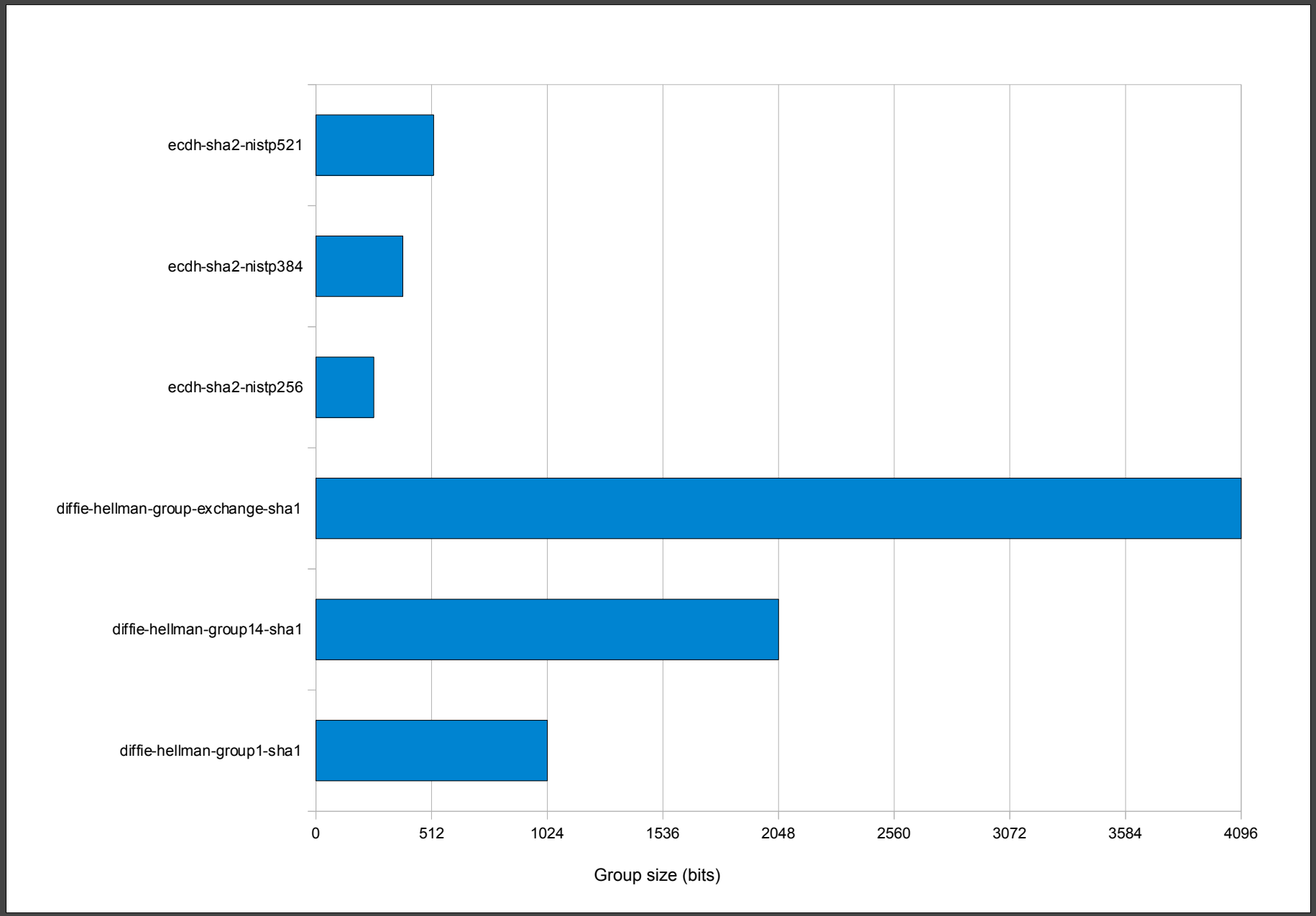
ECC in OpenSSH: Key Exchange

- OpenSSH >= 5.7 support Elliptic Curve Diffie-Hellman key exchange (ECDH)
- Three security levels provided by three different protocol methods, each with its own curve field:
  - ecdh-sha2-nistp256
  - ecdh-sha2-nistp384
  - ecdh-sha2-nistp521 (note: not 512)
- OpenSSL is used for elliptic curve operations, including point serialisation/parsing

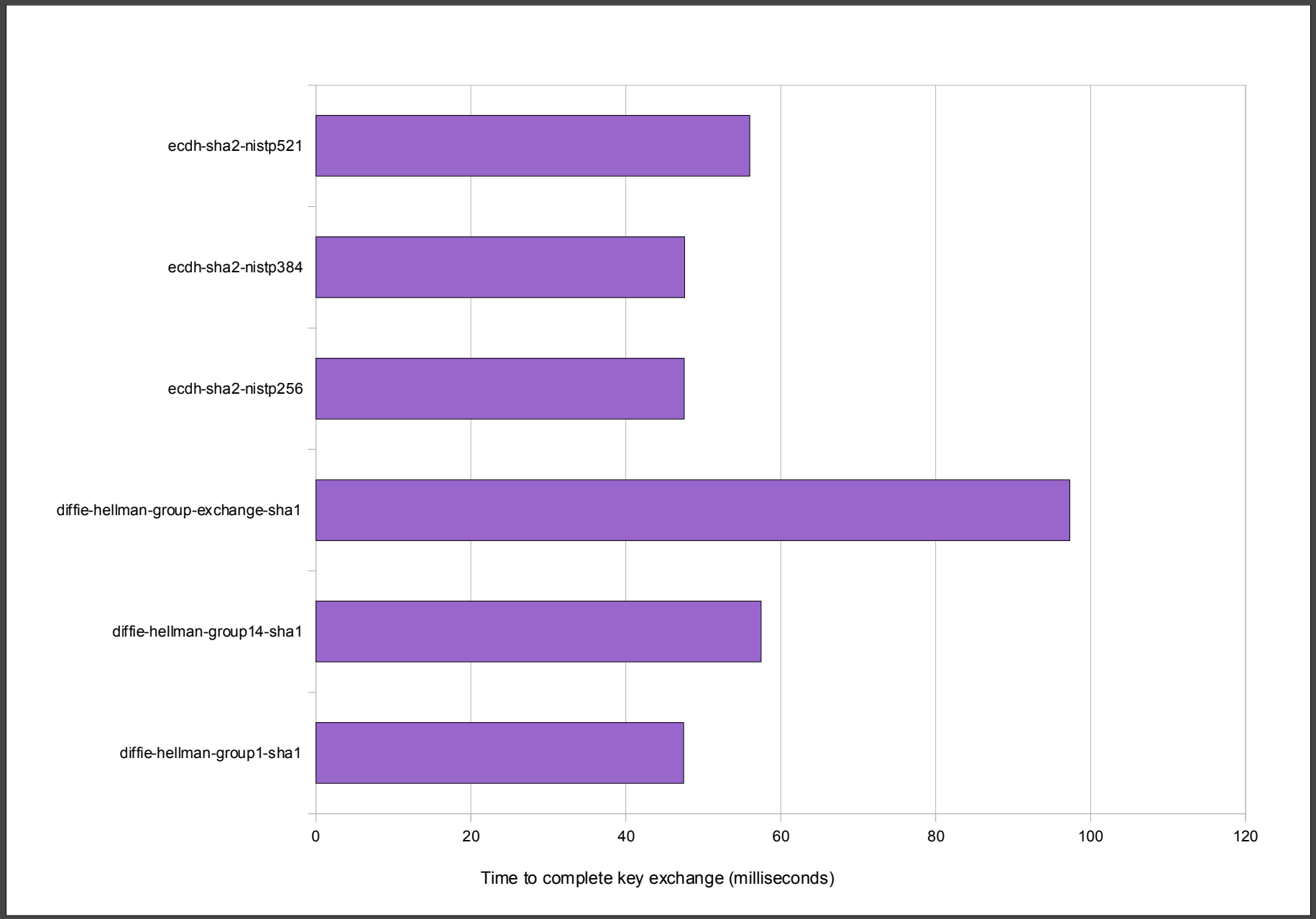
KEX – symmetric equivalent security



KEX – group size (bits)



KEX - time to complete



ECDH key exchange

- On by default if both ends support it in OpenSSH >= 5.7
- If you require more than 128 bits of symmetric equivalent security, then you should use the sshd_config *KexAlgorithms* option to chose the 384 or 521 bit ECC curve field.
- OpenSSL's ECC implementation is still being optimised
  - 2 x speedup in -current
  - Possibly 4 x speedup if we use a hand-optimised 224-bit curve field.

ECC in OpenSSH: keys

- OpenSSH >= 5.7 supports Elliptic Curve DSA (ECDSA) for user and host keys
- Again, the curve field is explicit and defines the security level of the algorithm
- We use the same three curves (mandatory in RFC5656):
  - `ecdsa-sha2-nistp256`
  - `ecdsa-sha2-nistp384`
  - `ecdsa-sha2-nistp521`
- All hidden behind “ecdh” key type used on command-line

ECC in OpenSSH: keys

- ECDSA is slightly faster than regular DSA
  - Still a benefit in symmetric-equivalent security
  - Shorter keys too
- ECDSA keys can appear wherever RSA or DSA keys work:
  - User keys (`~/.ssh/id_ecdsa`, `~/.ssh/authorized_keys`)
  - Host keys (`/etc/ssh/ssh_host_ecdsa_key`)
  - Certificates (as signed key or as CA)
- ECDSA keys are preferred when both ends support them

Sandboxed privsep - background

- OpenSSH sshd was one of the first network daemons to use privilege separation to mitigate attacks (postfix and vsftpd were earlier)

- Concept: split sshd into two processes
  - Privileged *monitor* implements only those options that require root access
  - Unprivileged child process handles network communication, packet parsing and most crypto
  - Communicate via lightweight RPC over shared socket
  - Pre-authentication child process is chrooted to an empty directory

Sandboxed privsep - background

- Most attack surface runs without privilege, so successful attackers no longer automatically get root
- A compromised unprivileged child can still be dangerous
  - Act as proxy to relay attacks against other hosts
  - Probe local kernel attack surface, attempt privilege escalation
- The most critical case is before the user is authenticated (a.k.a *preauth*)
  - No authentication barrier to attackers
  - A good exploit may be used to create a worm

Sandboxed privsep - sandboxing

- Solution: voluntarily remove capability from the pre-auth child process
- Ideal case: child is allowed access to precisely the resources (file descriptors) and system calls it needs and nothing more
- Unfortunately we can't get close to the ideal using POSIX facilities, but many platforms offer APIs to restrict process' power
- Hardest part in implementing was arranging for pre-auth child to make no socket() calls
    - Was using syslog for logging, now piped to monitor

Sandboxed privsep - systrace

- Sandbox implementation uses OpenBSD's systrace(4) device in unsupervised mode
  - No “cradle” systrace(8) process to inspect syscall args
  - Just a simple list of allowed syscalls
  - Extended systrace(4) to SIGKILL on policy violation
- This implementation is pretty close to the ideal
  - Only whitelisted syscalls are permitted
  - Most kernel attack surface is excluded
  - No possibility of attacker opening sockets to proxy
- Some maintenance burden of permitted syscall list

Sandboxed privsep – OS X seatbelt

- Sandbox implementation using Seatbelt / sandbox_init(3) implemented in OS X 10.5

- Uses policy `kSBXProfilePureComputation` that prohibits access to “all operating system services”
  - Haven't tested this enforcement in depth
  - Seems to allow creation of sockets, though operations attempted on them fail
  - We also use rlimit sandboxing (see next) for extra paranoia

Sandboxed privsep – rlimit

- What about platforms that lack stronger mechanisms?
- setrlimit(2) to zero hard fd and process limits
  - Prevent opening sockets and fork()-like syscalls
- Blocks attacker's proxying through compromised sshd
- Unfortunately does not reduce local kernel attack surface to reduce risk of privilege escalation
- Doesn't work everywhere – some platforms won't set zero fd limit when there remain open descriptors.

Sandboxed privsep – future work

- More sandboxes!
  - FreeBSD Capsicum (probably the best API for this)
  - ptrace() sandbox like vsftpd? (maybe not - complexity)
- Linux is conspicuously lacking a good sanbox at present
  - Pending patch for SELinux based sandbox
  - Kernel lacks a sufficiently general mechanism (see Will Drewry's patches to extend SECCOMP)
- Make setrlimit() sandbox work in more places
  - Weaken to allow setting low (not zero) fd limit
  - Detect when those fds close unexpectedly

OpenSSH – what's next?

- Small features. E.g.
  - Hostname canonicalisation
  - Fetch authorized_keys from agent
- Refactoring
  - E.g. make key-handling, agent client code available as a library
- Better testing
  - Unit tests
  - Better feature coverage

Thanks

Bonus Slides

Match

- This feature isn't so new, actually introduced in 4.4
- Allows variation of sshd's config depending on
  - Username
  - Group
  - Source address
  - Source hostname (if you trust DNS)
- Replaces previous hack of multiple instances + AllowUsers/AllowGroups

Match

- Very useful for:
  - Restricted accounts (e.g. mandatory chroot)
  - Limiting authentication by source network
    - (e.g disable password auth from internet)

Match - example: controlling auth

```
PasswordAuthentication no

# Override main configuration
Match address 10.0.0.0/8
  PasswordAuthentication yes
```

Match - example: controlling options

```
AllowTcpForwarding no

Match group wheel,fwd
  AllowTcpForwarding yes

# Wildcard predicates == ok
Match user hosted-*
  PasswordAuthentication no
  PubkeyAuthentication yes
```

Match - example: anonymous sftp

```
Match user anonsftp
  ForceCommand internal-sftp -R
  ChrootDirectory /chroot/home
  PermitEmptyPasswords yes
  PasswordAuthentication yes
  AllowAgentForwaring no
  AllowTcpForwarding no
  X11Forwarding no
```