Deploying high-security cryptography

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http://cr.yp.to/talks.html
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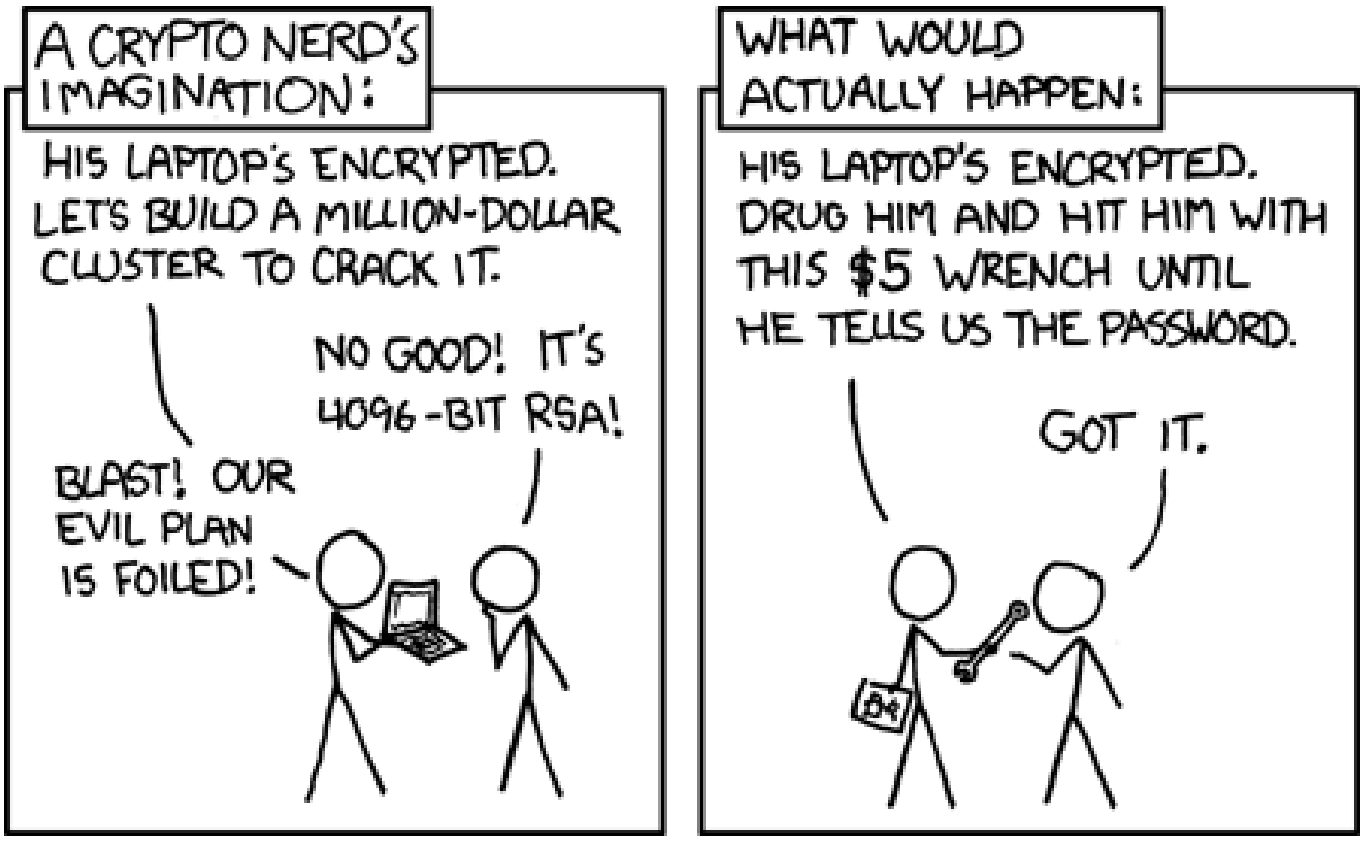

http://xkcd.com/538/

nacl.cr.yp.to: NaCl (“salt”),
a new cryptographic library.

Core development team:
Tanja Lange (Eindhoven); Peter
Schwabe (Academia Sinica); me.

Acknowledgments:
code contributions from
Matthew Dempsky (Mochi
Media), Niels Duif (Eindhoven),
Emilia Käsper (Leuven),
Adam Langley (Google),
Bo-Yin Yang (Academia Sinica).

The basic question

You're a programmer.
Your program will send data through a dangerous link:

- WiFi at hotel, airport, coffee shop, etc.
- Firewalled corporate network with thousands of computers.
- Your own hard drive, communicating to you.

You're worried about espionage, corruption, sabotage.

How to protect the data?

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PGP, SSH, SSL, etc.

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Focus of this talk:
using NaCl to deploy
high-security cryptography
in applications that
don't have cryptography yet.

Case study: Retrieving `http://www.kuleuven.be`.

1. Browser → web server:

```
GET / HTTP/1.1
Host: www.kuleuven.be
```

2. Web server → browser:

```
HTTP/1.1 200 OK
Date: Wed, 07 Mar 2012
10:23:23 GMT
Server: Apache/1.3.37
(Unix) AuthMySQL/2.20
mod_ssl/2.8.28
OpenSSL/0.9.7e
Content-Type: text/html
```

etc.

These network packets
have no security:
no confidentiality,
no integrity, no availability.

Network eavesdropper "Eve"
easily sees and controls
all packets on network.

Espionage: Eve sees data.
Corruption: Eve modifies data.
Sabotage: Eve kills connection
(e.g., forging TCP RST packet).

How do we add security?

Actually, retrieving
`http://www.kuleuven.be`
has even more steps.

1. Browser → DNS server:
`Where is www.kuleuven.be`?

2. DNS server → browser:
`www.kuleuven.be has IP address 134.58.64.12.`

3. Browser → 134.58.64.12:
`GET / HTTP/1.1` etc.

4. 134.58.64.12 → browser:
`HTTP/1.1 200 OK` etc.

Actually even more steps:

proxies, redirects, images, etc.

1. Browser → DNS cache:

`Where is www.kuleuven.be?`

2. DNS cache → DNS server:

`Where is www.kuleuven.be?`

3. DNS server → DNS cache:

`www.kuleuven.be has IP address 134.58.64.12.`

4. DNS cache → browser:

`www.kuleuven.be has IP address 134.58.64.12.`

5. Browser → 134.58.64.12:

`GET / HTTP/1.1` etc.

6. 134.58.64.12 → browser:

`HTTP/1.1 302 Found`
`Location:`
`http://www.kuleuven.be`
`/kuleuven/` etc.

7. Browser → 134.58.64.12:

`GET /kuleuven/ HTTP/1.1` etc.

8. 134.58.64.12 → browser:

`HTTP/1.1 200 OK` etc.

+ more servers, more packets . . .

Browser and `kuleuven.be`
both support SSL.

Encrypts client's HTTP requests;
encrypts and authenticates
server's HTTP responses.

My top concern with SSL:

- Wide deployment is painful.

Other concerns:

- Doesn't even try to stop DoS.
- Limited confidentiality.
- Too many trusted parties.
- Too complex to be secure.

“DNSCrypt”:
New OpenDNS project
using NaCl for easy-to-deploy
confidentiality, integrity,
availability of packets between
browser $\leftrightarrow$ DNS cache.

2011.12: First release—
free DNSCrypt software for Mac.

2012.02: “10’s of 1000’s more
have downloaded DNSCrypt for
Mac and are running it today.”

If Eve forges packet
DNS cache $\rightarrow$ browser,
DNSCrypt simply drops it,
waits for correct packet.

Eve can still deny service
by flooding the network—
but floods cost much more,
so Eve has fewer victims.

Clear availability benefit.

Eve still denies service
by forging packets
DNS cache $\leftrightarrow$ DNS server
or browser $\leftrightarrow$ web server.

Fix: Protect those packets too!
"DNSCurve" for DNS server,
"HTTPCurve" for HTTP server.
Have prototypes using NaCl.

Should end up reasonably easy
to deploy confidentiality,
integrity, availability
for every Internet packet.

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Answer 4: Encryption is
practically free along with
authentication. Making it optional
would be pointless complexity.

Cryptographic library APIs

Alice using a
typical cryptographic library:

Generate random AES key.
Use AES key to encrypt packet.
Hash encrypted packet.
Read RSA key from wire format.
Use key to sign hash.
Read Bob's key from wire format.
Use key to encrypt signature etc.
Convert to wire format.

Plus more code:
allocate storage,
handle errors, etc.

Gutmann cryptlib library: "high-level interface" that "provides anyone with the ability to add strong security capabilities to an application in as little as half an hour, without needing to know any of the low-level details that make the encryption or authentication work."

Alice using cryptlib:
Look at the first code segment in the cryptlib manual
("the best way to illustrate what cryptlib can do").

```
cryptCreateEnvelope(
 &cryptEnvelope,cryptUser,
 CRYPT_FORMAT_SMIME);
cryptSetAttributeString(
 cryptEnvelope,
 CRYPT_ENVINFO_RECIPIENT,
 recipientName,recipientNameLength
cryptPushData(cryptEnvelope,
 message,messageSize,
 &bytesIn);
cryptFlushData(cryptEnvelope);
cryptPopData(cryptEnvelope,
 encryptedMessage,encryptedSize,
 &bytesOut);
cryptDestroyEnvelope(cryptEnvelope
```

Start with `cryptInit`.

Also check that each function
returns `CRYPT_OK`.
(Page 35 of manual:
the wrong code without checks
is included "for clarity".)

Also loop around
`cryptPushData`, checking
`bytesIn`. (Page 53 of manual.)

Data is encrypted
without authentication.
Do more work to add signatures.

Alice using NaCl:

```
c = crypto_box(m,n,pk,sk)
```

Alice using NaCl:

`c = crypto_box(m,n,pk,sk)`

32-byte secret key `sk`.

32-byte public key `pk`.

24-byte nonce `n`.

`c` is 16 bytes longer than `m`.

All objects are C++ `std::string` variables represented in wire format, ready for storage/transmission.

If `crypto_box` runs out of memory, it raises an exception.

Bob verifying, decrypting:

```
m=crypto_box_open(c,n,pk,sk)
```

Initial key generation:

```
pk = crypto_box_keypair(&sk)
```

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Can instead use **signatures**
for public messages:

```
pk = crypto_sign_keypair(&sk)
```

64-byte secret key,
32-byte public key.

```
sm = crypto_sign(m,sk)
```

64 bytes overhead.

```
m = crypto_sign_open(sm,pk)
```

More languages

C: released.
Disadvantages: strings are
passed as pointers and lengths;
must check return value
from `crypto_*_open`.
Advantages: No heap usage.
Controlled stack usage.
Most functions cannot fail.

C++: released.

Python: bindings online
from Sean Lynch (Facebook),
Adam Langley, Jan Mojzis;
have integrated; testing.

To the extent possible, identical—purely functional—interface in every language.

Python:

```
sm = crypto_sign(m,sk)
```

C++:

```
sm = crypto_sign(m,sk)
```

C:

```
crypto_sign(sm,&smlen,
            m,mlen,sk)
```

Security features

NaCl systematically avoids
all array indices
that depend on secret data.

NaCl systematically avoids
all branch conditions
that depend on secret data.

NaCl does not decrypt
unless message is authenticated.
Verification procedure rejects
all forgeries in constant time.

NaCl has *deterministic* `crypto_box` and `crypto_sign`. Randomness only for `keypair`. Avoids PS3 signing disaster and many potential problems.

Also simplifies testing. NaCl uses automated test battery from eBACS (ECRYPT Benchmarking of Cryptographic Systems).

NaCl *pays attention to cryptanalysis* and makes very conservative choices of cryptographic primitives.

NaCl has no low-security options.

e.g. `crypto_box` always
encrypts *and* authenticates.

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Remaining risk:
Users find NaCl too slow $\Rightarrow$
switch to low-security libraries
or disable crypto entirely.

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How NaCl avoids this risk:
NaCl is exceptionally fast.
Much faster than other libraries.
Keeps up with the network.

Speed

NaCl operations per second
for any common packet size,
using AMD Phenom II X6 1100T
CPU, 189€ on kieskeurig.be:

- `crypto_box`: >80000.
- `crypto_box_open`: >80000.
- `crypto_sign_open`: >70000.
- `crypto_sign`: >180000.

Putting this into perspective:
80000 50-byte packets/second
network usage is 32 Mbps
plus per-packet overhead.

But wait, it's even faster!

1. Pure secret-key crypto
for longer packets:
80000 1500-byte packets/second
fill up a 1 Gbps link.

2. Pure secret-key crypto
for many packets
from same public key,
if application splits
`c = crypto_box(m,n,pk,sk)`
into
`k = crypto_box_beforenm(pk,sk)`
and then
`c = crypto_box_afternm(m,n,k)`.

3. Very fast rejection
of forged packets
under known public keys:
no time spent on decryption.

(This doesn't help much
for forgeries under *new* keys,
but flooded server can
continue providing fast service
to *known* keys.)

4. Fast batch verification,
doubling speed of
`crypto_sign_open`
for valid signatures.
(Not integrated yet.)

News: We've just finished initial NaCl smartphone optimizations.

800 MHz Cortex A8, 1 core, operations per second:

- `crypto_box`: 1500.
- `crypto_box_open`: 1500.
- `crypto_sign_open`: 1200.
- `crypto_sign`: 2100.

Secret-key crypto:
2.78 Gbps for authenticator.
1.14 Gbps for cipher.

Cryptographic details

The main work we did:
achieve these speeds
without compromising security.

ECC, not RSA:
much stronger security record.
Curve25519, not NSA/NIST
curves: twist-security et al.
Salsa20, not AES:
much larger security margin.
Poly1305, not HMAC:
information-theoretic security.
EdDSA, not ECDSA:
collision-resilience et al.

Tasks outside NaCl

NaCl key generation
relies completely on OS
as a source of random bytes:
e.g. `/dev/urandom`.

OS has much better access
to entropy sources than
any individual library does.

Reviewing centralized OS code
is much easier than reviewing
all the randomness-generation
code in libraries that decide
to do the job themselves.

NaCl relies on programmer
to supply a nonce `n`:
a message number, never reused.

One safe choice of nonce:
24 random bytes from the OS.

Or: 1 for first message,
2 for second message, etc.
Smaller; faster; allows
easy replay detection;
but sometimes a privacy leak.

Protocol integration

Have an unprotected protocol.
Want to apply NaCl.
What to do?

How do DNSCrypt etc. use NaCl?

Easy: Before sending a packet,
feed it to `crypto_box`.
Transmit `pk`, `n`, `c`.

When a packet arrives,
feed it to `crypto_box_open`,
and throw it away if it's bad.

How does client know
that server will tolerate
cryptographic packets?

DNSCrypt answer:
OpenDNS will tolerate
cryptographic packets.

DNSCurve answer:
Look for DNSCurve indicator
in *name* of the DNS server.

HTTPCurve answer:
Look for DNS alias (CNAME)
to an HTTPCurve indicator.

How does client find
server's public key?

DNSCrypt answer:
Use DNS TXT lookup to retrieve signed short-term public key from server. Check signature under long-term OpenDNS public key included with DNSCrypt software.

DNSCurve answer:
Look for DNSCurve public key in name of the DNS server.

HTTPCurve answer: Similar.