NaCl: Cryptography for the Internet

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Joint work with Dan Bernstein and Tanja Lange

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Workshop on Cryptography for the Internet, Tenerife, Spain
Why are we here?

- Various well understood algorithms, e.g. AES-128, RSA-2048, SHA-2, SHA-3 etc.
- Various implementations of these algorithms, bundled in libraries (e.g., OpenSSL)
- Applications simply use the libraries and the world (i.e., the Internet) is safe
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Two answers

- The above is wrong (I hope everybody here agrees)
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Two answers

- The above is wrong (I hope everybody here agrees)
- “Crypto for 2020” not only needs to fix existing problems but anticipate future ones
NaCl: A new cryptographic library

- Networking and Cryptography library (NaCl, pronounced “salt”)
- Aim: Fix the problems of crypto for the Internet
- Acknowledgment: Contributions by
  - Matthew Dempsky (Mochi Media)
  - Niels Duif (TU Eindhoven)
  - Emilia Käsper (KU Leuven, now Google)
  - Adam Langley (Google)
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This talk
- Introduce NaCl
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This talk

- Introduce NaCl
- Topics I would like to discuss in the context of NaCl
Space shuttles vs. elevators

“OpenSSL is the space shuttle of crypto libraries. It will get you to space, provided you have a team of people to push the ten thousand buttons required to do so. NaCl is more like an elevator – you just press a button and it takes you there. No frills or options.

I like elevators.”

Matthew Green in his blog entry The anatomy of a bad idea
Protecting Internet communication . . .

- Alice wants to send a message \( m \) to Bob
- Alice uses Bob’s public key and her own private key to compute an authenticated ciphertext \( c \), sends \( c \) to Bob
- Bob uses his private key and Alice’s public key to verify and recover \( m \)
... with the space-shuttle approach

- First choose algorithms and parameters, e.g. AES-128, RSA-2048, SHA-256
- Generate random AES key
- Use AES to encrypt packet
- Hash encrypted packet
- Read RSA private key from wire format
- Use key to sign hash
- Read Bob’s RSA public key from wire format
- Use key to encrypt AES key and signature
- ...
... with the space-shuttle approach

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- ... 
- Plus more code to allocate storage, handle errors etc.
... with the elevator approach

c = crypto_box(m, n, pk, sk)
... with the elevator approach

\[ c = \text{crypto\_box}(m, n, pk, sk) \]

- **sk**: Alice’s 32-byte private key
- **pk**: Bob’s 32-byte public key
- **n**: 24-byte nonce
- **c**: authenticated ciphertext, 16 bytes longer than plaintext \( m \)
... with the elevator approach

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- Bob verifies and decrypts:

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  \[ m = \text{crypto\_box\_open}(c, n, pk, sk) \]
- Initial keypair generation for Alice and Bob:
  \[ \text{pk} = \text{crypto\_box\_keypair}(\&\text{sk}) \]
Signatures in NaCl

- `crypto_box` does not use signatures but a public-key authenticator.
- Sometimes non-repudiability is required or one wants broadcast authenticated communication.

```c
pk = crypto_sign_keypair(&sk)
generates a 64-byte private key and a 32-byte public key.
sm = crypto_sign(m, sk)
signs `m` under `sk`; `sm` is 64 bytes longer than `m`.
m = crypto_sign_open(sm, pk)
verifies the signature and recovers `m`.
```
Signatures in NaCl

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- Sometimes non-repudiability is required or one wants broadcast authenticated communication.
- NaCl also contains signatures with an easy-to-use interface:

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Back to space-shuttles and elevators: Security.

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Back to space-shuttles and elevators: Security.

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“the only known free-fall incident in a modern cable-borne elevator happened in 1945 when a B-25 bomber struck the Empire State Building in fog”
http://en.wikipedia.org/wiki/Elevator
NaCl Security: No secret load addresses

- Osvik, Shamir, and Tromer in 2006: 65 ms to steal Linux dm-crypt AES key used for hard-disk encryption
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- Attack background:
  - Most AES implementations use lookup tables
  - Secret AES key influences load addresses
  - Load addresses influence cache state
  - Cache state influences measurable timings
  - Use timing measurements to compute the key
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- Obscuring the influence on timings is not very confidence inspiring
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- **NaCl systematically avoids all loads from addresses that depend on secret data**
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NaCl Security: No padding oracles

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- Attack background:
  - SSL first inverts RSA, then checks for PKCS padding (which many forgeries have)
  - Subsequent processing applies more serious integrity checks
  - Server responses reveal pattern of PKCS forgeries
  - Pattern reveals plaintext

- Typical protection: try to hide differences between padding checks and subsequent integrity checks
- Hard to get right; see, e.g., Crypto 2012 paper by Bardou, Focardi, Kawamoto, Steel, and Tsay
- NaCl does not decrypt unless ciphertext passes MAC verification
- MAC verification in NaCl rejects forgeries in constant time
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- **NaCl uses** /dev/urandom, the OS random-number generator
- Reviewing this code is much more tractable than reviewing separate RNG in every library
NaCl Security: No unnecessary randomness

▶ “Bushing”, Cantero, Boessenkool, Peter in 2010: Sony ignored ECDSA requirement of new randomness for each signature
▶ Signatures leaked PlayStation 3 code-signing key
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- NaCl uses deterministic crypto_box and crypto_sign
- Also simplifies testing: NaCl uses automated test battery by eBACS (ECRYPT Benchmarking of Cryptographic Systems)
NaCl Security: Conservative choice of primitives

- Stevens, Sotirov, Appelbaum, Lenstra, Molnar, Osvik, de Weger in 2008: rogue CA certificate, exploiting MD5 weakness
- “Flame” in 2012: New MD5 attack
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- Many applications today use RSA-1024 (Google SSL, Tor, DNSSEC)
- Shamir and Tromer in 2003: RSA-1024 is breakable (1 year, $\approx 10^7$ USD)
- Reaction by NIST and RSA labs: Move to RSA-2048 by 2010
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- **NaCl pays attention to cryptanalysis and makes very conservative choices**
- Primitives in NaCl all offer 128 bits of security
You might think that elevators are slow...

- Typical reason for low-security crypto or no crypto: speed
- For example, DNSSEC on using RSA-1024:
  
  “tradeoff between the risk of key compromise and performance...”
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▶ Typical reason for low-security crypto or no crypto: speed
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  "tradeoff between the risk of key compromise and performance..."

▶ **NaCl offers exceptionally high speeds, keeps up with the network**
▶ NaCl operations per second on AMD Phenom II X6 1100T for any reasonable packet size:
  ▶ > 80000 crypto_box
  ▶ > 80000 crypto_box_open
  ▶ > 70000 crypto_sign_open
  ▶ > 180000 crypto_sign
▶ Handles arbitrary packet floods up to ≈ 30 Mbps per CPU, depending on protocol
Even higher NaCl Speed

- Pure secret-key crypto for any packet size, 80000 packets of 1500 bytes fill up a 1 Gbps link
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- Very fast rejection of forged packets under known public keys
- Fast batch signature verification: doubling verification speed
- Also fast on mobile devices: See our CHES 2012 paper “NEON crypto”
NaCl online

http://nacl.cr.yp.to

- No license: NaCl is in the public domain
- No patents that we are aware of
Topics/Questions I’d like to discuss

- Is the “elevator approach” the right one to secure the Internet?
- What other functionalities (elevator buttons) are required?
- What important crypto-layer problems are not addressed by NaCl?
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▶ Deployment...
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- Deployment...
- NaCl for embedded devices
- Side-channel-protection requirements
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- NaCl for embedded devices
- Side-channel-protection requirements
- Importance of correctness proofs
- Importance of post-quantum NaCl