Rosenpass

Securing & Deploying Post-Quantum WireGuard

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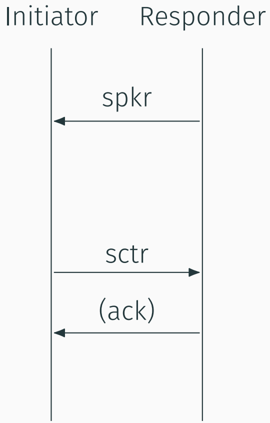
RWPQC23 | https://rosenpass.eu/whitepaper.pdf

Structure of the talk

- Post-quantum WireGuard[1]: How to build an interactive key exchange from KEMs
- Contribution: State Disruption Attacks & cookies as a defense
- Contribution: Symbolic analysis of the Rosenpass protocol
- Contribution: Noise-like specification
- Contribution: New hashing & domain separation scheme
- Contribution: Reference implementation – Securing WireGuard in practice

[1] Andreas Hülsing, Kai-Chun Ning, Peter Schwabe, Florian Weber, and Philip R. Zimmermann. "Post-quantum WireGuard". In: 42nd IEEE Symposium on Security and Privacy, SP 2021, San Francisco, CA, USA, 24-27 May 2021. Full version: https://eprint.iacr.org/2020/379

Post-quantum WireGuard: Three encapsulations



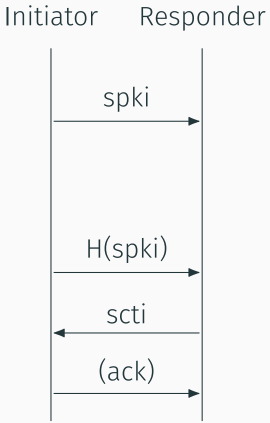
Initiator Responder

spkr

sctr

(ack)

Responder Auth



Initiator Responder

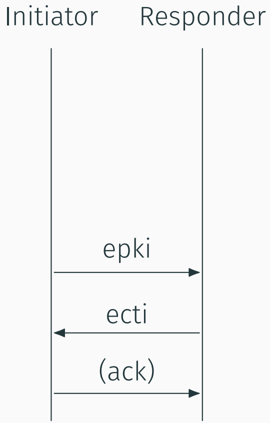
spki

H(spki)

scti

(ack)

Initiator Auth



Initiator Responder

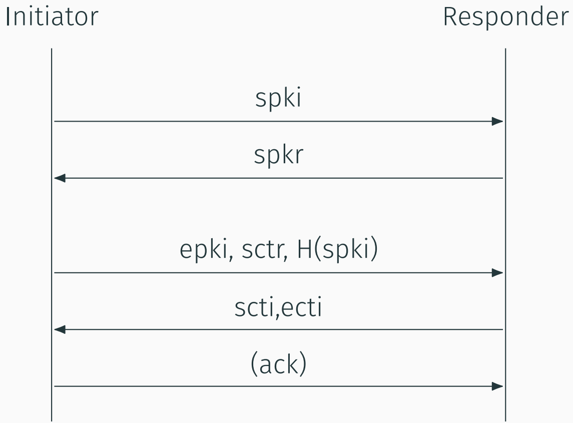
epki

ecti

(ack)

Forward secrecy

Combining the three encapsulations in one protocol



Initiator

Responder

spki

spkr

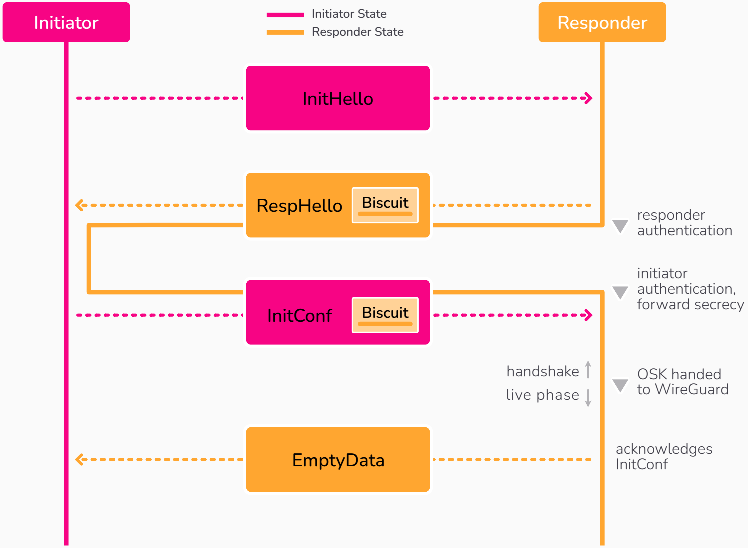
epki, sctr, H(spki)

scti,ecti

(ack)

Note that the initiator is not authenticated until they send “(ack)”.

The Rosenpass protocol



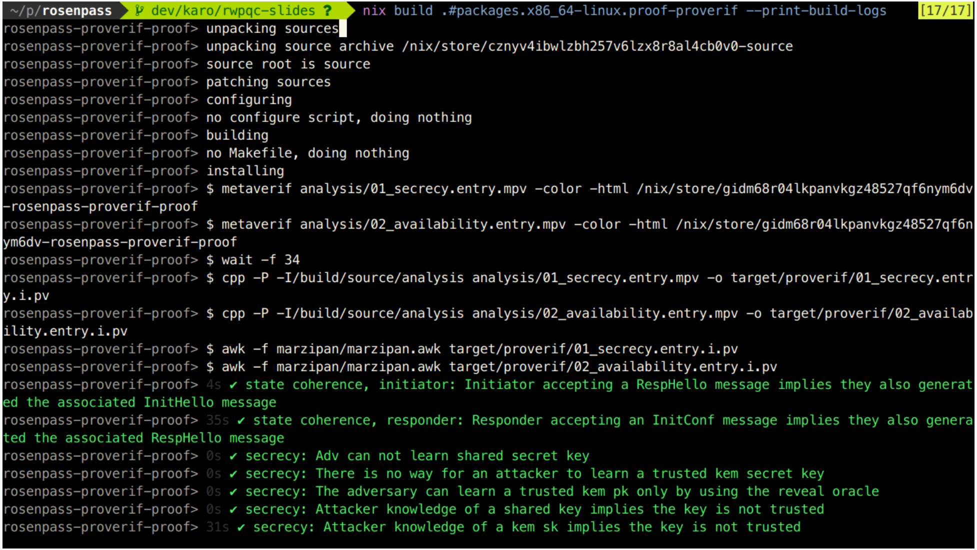
CVE-2021-46873 – DOS against WireGuard through NTP

- The replay protection in classic WireGuard assumes a monotonic counter
- But the system time is attacker controlled because NTP is insecure
- This generates a kill packet that abuses replay protection and renders the initiator’s key-pair useless
- Attack is possible in the real world!
- Similar attack in post-quantum WireGuard is worse since InitHello is unauthenticated
- Solution: Biscuits

Security analysis of rosenpass

- CryptoVerif in progress
- Symbolic analysis using ProVerif
- Code is part of the software repository & build system
- Symbolic analysis is fast (about five minutes), runs in parallel and is

ProVerif in technicolor



```
~/p/rosenpass  dev/karo/rwpqc-slides ?  nix build .#packages.x86_64-linux.proof-proverif --print-build-logs   [17/17]
rosenpass-proverif-proof> unpacking sources
rosenpass-proverif-proof> unpacking source archive /nix/store/cznyv4ibwlzbh257v6lzx8r8al4cb0v0-source
rosenpass-proverif-proof> source root is source
rosenpass-proverif-proof> patching sources
rosenpass-proverif-proof> configuring
rosenpass-proverif-proof> no configure script, doing nothing
rosenpass-proverif-proof> building
rosenpass-proverif-proof> no Makefile, doing nothing
rosenpass-proverif-proof> installing
rosenpass-proverif-proof> $ metaverif analysis/01_secrecy.entry.mpv -color -html /nix/store/gidm68r04lkpanvkgz48527qf6nym6dv
-rosenpass-proverif-proof
rosenpass-proverif-proof> $ metaverif analysis/02_availability.entry.mpv -color -html /nix/store/gidm68r04lkpanvkgz48527qf6n
ym6dv-rosenpass-proverif-proof
rosenpass-proverif-proof> $ wait -f 34
rosenpass-proverif-proof> $ cpp -P -I/build/source/analysis analysis/01_secrecy.entry.mpv -o target/proverif/01_secrecy.entr
y.i.pv
rosenpass-proverif-proof> $ cpp -P -I/build/source/analysis analysis/02_availability.entry.mpv -o target/proverif/02_availab
ility.entry.i.pv
rosenpass-proverif-proof> $ awk -f marzipan/marzipan.awk target/proverif/01_secrecy.entry.i.pv
rosenpass-proverif-proof> $ awk -f marzipan/marzipan.awk target/proverif/02_availability.entry.i.pv
rosenpass-proverif-proof> 4s ✔ state coherence, initiator: Initiator accepting a RespHello message implies they also generat
ed the associated InitHello message
rosenpass-proverif-proof> 35s ✔ state coherence, responder: Responder accepting an InitConf message implies they also genera
ted the associated RespHello message
rosenpass-proverif-proof> 0s ✔ secrecy: Adv can not learn shared secret key
rosenpass-proverif-proof> 0s ✔ secrecy: There is no way for an attacker to learn a trusted kem secret key
rosenpass-proverif-proof> 0s ✔ secrecy: The adversary can learn a trusted kem pk only by using the reveal oracle
rosenpass-proverif-proof> 0s ✔ secrecy: Attacker knowledge of a shared key implies the key is not trusted
rosenpass-proverif-proof> 31s ✔ secrecy: Attacker knowledge of a kem sk implies the key is not trusted
```

Noise-like specification (easier for engineers)

Initiator Code | Responder Code | Comments

1 InitHello { sidi, epki, sctr, pidiC, auth } 2

Line	Variables	← Action	Variables	← Action	Line	Comment
IHI1	ck	← lhash("chaining key init", spkr)	ck	← lhash("chaining key init", spkr)	IHR1	Initialize the chaining key, and bind to the responder's public key.
IHI2	sidi	← random_session_id();				The session ID is used to associate packets with the handshake state.
IHI3	eski, epki	← EKEM::keygen();				Generate fresh ephemeral keys, for forward secrecy.
IHI4		mix(sidi, epki);		mix(sidi, epki)	IHR4	InitHello includes sidi and epki as part of the protocol transcript, and so we mix them into the chaining key to prevent tampering.
IHI5	sctr	← encaps_and_mix<SKEM>(spkr);		decaps_and_mix<SKEM>(sskr, spkr, ct1)	IHR5	Key encapsulation using the responder's public key. Mixes public key, shared secret, and ciphertext into the chaining key, and authenticates the responder.
IHI6	pidiC	← encrypt_and_mix(pidi);	spki, psk	← lookup_peer(decrypt_and_mix(pidiC))	IHR6	Tell the responder who the initiator is by transmitting the peer ID.
IHI7		mix(spki, psk);		mix(spki, psk);	IHR7	Ensure the responder has the correct view on spki. Mix in the PSK as optional static symmetric key, with epki and spkr serving as nonces.
IHI8	auth	← encrypt_and_mix(empty())		decrypt_and_mix(auth)	IHR8	Add a message authentication code to ensure both participants agree on the session state and protocol transcript at this point.

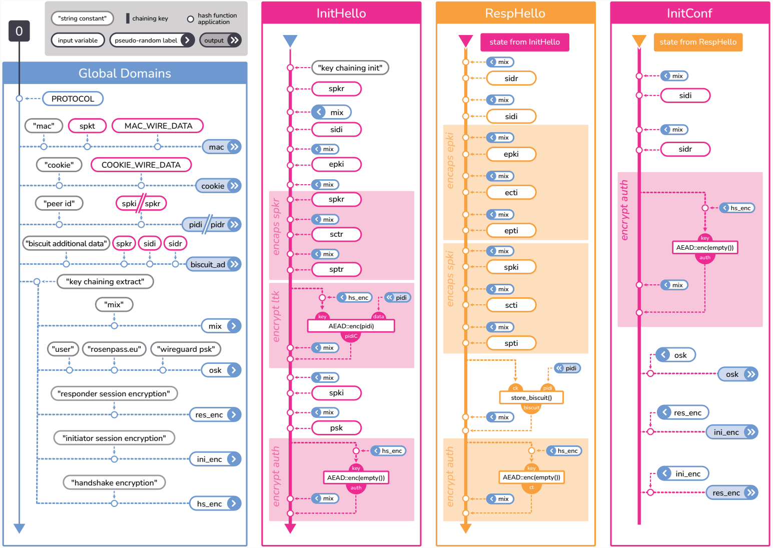
4 RespHello { sidr, sidi, ecti, scti, biscuit, auth } 3

Line	Variables	← Action	Variables	← Action	Line	Comment
RHI1			sidr	← random_session_id()	RHR1	Responder generates a session ID.
RHI2	ck	← lookup_session(sidi);			RHR2	Initiator looks up their session state using the session ID they generated.
RHI3		mix(sidr, sidi);		mix(sidr, sidi);	RHR3	Mix both session IDs as part of the protocol transcript.
RHI4		decaps_and_mix<EKEM>(eski, epki, ecti);	ecti	← encaps_and_mix<EKEM>(epki);	RHR4	Key encapsulation using the ephemeral key, to provide forward secrecy.
RHI5		decaps_and_mix<SKEM>(sski, spki, scti);	scti	← encaps_and_mix<SKEM>(spki);	RHR5	Key encapsulation using the initiator's static key, to authenticate the initiator, and non-forward-secret confidentiality.
RHI6		mix(biscuit)	biscuit	← store_biscuit();	RHR6	The responder transmits their state to the initiator in an encrypted container to avoid having to store state.
RHI7		decrypt_and_mix(auth)	auth	← encrypt_and_mix(empty());	RHR7	Add a message authentication code for the same reason as above.

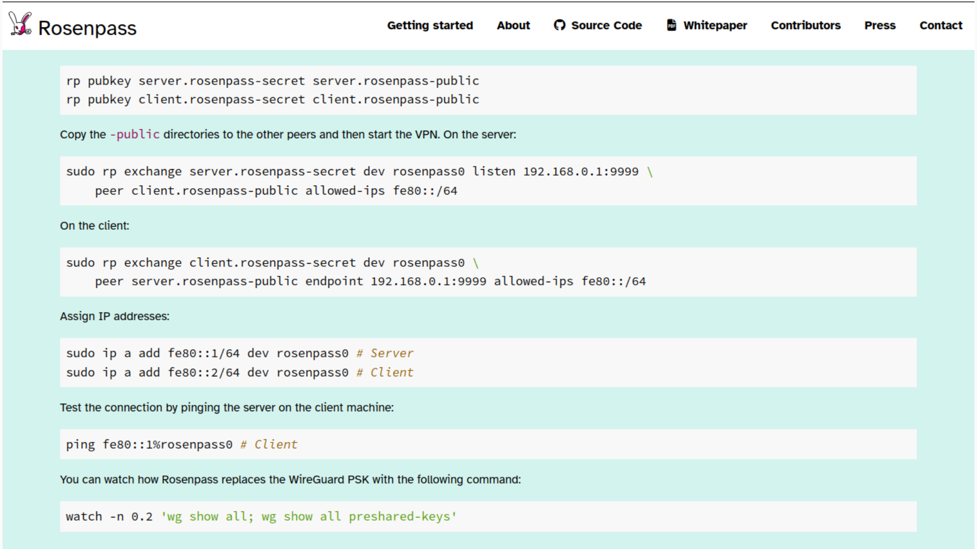
5 InitConf { sidi, sidr, biscuit, auth } 6

Line	Variables	← Action	Variables	← Action	Line	Comment
ICI1			biscuit_no	← load_biscuit(biscuit);	ICR1	Responder loads their biscuit. This restores the state from after RHR6.
ICI2				encrypt_and_mix(empty());	ICR2	Responder recomputes RHR7, since this step was performed after biscuit encoding.
ICI3		mix(sidi, sidr);		mix(sidi, sidr);	ICR3	Mix both session IDs as part of the protocol transcript.
ICI4	auth	← encrypt_and_mix(empty);		decrypt_and_mix(auth);	ICR4	Message authentication code for the same reason as above, which in particular ensures that both participants agree on the final chaining key.
ICI5				assert(biscuit_no > biscuit_used);	ICR5	Biscuit replay detection.
ICI6			biscuit_used	← biscuit_no;	ICR6	Biscuit replay detection.
ICI7		enter_live();		enter_live();	ICR7	Derive the transmission keys, and the output shared key for use as WireGuard's PSK.

New Hashing/Domain separation scheme



Reference implementation in rust, deploying post-quantum-secure WireGuard



```
rp pubkey server.rosenpass-secret server.rosenpass-public
rp pubkey client.rosenpass-secret client.rosenpass-public
```

Copy the `-public` directories to the other peers and then start the VPN. On the server:

```
sudo rp exchange server.rosenpass-secret dev rosenpass0 listen 192.168.0.1:9999 \
    peer client.rosenpass-public allowed-ips fe80::/64
```

On the client:

```
sudo rp exchange client.rosenpass-secret dev rosenpass0 \
    peer server.rosenpass-public endpoint 192.168.0.1:9999 allowed-ips fe80::/64
```

Assign IP addresses:

```
sudo ip a add fe80::1/64 dev rosenpass0 # Server
sudo ip a add fe80::2/64 dev rosenpass0 # Client
```

Test the connection by pinging the server on the client machine:

```
ping fe80::1%rosenpass0 # Client
```

You can watch how Rosenpass replaces the WireGuard PSK with the following command:

```
watch -n 0.2 'wg show all; wg show all preshared-keys'
```