Cryptographic aspects in WireGuard, a modern VPN protocol

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Telsy

www.telsy.com

- Founded in 1971
- Today 100% part of TIM group
- Focused on cryptography and cybersecurity
- Both governmental (B2G) and business (B2B) markets
- Under Golden Power
- Strong research activity

What is WireGuard?

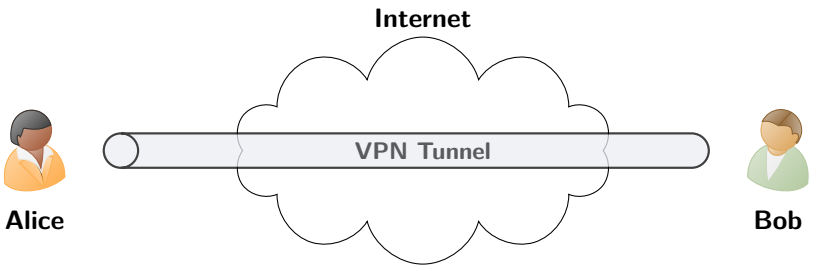
- modern VPN protocol presented in 2016 by Jason A. Donenfeld [Don17]
- merged into Linux kernel in 2020
- better performance than the other VPNs such as IPsec, OpenVPN
- designed with ease-of-implementation and simplicity in mind

Outline

1- Network aspects

VPN (Virtual Private Network)

- to establish a virtual secure connection
- tunneling protocol



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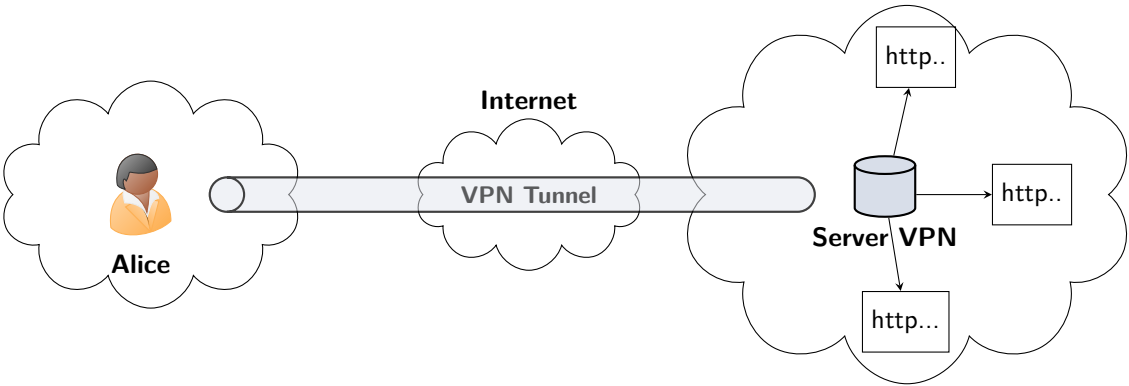

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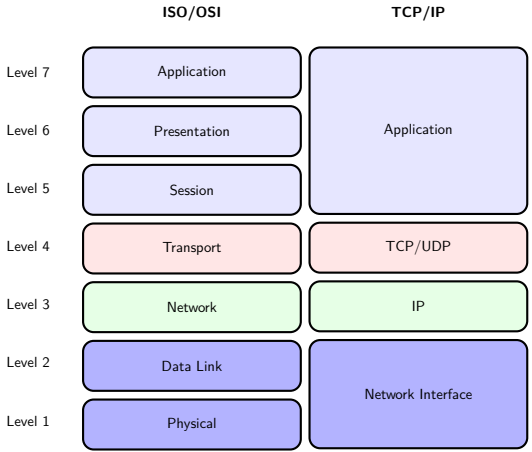
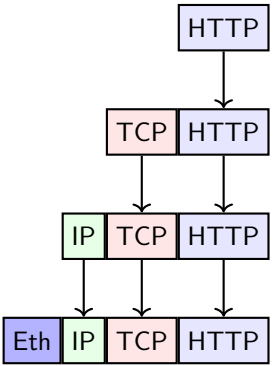
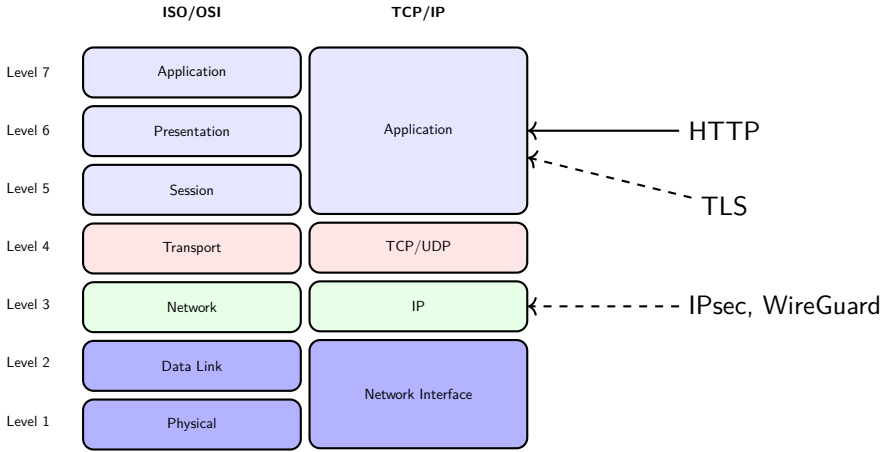
Communication Models





Where is encryption used?

Communication Models



Where is encryption used?

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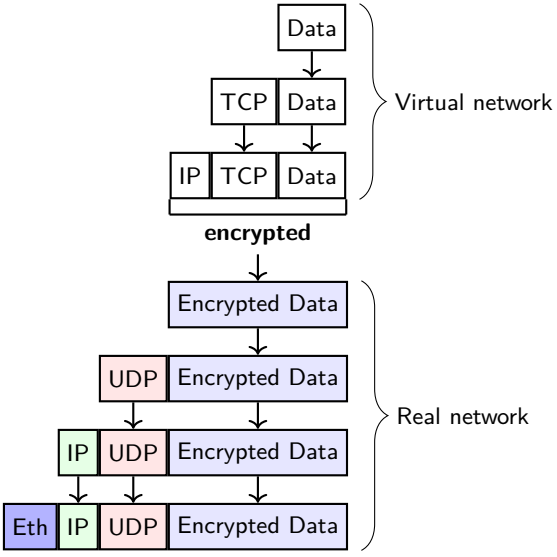
WireGuard Packet



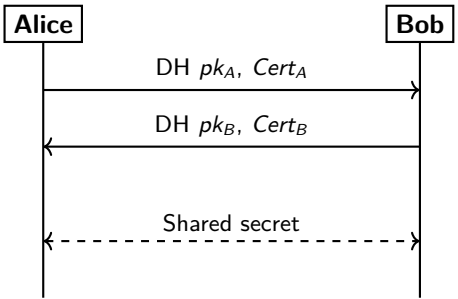
2- Authenticated Key Exchange

Authenticated Key Exchange

- Interactive method for establishing one or more shared secrets which provides (mutual) authentication
- Security against active adversaries
- Cryptographic properties:
  - Forward secrecy (FS or PFS)
  - Key-Compromise Impersonation (KCI) attacks resistance
  - Replay attacks resistance
- Other desirable properties:
  - Denial of Service (DoS) attacks mitigation
  - Identity hiding of static public keys

Authenticated Key Exchange - Design

- Starting point: authenticated (certified) static keys
- Typically, AKEs use Diffie-Hellman for key exchange



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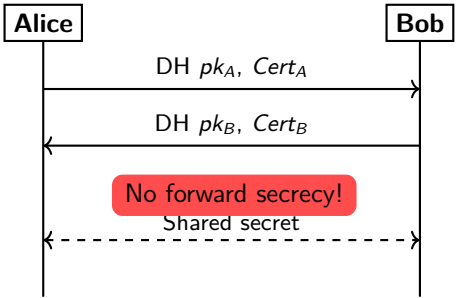
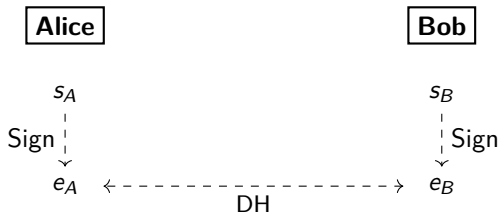


$\Longrightarrow$ Use ephemeral keys

Combine ephemeral keys with static authenticated keys

Authenticated Key Exchange - Design

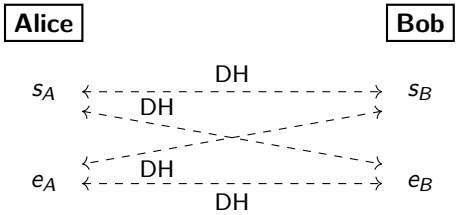
With signature
(explicit authentication)



adopted in

- TLS
- OpenVPN
- IPsec

Without signature
(implicit authentication)

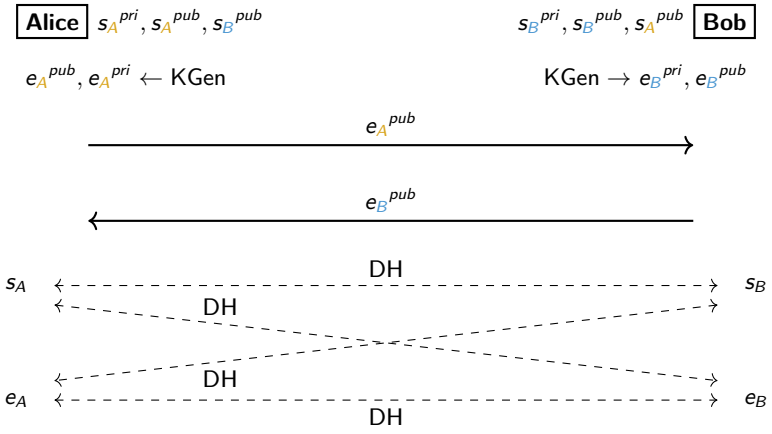


adopted in

- WhatsApp (client-server)
- Signal (X3DH)
- Noise protocol framework [Per18]
- WireGuard

3- WireGuard Protocol

Towards WireGuard Protocol



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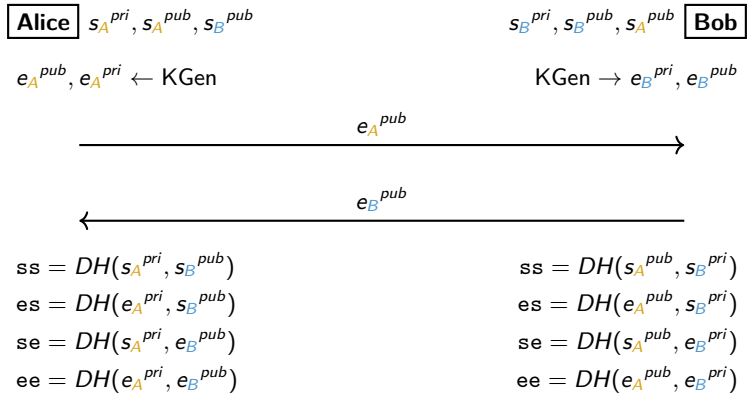

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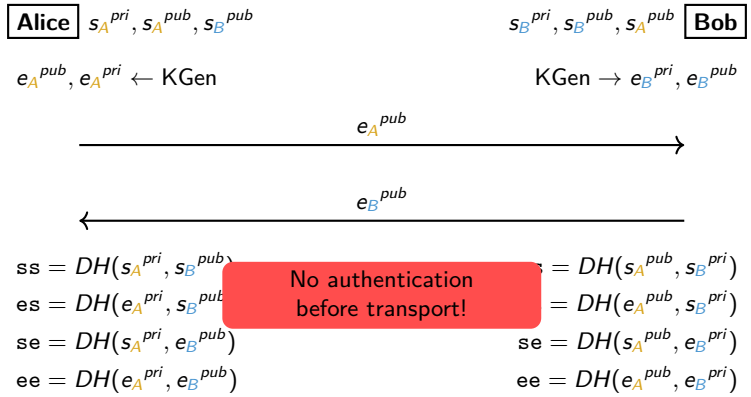
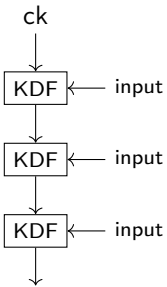


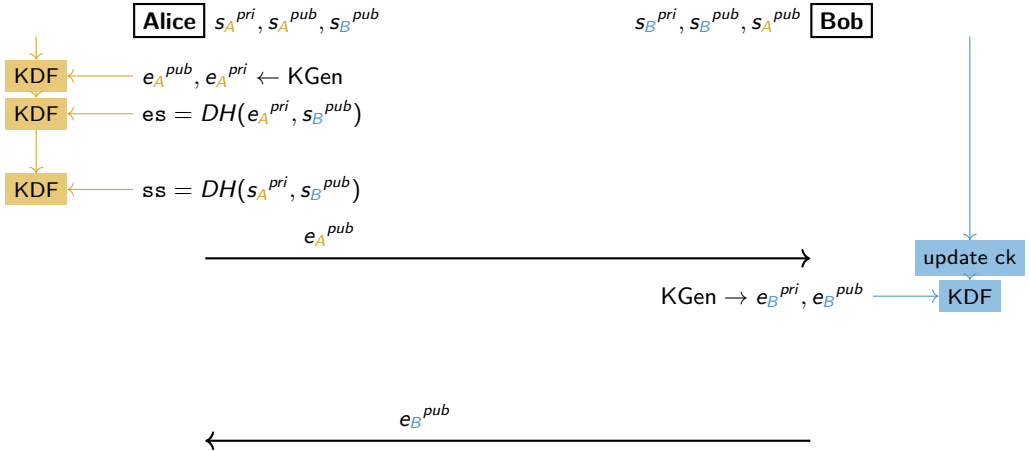
Valuable Ingredients

- KDF (Key Derivation Function)
- Chaining Key



- AEAD (Authenticated Encryption with Associated Data)

Towards WireGuard Protocol



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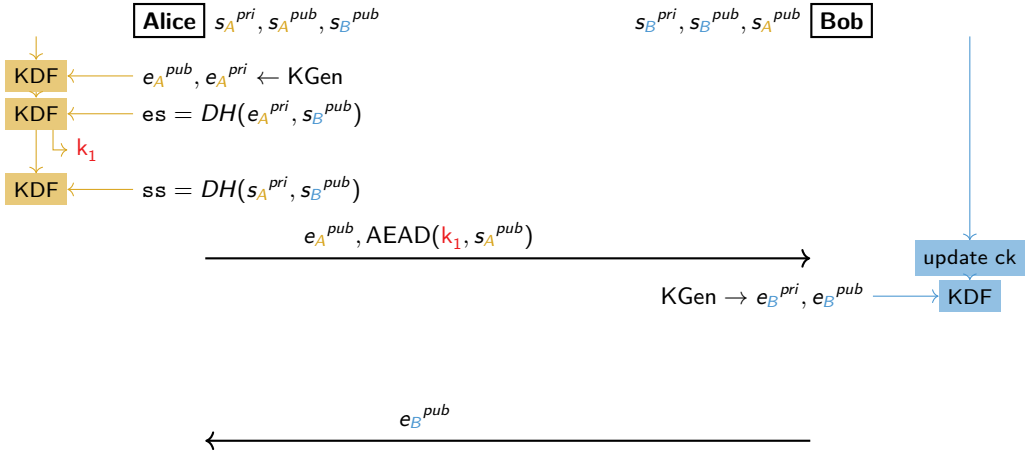

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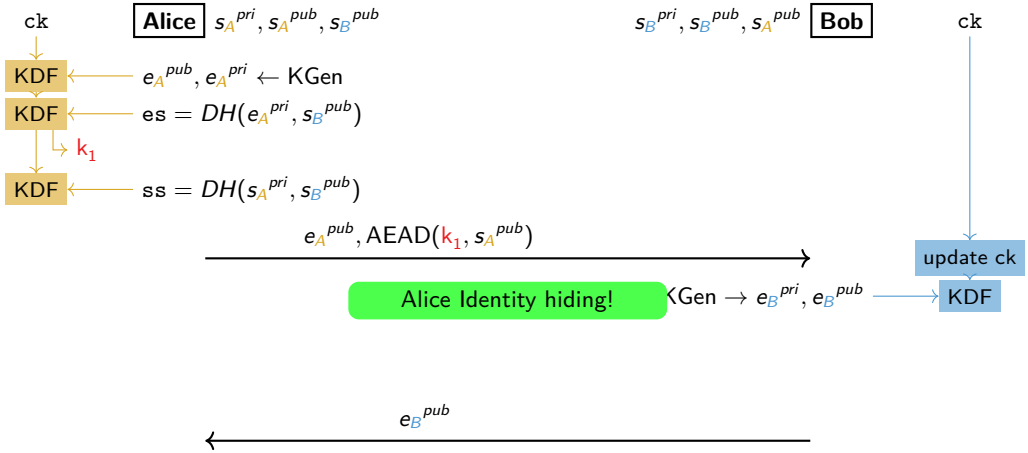

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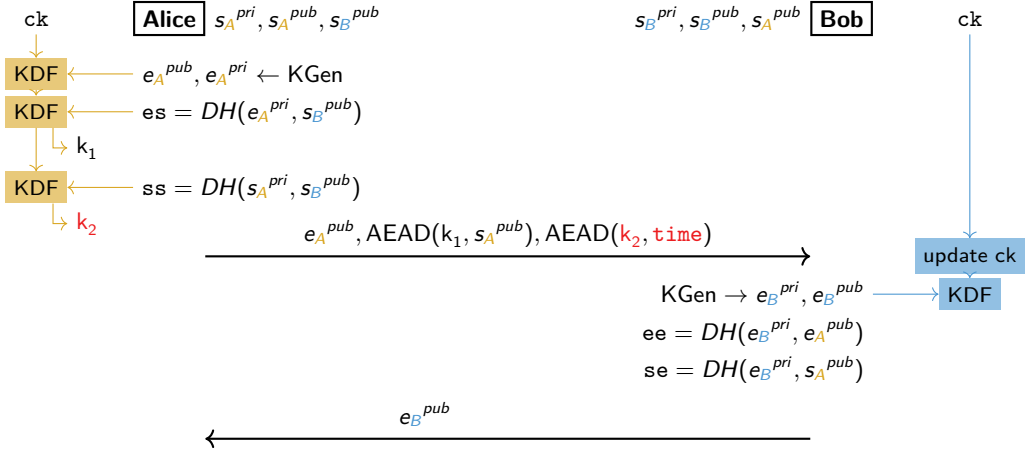

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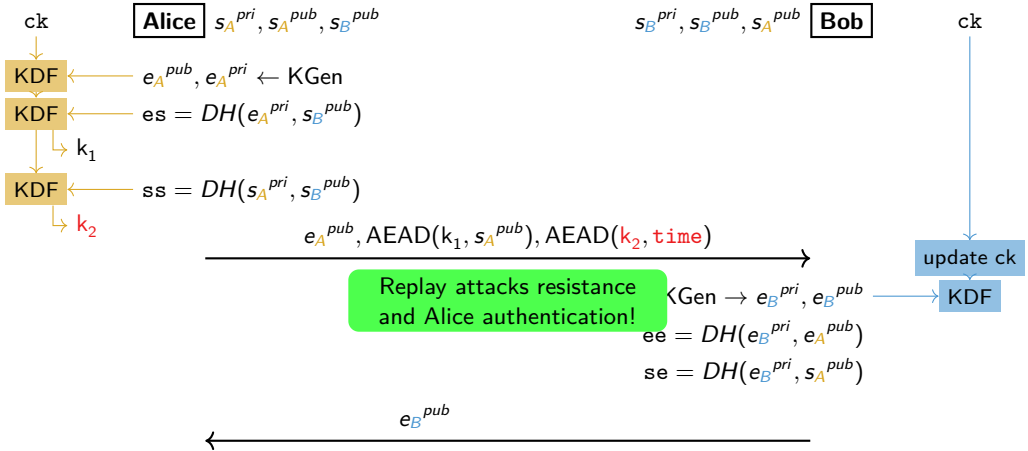

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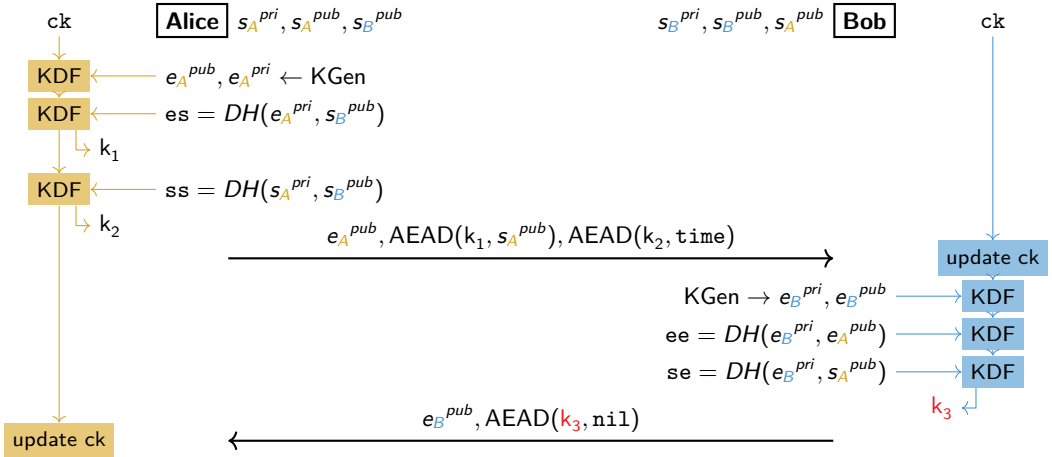

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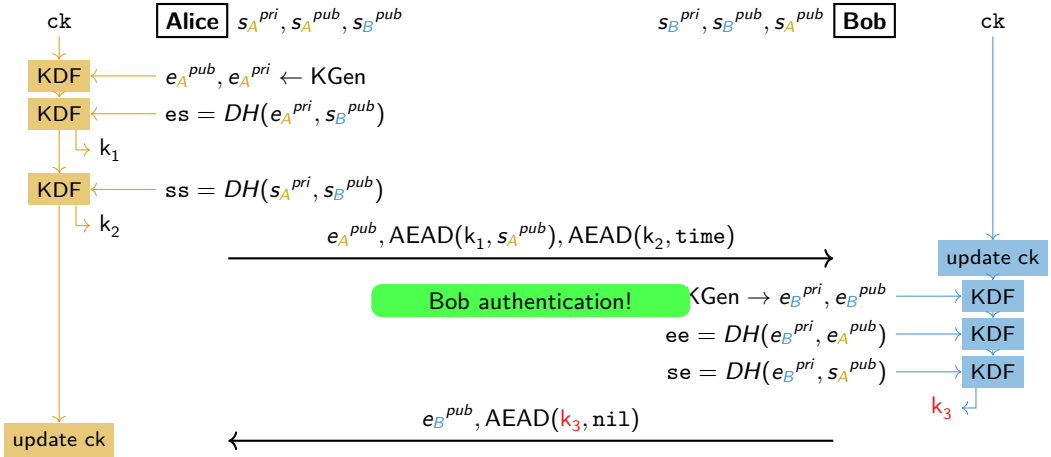

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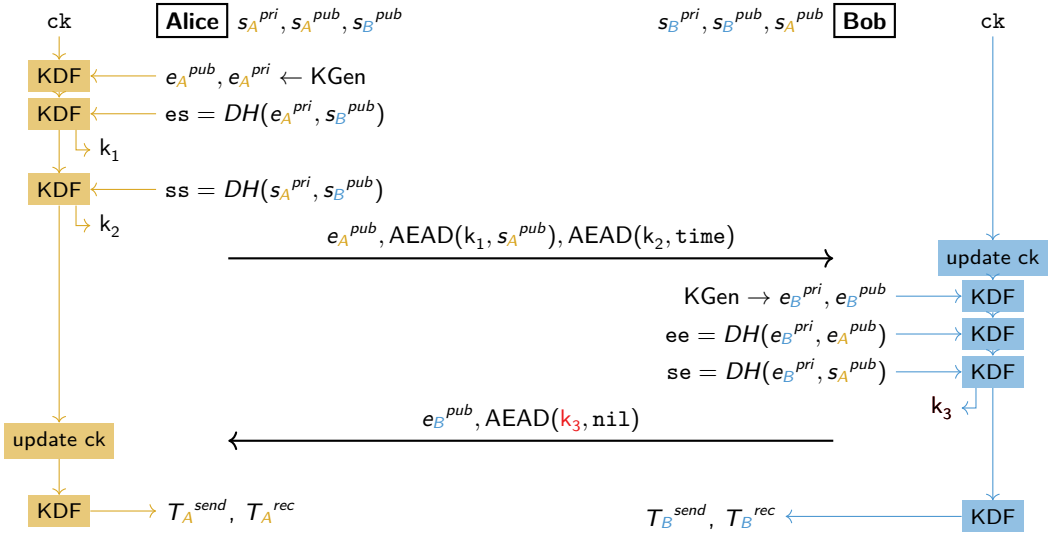

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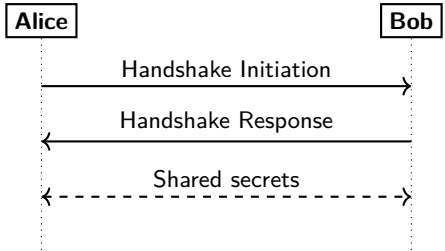
4- Other Security Considerations

Primitives and no negotiation phase



- No negotiation phase. Reduces the number of handshake packets and eliminate any potential negotiation attacks.
- Opinionated choice of cryptography. Supported Crypto Suite:
  - **DH**: X25519
  - **AEAD**: ChaCha20-Poly1305
  - **Hash**: Blake2s
  - **KDF**: HKDF with HMAC-BLAKE2s

Post-Quantum Cryptography in WireGuard

WireGuard proposes an optional pre-shared symmetric key to achieve post-quantum confidentiality

Totally PQ solution

Post-quantum WireGuard, Hülsing et al. [Hül+21]

- maintain all security properties
- McEliece for static keys
- a Saber variant for ephemeral keys

Hybrid solution

Combine classic cryptography with post-quantum cryptography.

- DH are replaced with KEMs that are interactive
- Post-quantum keys and ciphertexts are bigger than the classic ones.

Security properties

Formal verifications

- Computational proof in eCK-PFS-PSK model, Benjamin Dowling and Kenneth G. Paterson [DP18]
- Symbolic verification using Tamarin, Jason A. Donenfeld and Kevin Milner [DM17]

- Key confidentiality
- Key uniqueness
- Authentication
- Forward-secrecy
- KCI attack resistance
- Replay attack resistance
- DDos mitigation
- Identity hiding

Conclusions

WireGuard strengths:

- Easily implemented
- No negotiation phase
- Opinionated choice of primitives

security efficiency auditability

References

[DM17] Jason A Donenfeld and Kevin Milner. "Formal verification of the WireGuard protocol". In: *Technical Report, Tech. Rep* (2017).

[Don17] Jason A Donenfeld. "Wireguard: next generation kernel network tunnel.". In: *NDSS*. 2017, pp. 1–12.

[DP18] Benjamin Dowling and Kenneth G Paterson. "A cryptographic analysis of the WireGuard protocol". In: *International Conference on Applied Cryptography and Network Security*. Springer. 2018, pp. 3–21.

[Hül+21] Andreas Hülsing, Kai-Chun Ning, Peter Schwabe, Florian Weber, and Philip R Zimmermann. "Post-quantum wireguard". In: *2021 IEEE Symposium on Security and Privacy (SP)*. IEEE. 2021, pp. 304–321.

[Per18] Trevor Perrin. "The Noise protocol framework". In: *PowerPoint Presentation* (2018).

Thanks for your attention

Q&A

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