FROST: Flexible Round-Optimized Schnorr Threshold Signatures

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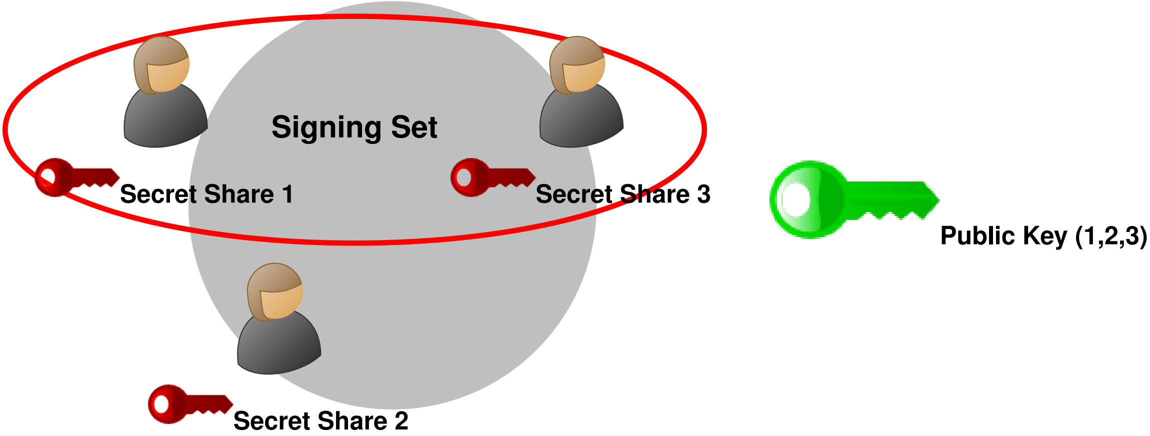
Selected Areas in Cryptography, October 2020

CrySP
Cryptography, Security, and Privacy
— Research Group @ uWaterloo —

ZF

Threshold Signatures: Joint Public Key, Secret-Shared Private Key



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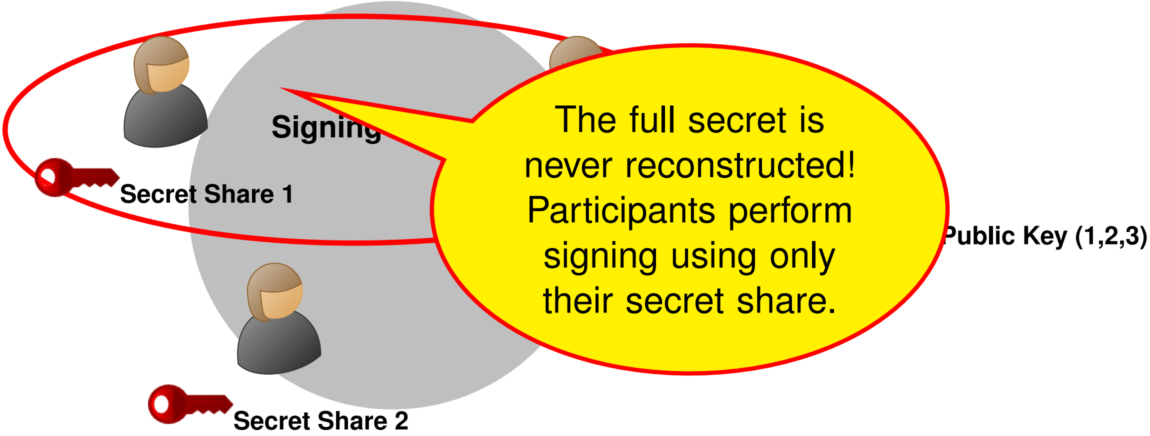

Contributions of FROST

- Two-round threshold signing protocol, or single-round protocol with preprocessing
- Signing operations are secure when performed concurrently, improving upon prior similar schemes.
- Signing can be performed with a threshold t number of signers, where t can be less than the number of possible signers n.
- Secure against an adversary that controls up to $t - 1$ signers.

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Tradeoffs Among Constructions

- **Number of Signing Rounds:** Required network rounds to generate one signature.
- **Robust:** Can the protocol complete when participants misbehave?
- **Required Number of Signers:** Can a signature be created by just t participants, or are all n needed?
- **Parallel Secure:** Can signing operations be done in parallel without a reduction in security (Drijvers attack)?

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Tradeoffs Among Constructions

	Num. Rounds	**Robust**	**Num. Signers**	**Parallel Secure**
Stinson Strobl	4	Yes	t	Yes
Gennaro et al.	1 w/ preprocessing	No	n	No
FROST	1 w/ preprocessing	No	t	Yes

Single-Party Schnorr Signing and Verification

Signer

Verifier

$(x, Y) \leftarrow KeyGen()$

$$\xleftarrow{(m, Y)}$$

$k \xleftarrow{\$} \mathbb{Z}_q$

$R = g^k \in \mathbb{G}$

$c = H(R, Y, m)$

$z = k + c \cdot x$

$$\xrightarrow{(m, \sigma = (R, z))}$$

$c = H(R, Y, m)$

$R' = g^z \cdot Y^{-c}$

Output $R \stackrel{?}{=} R'$

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FROST Keygen

- Can be performed by either a trusted dealer or a Distributed Key Generation (DKG) Protocol
- The DKG is an n-wise Shamir Secret Sharing protocol, with each participant acting as a dealer
- After KeyGen, each participant holds secret share s_i and public key Y_i (used for verification during signing) with joint public key Y.

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FROST Preprocess

Participant i

Commitment Server

$((d_{ij}, e_{ij}), \ldots) \xleftarrow{\$} \mathbb{Z}_q^* \times \mathbb{Z}_q^*$

$(D_{ij}, E_{ij}) = (g^{d_{ij}}, g^{e_{ij}})$

Store $((d_{ij}, D_{ij}), (e_{ij}, E_{ij}), \ldots)$

$$\xrightarrow{((D_{ij}, E_{ij}), \ldots)}$$

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FROST Sign

Signer i

Signature Aggregator

$B = ((1, D_1, E_1), \ldots, (t, D_t, E_t))$

(m, B)

$\longleftarrow$

$\rho_\ell = H_1(\ell, m, B), \ell \in S$

$$R = \prod_{\ell \in S} D_\ell \cdot (E_\ell)^{\rho_\ell}$$

$c = H_2(R, Y, m)$

$z_i = d_i + (e_i \cdot \rho_i) + \lambda_i \cdot s_i \cdot c$

z_i

$\longrightarrow$

Publish $\sigma = (R, z = \sum z_i)$

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“binding value” to bind signing shares to ℓ, m, and B

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This step cannot be inverted by anyone who does not know (d_i, e_i).

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Signature format and verification are identical to single-party Schnorr.

Security against Drijvers

Without $\rho_\ell = H_1(\ell, m, B)$, an adversary could produce a c^* such that:

$$c^* = H(R^*, Y, m^*) = \sum_{i=1}^{k} H(R_i, Y, m_i) = \sum c_i \text{ for some } (R_i, m_i), \ldots$$

,

After sending receiving the victim's z_i for each (R_i, m_i), the adversary can produce a valid forgery $\sigma^* = (R^*, z)$, as

$$z = \sum d_i + e_i + \lambda_t \cdot s_t \cdot \sum c_i = \sum d_i + e_i + \lambda_t \cdot s_t \cdot c^*$$

The binding factor in FROST makes each z_i strongly tied to (m_i, R_i).

$$z = \sum d_i + (e_i * \rho_i) + \lambda_t \cdot s_t \cdot \sum c_i$$

Resulting in an invalid signature: $R^* \neq g^z \cdot Y^{-c}$

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- Total bandwidth overhead scales quadratically
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Real-World Applications

- Use in cryptocurrency (Zcash) protocols for signing transactions
- Consideration for standardization by CFRG
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