Light-Weight, Delay-Aware and Scalable Authentication for Smart-Grid System

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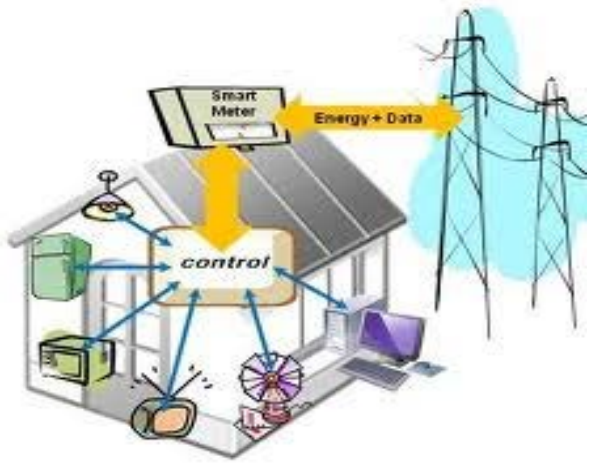
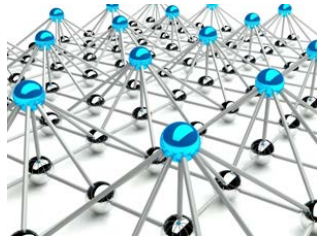
Research Need: Fast and Scalable Authentication

- **Critical vulnerabilities for smart-grids:**
  - False data injection attacks
  - Tampering commands
  - Cascade failures



- **Authentication of commands/measurements is vital!**
  - **Real-time:** 60-120 messages per second
  - **Scalable:** Broadcast authentication for large number of components



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Research Gap: Lack of Real-time Signatures

- **Symmetric crypto methods:** Unscalable for large distributed systems, lack of non-repudiation and public verifiability.

- **Traditional PKC Signatures:** (e.g., RSA [2], ECDSA [3], and Schnorr [4])
  - High computational cost, they require modular exponentiation (ExpOp) at the signer side.

- **Pre-computation:** Token-ECDSA [5] and online/offline signatures [6,7] do not require ExpOp at the signer side.
  - Linear memory overhead, K items require storing O(K) keys at the signer.

- **One-time/multiple-time Signatures:** (e.g., HORS [8])
  - They are computationally very efficient.
  - Very large signature size (2.5/5 KB) and communication overhead
  - Very large one-time public key (5 KB) for each item to be signed

Our Contribution: A new Real-Time Signature

- Structure-Free Compact Real-Time Authentication (SCRA [1])
- **Generic Design:** Transform **any** aggregate signature into a fast signing signature.
- **Ultra-Low End-to-End Delay:** SCRA schemes offer the lowest end-to-end delay among their counterparts.
  - SCRA-C-RSA: It is 7 and 19 times faster than ECDSA (pre-computed) and RSA, respectively.
- **Compact Signatures:** The signature size is almost identical to base schemes with all these improved efficiencies.
- **Limitation:** A small constant-size table stored at the signer side (highly feasible even for some embedded devices).

Main Idea: Generic SCRA from Aggregate Signatures

- **Observation:** Signature aggregation is much faster than signature generation.
- Create offline signature components to be combined (aggregated) online!
  - d-bit hash output is split into b-bit L sub-field
  - *Asig* is an aggregate digital signature scheme
  - *P* is a random padding

Pre-compute signature table **Γ** **(offline)**

Field 1 (b-bit)	Field 2 (b-bit)	.....	Field L (b-bit)
$\sigma_{1,0} = Asig_{sk}(1 \| 0 \| P)$	$\sigma_{2,0} = Asig_{sk}(2 \| 0 \| P)$		$\sigma_{L,0} = Asig_{sk}(L \| 0 \| P)$
$\vdots$	$\vdots$		$\vdots$
$\sigma_{1,2^b-1} = Asig_{sk}(1 \| 2^b - 1 \| P)$	$\sigma_{2,2^b-1} = Asig_{sk}(2 \| 2^b - 1 \| P)$		$\sigma_{L,2^b-1} = Asig_{sk}(L \| 2^b - 1 \| P)$

Sign **(online)**

(M||r), |r|= κ-bit random number $\Longrightarrow$ $(M_1^*,...,M_L^*) \leftarrow H(M \| r)$ b-bit indexes

Field 1 (b-bit)	Field 2 (b-bit)	.....	Field L (b-bit)
σ_1'	σ_2'		σ_L'

Fetch corresponding signatures from table **Γ** and aggregate them

$$s \leftarrow Asig.Agg(\sigma_1',...,\sigma_L') \Longrightarrow \sigma = (s, r)$$

Verify **(online)**

$$(M_1^*,...,M_L^*) \leftarrow H(M \| r)$$

$$\{0,1\} \leftarrow Asig.Ver(\langle 1 \| M_1^* \| P,...,L \| M_L^* \| P \rangle, s, PK)$$

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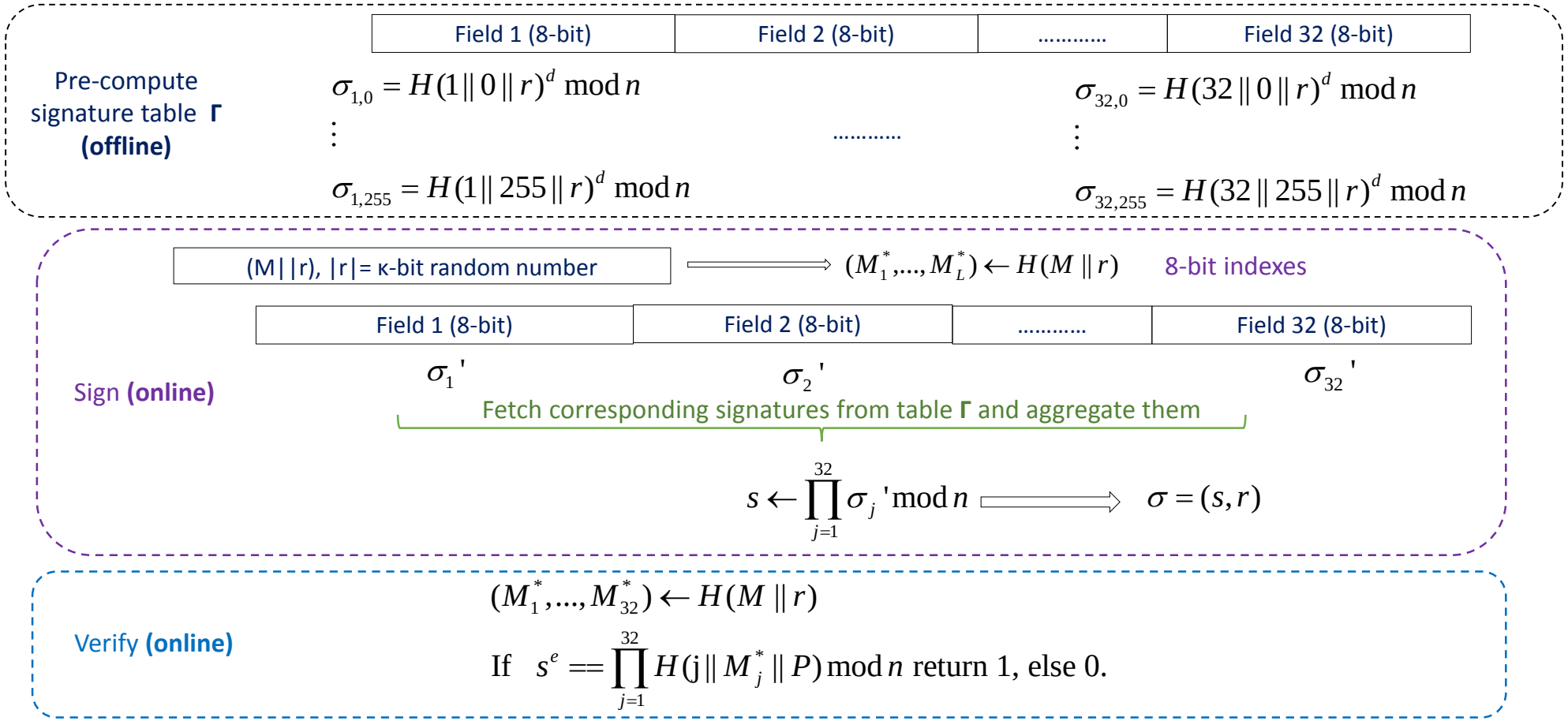
SCRA-C-RSA Instantiation

- C-RSA signature aggregation is just a modular multiplication and verification is very efficient ➔ Overall end-to-end delay is very low!



Performance Comparison (Commodity HW)

Protocol	Signing (ms)	Verification (ms)	End-to-End (ms)
ECDSA (pre-computed)	0.65	0.82	1.47
RSA	3.94	0.02	3.96
BGLS	0.46	34.00	34.46
NTRU	2.481	0.493	2.974
SCRA-C-RSA	**0.1639**	0.0513	**0.2152**
SCRA-BGLS	**0.0251**	34.21	**34.2351**
SCRA-NTRU	**0.0048**	0.507	**0.5118**

SCRA-C-RSA: Lowest end-to-end delay with mid-size table (2 MB)
SCRA-NTRU: Fastest signing with large-size table (12.33 MB)
SCRA-BGLS: The smallest table with larger delay (160 KB)

- We extended SCRA implementations to GPU setting with our collaborators!

Future Research Directions

- **Post-Quantum (PQ) Public Key Infrastructure (PKI) for Smart-Grid System**

- There are recently proposed efficient PQ key exchange schemes (e.g., New Hope [11]).

- There is a significant research gap in PQ authentication, especially for resource-limited devices.
  - We will develop new digital signature schemes, and **create a practical PQ PKI** to protect smart grids.
  - Such a PKI will have broader impact: e-commerce, Bitcoin infrastructure and IoT systems.

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