The Picnic Digital Signature Algorithm

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Picnic Overview

Security depends only on problems related to symmetric key primitives

- Secure hash function (ROM/QROM analysis implies all the usual properties: CR, PR, etc.)
- Secure block cipher (key recovery given a single plaintext/ciphertext pair)
- Unique design, conservative assumptions

The core of Picnic is an efficient zero knowledge proof for binary circuits

- Create a signature scheme using a non-interactive proof
- Use the Fiat-Shamir transform

Performance characteristics

- Keys are small, signatures are relatively large, possible to tradeoff speed/size

Picnic Signatures

Key Generation:

Generate a random plaintext block p

Generate a random secret key sk

Compute C = LowMC(sk, p)

Picnic public key is pk = (C, p), signing key is sk

Sign(sk, pk, m):

Prove knowledge of sk such that C = LowMC(sk, p)

Message m and public key pk are bound to the proof when computing the challenge

Picnic signature is the proof

Picnic Signatures

Key Generation:

Generate a random plaintext block p

Generate a random secret key sk

Compute C = LowMC(sk, p) Must be hard to recover sk

Picnic public key is pk = (C, p), secret key is sk

Sign(sk, pk, m):

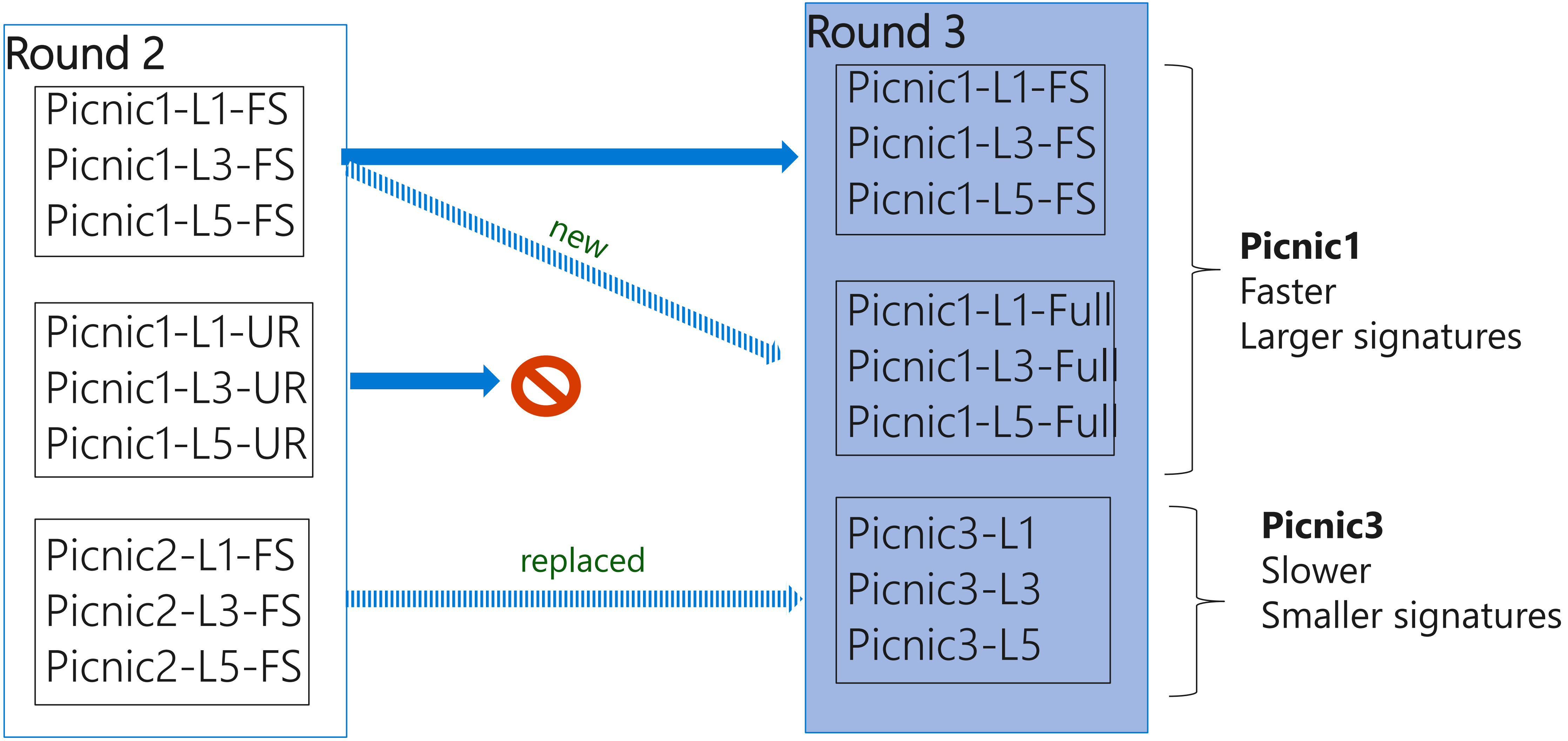
Prove knowledge of sk such that C = LowMC(sk, p)

Message m and public key pk are bound to the proof when computing the challenge

Picnic signature is the proof Must be zero-knowledge

Changes for Round 3

Parameter Sets



Picnic1-Full

- Same as Picnic1-FS but with alternative LowMC parameters
  - The number of 3-bit S-boxes per round is flexible in LowMC
  - Picnic previously used only LowMC instances with a **partial** S-box layer
  - Partial: needs more rounds (e.g., 20) vs Full: needs far fewer (e.g., 4)
  - LowMC Cryptanalysis Challenge [LCC] contains instances of both type
  - Partial has (arguably) more margin due to Dinur’s cryptanalysis [Din21] of Full

- Fewer rounds means faster sign and verify times and fewer round constants (lower code size)
- Signatures are slightly shorter (fewer total AND gates)

Picnic3

- Tweaks to Picnic2 aimed at making Sign and Verify faster
- Picnic's ZK proof is done using the MPC-in-the-head technique
  - Prover simulates an N-party MPC protocol, commits to the execution, then reveals parts of it to the verifier
  - **Reduce the number of MPC parties** N from 64 to 16. ~4x less computation
- Change LowMC parameters to use a Full S-box layer
- Tweaks to the MPC protocol
- Security analysis still holds

Considering adding a more conservative option with a Partial S-box layer LowMC instance, due to [Din21] (as we have with Picnic1)

Performance

Security level L1, Intel Xeon W-1233 @ 3.6GHz

Parameter set	Sign (ms)	Verify (ms)	Size (bytes)
Picnic1-FS	1.37	1.10	32,862
Picnic1-Full	1.0	0.8	30,821
Picnic2	40.95	18.20	12,341
Picnic3	5.17	3.96	12,595
Picnic2, N=16	10.42	5.00	13,831

See [KZ20] for additional details and benchmarks for L3 and L5

New Picnic implementations:
Resource-constrained and side-channel protected

Resource-Constrained Implementations

- Our x64 implementations do not optimize for memory use or code size
- Recent effort to reduce RAM usage, target is the ARM Cortex-M4
  - Must carefully compute parts of the signature as-needed
  - Recompute some values, rather than store
  - E.g., in Picnic3-L1 there are 250 MPC instances, and the prover will need 36 of them to respond to the challenge; we recompute these 36 rather than storing all 250
- Simple tweaks can further reduce RAM usage and improve times
  - (e.g., order that values are hashed/derived)

Masked Picnic

[GSE20] and [SBWE20] demonstrated some probing side-channel attacks on Picnic1.

We recently applied these attacks to Picnic3, and found a new one [ABE+21]. Analyzed, implemented and benchmarked a masked version of Picnic signing.

Takeaway: Under mild assumptions, masking overheads can be as low as 1.86x (for first-order protection). Watch the talk on Tuesday!

ARM Cortex-M4 Benchmarks

Using [pqm4] on the STM32F4 device, security level L1

Parameters	Implementation	Sign	Verify	Sig. Size
Picnic3-L1	opt	304M cycles 32KB RAM	203M cycles 32KB RAM	12.6KB
	opt-mem	310M cycles 24KB RAM		
	masked	546M cycles 32KB RAM		
Picnic1-L1-FS	opt	289M cycles 4KB RAM	126M cycles 4KB RAM	32.9KB
Picnic1-L1-Full + Tweaks	lowmem-mod	152M cycles 4.2KB RAM	55M cycles 3.5KB RAM	30.8KB

Ongoing effort: https://github.com/dkales/picnic_m4

Research and Security Analysis

Security Analysis

[GHHM20]: found a mistake in the QROM proof of Picnic3 and helped correct it.

Also generalizes results on the fault-resistance of Picnic (and related FS schemes) from [AOTZ20] from the ROM to the QROM

Tight QROM security of Picnic ([DFMS21], [Cha19])

- The recent results in [DFMS21] improve the existing, highly non-tight results for Picnic3.
- Alternate approach to tighter Picnic1 QROM analysis in [Cha19, 2021 revision].

Security Analysis

[CDF+20]: Picnic has stronger security properties than standard strong unforgeability. These properties are sometimes implicitly relied on by protocols. (Watch the talk on Wednesday!)

Efficient Implementation

[WBS20]: multiple ways to reduce Picnic1 RAM usage, and how to stream parts of the signature from a resource constrained device to a host device. Some ideas implemented in our M4 implementations of Picnic1.

AES-Based Signatures

FAQ: Can Picnic use AES instead of LowMC?

- Yes, but larger signatures

[BDK+21]: Banquet, a new AES-based MPCitH signature scheme

[DKR+21] and [DOT21]: Slightly faster and shorter signatures with AES

- Based on Banquet. Still slower or larger than Picnic3 (depending on parameters), but the gap is much smaller than previously
- E.g., 13.2KB signatures and ~20ms sign/verify

[DKR+21]: ciphers with large S-boxes (based on field inversion) improve performance **much** further

- E.g., 5.5 KB signatures and same sign/verify times as Picnic3, or
  8.5 KB signatures with sign/verify times <1 ms

Formal Verification

There is some recent work towards a formally verifying MPC-in-the-head (MPCitH) ZK proof protocols.

[SOS21]: formal verification of MPCitH protocols, EasyCrypt **machine checked security proof** of ZKBoo (a simpler version of the proof system used in Picnic1).

[ABEG+21]: Machine checked security proofs **and implementations** for MPCitH (more general than Picnic but simpler MPC protocol)

Summary

Compared to Round 2:

- Picnic3 is 4.5x to 13.9x faster than Picnic2
- New Picnic1 parameter sets are ~40% faster and ~10% shorter
- Implementations for the M4

Ongoing strong interest from the research community is amazing!

More information: microsoft.github.io/Picnic/

References are at the end of the presentation.

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