Classic McEliece: conservative code-based cryptography

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https://classic.mceliece.org/

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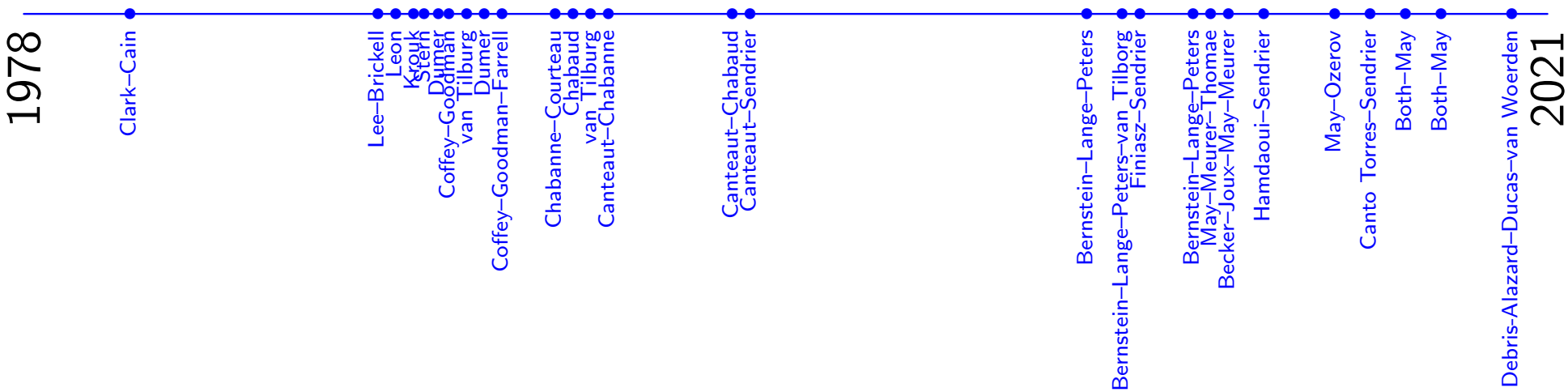
McEliece security stability

$$\lim_{K \to \infty} \frac{\log_2 \mathrm{AttackCost}_{\mathrm{year}}(K)}{\log_2 \mathrm{AttackCost}_{2021}(K)}$$



McEliece security stability

Blue: McEliece.

Red: Lattices have lost much more security. Lattices had 42% higher security levels a decade ago than they have today.

Concrete analysis

Attacking and defending the McEliece cryptosystem (Bernstein, Lange, Peters; 2008)

- McEliece original parameters (from 1978) $n = 1024, t = 50$, designed for 2^{64} security.
- Security estimate $2^{60.4}$ using 2008 Markov-chain analysis.
- Broken in 8000 core-days on CPU mix $\approx 2^{60.0}$ cycles on Core 2.
- Using improved version of Stern's algorithm.

A Finite Regime Analysis of Information Set Decoding Algorithms (Baldi, Barenghi, Chiaraluce, Pelosi, Santini; 2019)

- Covers Prange to BJMM and quantum versions.
- Bit operations & memory for all Classic McEliece parameters.

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Syndrome Decoding in the Goppa-McEliece Setting. Details on record 24 (Esser, May, Zweydinger; 2021)

- Challenge parameters $n = 1223, t = 23$.
- Security estimate $2^{58.9}$ using 2008 Markov-chain analysis.
- Broken in 3 days on 4 EPYC 7742 $\approx 2^{57.5}$ cycles on EPYC.
- Using BJMM/MMT variant.

Parameter sets – round 1

n	t	public key	secret key	ciphertext
8 192	128	1 357 824 bytes	14 080 bytes	240 bytes
Both n and t powers of 2.				
6 960	119	1 047 319 bytes	13 908 bytes	226 bytes
Max security with pkbytes $\leq 2^{20}$.				

Parameter sets – round 1, 2, and 3

n	t	public key	secret key	ciphertext
8 192	128	1 357 824 bytes	14 080 bytes	240 bytes
Both n and t powers of 2. Same as Round 1.				
6 960	119	1 047 319 bytes	13 908 bytes	226 bytes
Max security with pkbytes $\leq 2^{20}$. Same as Round 1.				
6 688	128	1 044 992 bytes	13 892 bytes	240 bytes
Max security with pkbytes $\leq 2^{20}$ if n and t are multiples of 32.				
4 608	96	524 160 bytes	13 568 bytes	188 bytes
Max security with pkbytes $\leq 2^{19}$ if n and t are multiples of 32.				
3 488	64	261 120 bytes	6 452 bytes	128 bytes
Max security with pkbytes $\leq 2^{18}$ if n and t are multiples of 32.				

Small ciphertext makes a large difference

PQ-WireGuard (Hülsing, Ning, Schwabe, Weber, Zimmermann; IEEE S&P 2021).

- Uses McEliece for long-term identity key in KEM-KEM construction.
- McEliece key exchanged out of band at registration.
- Strong benefit from short ciphertexts.
- Combined with lattice-based scheme for ephemeral keys.

McTiny (Bernstein, Lange; USENIX Security 2020)

- McEliece also used for ephemeral keys.
- Avoids DoS memory flooding attacks by using structure of code-based encryption. Server returns partial encryption and state in cookie encrypted to itself; cookie is smaller than network packet sent to server.
- Good speed and security with congestion control and surrounding protocol.

Timings on Haswell, in cycles

IND-CCA means we can generate key once and use it many times.

Timings for encapsulation and decapsulation matter.

system	keygen	keygen `f`	encap	decap
`mceliece348864`	46 526 112	36 627 388	43 832	134 184
`mceliece460896`	158 155 696	116 914 656	115 540	270 856
`mceliece6688128`	458 561 448	284 468 140	149 080	322 988
`mceliece6960119`	330 214 944	246 291 008	159 116	300 688
`mceliece8192128`	409 854 088	316 166 640	177 480	325 744

`f` version:

- Permit limited swaps of columns, $(\mu, \nu) = (32, 64)$.
- Increase chance of full-rank submatrix.
- Limit makes constant-time algorithm efficient.
- Introduced in round 2. Added to proposal in round 3.

Optimized implementations for Cortex-M4

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Classic McEliece implementation with low memory footprint (Roth, Karatsiolis, Krämer; CARDIS 2020). "an implementation of Classic McEliece on an ARM Cortex-M4 processor, optimized to overcome memory constraints"; stream public key off device

Classic McEliece on the ARM Cortex-M4 (Chen, Chou; CHES 2021). `mceliece348864` fits on Cortex-M4, including public key!

- 2 146 932 033 keygen (only 1 430 811 294 for `f` version).
- 582 199 encap
- 2 706 681 decap

`mceliece8192128`: 7 481 747 for decap (private keys are tiny).

See earlier talk Classic McEliece on the ARM Cortex-M4.

High-assurance

- New control-bits algorithm fully verified.
  See separate talk Fast verified post-quantum software, part 1: RAM subroutines.
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  This means the simplest and tightest proofs for FO apply.
  See Tighter proofs of CCA security in the quantum random oracle model (Bindel, Hamburg, Hövelmanns, Hülsing, Persichetti; TCC 2019).

Classic McEliece – ready for standardization

- In anticipation of standard, Round-3 expanded documentation:
  - Details secret key format, incl. options for compression.
  - Specifies full dataflow from RNG outputs.
  - Internal re-implementation from spec matches test vectors of optimized implementation.
- Open-source (public domain) implementations.
  - Constant-time software implementations.
    `ref`, `vec`, `sse`, `avx`, `m4`.
  - FPGA implementation.
- No patents.

See https://classic.mceliece.org for more details.