

Classic McEliece: conservative code-based cryptography

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<https://classic.mceliece.org/>

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— Classic McEliece is carefully designed to rely on a minimal, well-studied security assumption for McEliece: OW-CPA, i.e., OW-Passive, i.e., hardness of the pure search problem for a random plaintext.

Careful security analysis

Top-down view of the analysis in the Classic McEliece [security guide](#):

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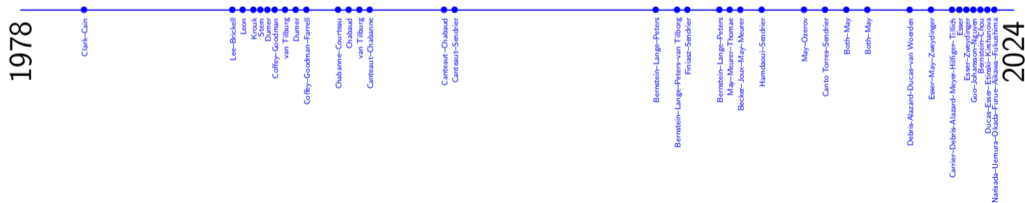
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The only ways something can possibly go wrong: disaster involving SHAKE256; mistake in tight reductions; better OW-CPA attack against original McEliece.

McEliece security stability

$$\lim_{K \rightarrow \infty} \frac{\log_2 \text{AttackCost}_{\text{year}}(K)}{\log_2 \text{AttackCost}_{2024}(K)}$$



McEliece security stability ∞

Blue: McEliece.

Red: Lattices had 45% higher security levels in 2010 than they have today.

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Leon

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Chabanne-Courteau

Chabaud

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Canteaut-Sandrier

Bernstein-Lange-Peters

Bernstein-Lange-Peters-van Tilburg

Finiasz-Sandrier

Bernstein-Lange-Peters

May-Muener-Thomas

Becker-Jour-May-Muener

Hamdoui-Sandrier

May-Ozerov

Canto Torres-Sandrier

Both-May

Both-May

Debris-Alazard-Ducas-van Woerden

Eiser-May-Zweydinger

Carrier-Debris-Alazard-Meyer-Hilliger-Tillich

Eiser-Zweydinger

Guo-Johansson-Nguyen

Bernstein-Croux

Ducas-Eiser-Ellers-Finiasz-Fukuhima

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Bernstein

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1.180

Ajta-Kumar-Sivakumar

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Becker-Jour-May-Muener

Hamdoui-Sandrier

May-Ozerov

Laarhoven-El Wiger

Becker-Ducas-Gama-Laarhoven

Canto Torres-Sandrier

Both-May

Both-May

Debris-Alazard-Ducas-van Woerden

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Carrier-Debris-Alazard-Meye-Hilliger-Tillich

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Length of the history matters:
SIKE security was stable 2011–2022.

Measuring stability beyond asymptotics

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- ▶ Crypto 2024 Bernstein–Chou “**CryptAttackTester**: high-assurance attack analysis”: software to (1) build complete attack circuits, (2) predict circuit cost and probability, (3) run small attacks to check accuracy. CryptAttackTester predicts $2^{156.96}$ bit ops for 348864 using attack ideas from the 1980s (isd1), $2^{150.59}$ bit ops using latest attacks (isd2).

Understanding a security-level comparison

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- ▶ Direct quantitative comparison of keygen+dec decoding power: McEliece creates vectors much farther from lattice than Kyber, NTRU, etc.
- ▶ Conclusion about difficulty of attack problem: the bigger distance easily explains a big increase in attack cost.

Very large security margin against key recovery

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Sometimes faster than ISD for extreme parameter sets,
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There are also papers on merely *distinguishing* McEliece public keys from random matrices. Again much slower than ISD for our selected parameter sets, *and* structurally irrelevant to the Classic McEliece security analysis.

Software correctness, part 1

The [official Classic McEliece software](#) is designed for deployment.

Internally, this software is CHES 2017 Chou “[McBits revisited](#)”

- + extending software to more parameter sets
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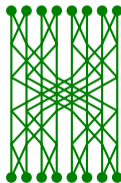
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Many eyeballs on spec. Every function implemented at least twice.

Only one component, control-bits computation for private key, had same implementor for software and Sage package; that component uses [formulas with computer-checked proofs](#) and is double-checked by much simpler code.



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Compiled software for the sorting subroutine has **computer verification** of sorting all inputs correctly.

Side note: scope of the Classic McEliece spec

ISO's "Performance principle": "Whenever possible, requirements shall be expressed in terms of performance rather than design or descriptive characteristics. This principle allows maximum freedom for technical development and reduces the risk of undesirable market impacts (e.g. limiting development of innovative solutions)."

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The Classic McEliece specification says exactly what mathematical functions to compute. It does *not* constrain the algorithms used to compute those functions. There is a separate Classic McEliece [guide for implementors](#).

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McEliece software is naturally built from constant-time bit-vector operations. [libmceliece](#) has TIMECOP-like data-flow tests on the compiled library, and has proactive state-of-the-art source-level defenses ([cryptoint](#)).

Classic McEliece software for more and more environments

Ecosystem of unofficial libraries already available today:

- ▶ [libmceliece](#): easy-to-use packaging for the official software.
- ▶ [Debian](#) and [Ubuntu](#) have integrated libmceliece.
- ▶ [PQClean](#) and [liboqs](#) have integrated the official software.
- ▶ [libgcrypt](#) has integrated the official software for `mceliece6688128`.
- ▶ [pymceliece](#) is a Python wrapper for libmceliece.
- ▶ [node-mceliece-nist](#) is a Node wrapper for the official software.
- ▶ [classic-mceliece-rust](#) is a Rust translation of the official software.
- ▶ [Bouncy Castle](#) includes Java and C# translations of the official software.
- ▶ [McTiny](#) supports tiny network servers.
- ▶ [mceliece-arm-m4](#) supports ARM Cortex-M4 microcontrollers.
- ▶ [McOutsourcing](#) supports very-low-memory key generation.
- ▶ [pqc-classic-mceliece](#) implements Classic McEliece for FPGAs.

Examples of McEliece applications

Adva Network Security's [high-speed optical networks](#):

“Our real-world use-case [for Classic McEliece] . . . Encrypted layer 1 optical transport solutions (OTNsec) with 10-400 Gbit/s including BSI approval”.

Crypto4A's [hardware security modules](#): “Crypto4A currently uses Classic McEliece in all of its HSMs for three important use cases”.

[Mullvad](#) VPN software: [2022 announcement](#) of Classic McEliece experiment on some servers, [2022 announcement](#) of Classic McEliece experiment on all servers, [2023 announcement](#) of stable support for Classic McEliece.

[openssh-mceliece](#) is a patch for OpenSSH to support `mceliece6688128`.

[Rosenpass](#) VPN software: uses `mceliece460896` for static keys.

[Smoke](#) secure-messaging system—although this has not upgraded yet from a different McEliece-based system to Classic McEliece.

Aren't lattices more efficient?

One-time keys

[NIST SP 800-57 Part 1](#), “Recommendation for Key Management: Part 1 – General”: “Cryptoperiod: A public ephemeral key-agreement key is used for a single key-agreement transaction. The cryptoperiod of a public ephemeral key-agreement key ends immediately after it is used to generate a shared secret.”

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A lattice key agreement costs only about 2^{-28} dollars.

Most types of public keys are not one-time keys

Non-ephemeral public-key types listed in NIST SP 800-57 Part 1:

- ▶ “Public signature-verification key”: “The cryptoperiod may be on the order of several years”.
- ▶ “Public authentication key”: “An appropriate cryptoperiod for a public authentication key would be no more than one or two years”.
- ▶ “Public key-transport key”: “a recommendation for the cryptoperiod is no more than one or two years”.
- ▶ “Public static key-agreement key”: “The cryptoperiod of a public static key-agreement key may be one or two years”.
- ▶ “Public authorization key”: “no more than two years”.

How should post-quantum cryptography handle these types of keys?

This question is not just about signatures

Signature-vs.-KEM choice for different types of static public keys:

- ▶ “Public signature-verification key”: Use signatures by definition. (Sometimes application needs offline signers or non-repudiation.)
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STOC 1998 [Bellare–Canetti–Krawczyk](#) “A modular approach to the design and analysis of authentication and key exchange protocols”: easily build public-key message authentication from public-key signatures *or* from public-key encryption.

KEM version: Bob encapsulates to Alice; Alice uses session key with a MAC.

This question is within scope

NIST's [post-quantum CFP](#): "NIST intends to standardize post-quantum alternatives to its existing standards for digital signatures (FIPS 186) and key establishment (SP 800-56A, SP 800-56B). These standards are used in a wide variety of Internet protocols, such as TLS, SSH, IKE, IPsec, and DNSSEC. . . . The importance of public-key size may vary depending on the application; if applications can cache public keys, or otherwise avoid transmitting them frequently, the size of the public key may be of lesser importance."

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[NIST SP 800-56A](#) says “can be a static key pair or an ephemeral key pair”; specifies static-static DH, static-ephemeral DH, ephemeral-ephemeral DH.

Note: Static-ephemeral DH can be viewed as KEM with static public key.

Many real-world examples of static public keys

Microsoft's [Encrypting File System](#) encrypts each file to the public key of the user authorized to access the file. This is [more than just disk encryption](#): “Encrypting File System (EFS) can be used to encrypt files on a BitLocker-protected drive. BitLocker helps protect the entire operating system drive against offline attacks, whereas EFS can provide additional user-based file level encryption for security separation between multiple users of the same computer.”

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Note that TLS *CA keys* are different from TLS *server keys*.

The current TLS data flow needs TLS CA keys to be signature keys.

Impact of static keys on KEM efficiency analysis

Cost of client sending 2^{15} ciphertexts to server's static KEM key:
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In this scenario, a lattice system costs roughly 2^{-14} dollars,
while total cost of `mceliece6960119` is only 2^{-17} dollars.

**Reverses the cost winner compared to the situation of one-time keys.
Classic McEliece is the most efficient choice here, not just the safest!**

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keygen cycles + pk bytes + $2^{15} \cdot (\text{enc cycles} + \text{ct bytes} + \text{dec cycles})$.



In this scenario, a lattice system costs roughly 2^{-14} dollars,
while total cost of `mceliece6960119` is only 2^{-17} dollars.

**Reverses the cost winner compared to the situation of one-time keys.
Classic McEliece is the most efficient choice here, not just the safest!**

As this illustrates, we can gain overall efficiency by paying attention to
the full range of key types already recognized in NIST SP 800-57,
not just static signature keys and one-time encryption keys.

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(Same reversal appears when a popular server's public key is broadcast to
many different clients, even if key is changed every five minutes.)

Example: the Rosenpass VPN

Rosenpass provides a complement to the well-known WireGuard protocol, adding quantum-hardened cryptography and key exchange while keeping the established WireGuard standard encryption security. So Rosenpass functions as an add-on, enhancing WireGuard's key negotiation process with Post Quantum Secure (PQS) cryptography, based a combination of Classic McEliece and Kyber.

Uses Classic McEliece for static keys, the foundation of security for identifying and authenticating the server, as well as for encrypting data. Ciphertexts are continually sent to those keys; the keys themselves are almost always cached.

Uses Kyber just for forward secrecy: a break of Kyber does not damage security unless the attacker can also steal secret keys through, e.g., hardware theft.

Trying to reuse Kyber for the static keys would increase security risks; increase costs; and consume extra key-exchange packets, making denial of service easier.

Summary of how to maximize efficiency

Most efficient post-quantum choice depends on the key type:

- ▶ “Public ephemeral key-agreement key”:
use KEMs; most efficient choice: lattices.
(Pre-quantum uses ephemeral-ephemeral DH from SP 800-56A.)
- ▶ “Public key-transport key” or “public static key-agreement key”:
use KEMs; most efficient choice: **Classic McEliece**.
(Pre-quantum uses static-ephemeral DH from SP 800-56A.)
- ▶ “Public authentication key” or “public authorization key”:
can use signatures or KEMs; most efficient choice: **Classic McEliece**.
(Pre-quantum again uses static-ephemeral DH from SP 800-56A.)
- ▶ “Public signature-verification key”:
use signatures; most efficient choice: outside scope of this talk.

Recommendations

We recommend recognizing the importance of static encryption keys, as in NIST SP 800-56A, NIST SP 800-57, and many applications.

Independently of KEM choices made for ephemeral encryption keys, we recommend standardizing Classic McEliece as the best option for static encryption keys: the safest and most efficient option.

(We also recommend recognizing the intermediate case of keys that are periodically rotated for forward secrecy but still used many times.)