NIST 5th PQC Standardization Conference

April 8-10, 2024

A lean BIKE KEM design for ephemeral key agreement

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BIKE - Bit Flipping Key Encapsulation

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$(sk, h, \sigma) \leftarrow KeyGen(\cdot)$

$\sigma \xleftarrow{\$} \{0,1\}^{256}$

$h_0, h_1 \xleftarrow{D_1} S^2_{r,d}$

$sk = (h_0, h_1, \sigma)$

$pk = h = h_1 h_0^{-1}$

Return (sk, pk, σ)

$(C, K) \leftarrow Encaps(h)$

$m \xleftarrow{\$} \{0,1\}^{256}$

$e = (e_0, e_1) \xleftarrow{D_2} S_{2r,t}(m||h)$

$C = (c_0, c_1) = \left(e_0 + e_1 h, m \oplus \mathbf{L}(e_0, e_1)\right)$

$K = \mathbf{K}(m, C)$

Return (C, K)

BIKE(r,d)

$m = Decaps(sk, \sigma, h, C)$

$e' = (e'_0, e'_1) = Decode(sk, C)$

$m' = c_1 \oplus \mathbf{L}(e')$

If $S_{n,t}(m'||h) \neq e'$ then $m' = \sigma$

Return $\mathbf{K}(m', C)$

BIKE: a **Code-based** KEM

NIST seeks a **non-lattice** KEM alternative

Round 4 standardization (alternative)

Let's think of different bikes

The state of the BIKE (& some other code-based KEMs) Decoding Failure Rates: where are we now?

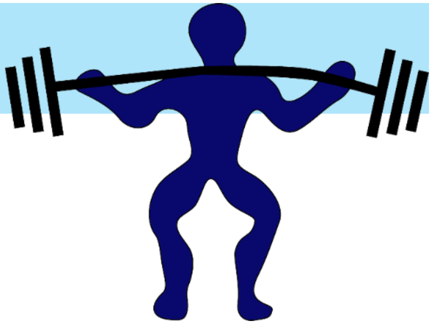
- Two NIST's code-based KEM candidates, HQC and BIKE, require a decoder with a sufficiently low DFR
- Current methods to study DFR on a given decoder rely on an assumption(s) and then some empirical estimates backed up by (extensive) simulations & extrapolations.
- This gives a **solid indication & convincing evidence** to a low DFR but not a proven upper bound of, say, 2^{-128}
- **We tested with 2^{45} messages (no decoding failure)**

Can't brush under the rug

Proven: If BIKE is used with a decoder that has sufficiently low DFR (e.g., < 2^{-128}) then BIKE has CCA security

[4] DGKP, "On the applicability of the Fujisaki-Okamoto transformation to the BIKE KEM"

CCA security is a heavy lifting!



The impact of taking on CCA challenge so

- Requires very careful constant time implementations
- All side channel attacks (HQC / BIKE) targeted a fixed key reused multiple times (CCA scenario)
- Higher complexity → Implementation mistakes
- Strict decoder specification

Why *always* pay the full cost of (hopeful) CCA when many (most?) usages settle with CPA security?

Hmmm

Forward secrecy needs ephemeral key agreement

(using key pair is used once)

BIKE CPA security has a proven reduction to a hard decoding problem

We already have support!

BIKE CPA security has a proven reduction to a hard decoding problem

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This is BIKE

$\underline{\boldsymbol{m = Decaps(sk, \sigma, h, C)}}$

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$(sk, h, \sigma) \leftarrow KeyGen(\cdot)$

$\sigma \overset{\$}{\leftarrow} \{0,1\}^{256}$

$h_0, h_1 \overset{D_1}{\leftarrow} S_{r,d}^2$

$sk = (h_0, h_1, \sigma)$

$pk = h = h_1 h_0^{-1}$

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$(C, K) \leftarrow Encaps(h)$

$m \overset{\$}{\leftarrow} \{0,1\}^{256}$

$e = (e_0, e_1) \overset{D_2}{\leftarrow} S_{2r,t}(m||h)$

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Return (C, K)

This is what we pay for a CCA claim for BIKE (assuming a low DFR decoder)

$m = Decaps(sk, \sigma, h, C)$

$e' = (e'_0, e'_1) = Decode(sk, C)$

$m' = c_1 \oplus \boldsymbol{L}(e')$

If $S_{n,t}(m'||h) \neq e'$ then $m' = \sigma$

Return $\boldsymbol{K}(m', C)$

Coming soon: + binding to public key

Lean BIKE

An optimized type of BIKE design
with the minimum needed for CPA security
(to be used with ephemeral keys)

What can we peel off from BIKE

To get a Lean BIKE

- **No FO transform**
- **No re-encryption**
- **No CT-sampling**
- **No binding**
- **Choice of seed-to-PRF expansion**
- **BYOD (Bring Your Own Decoder)**

$\underline{(\boldsymbol{sk}, \boldsymbol{h}) \leftarrow \boldsymbol{KeyGen}(\cdot)}$

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$\underline{(\boldsymbol{C}, \boldsymbol{K}) \leftarrow \boldsymbol{Encaps}(\boldsymbol{h})}$

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Lean BIKE

$\underline{\boldsymbol{m} = \boldsymbol{Decaps}(\boldsymbol{sk}, \boldsymbol{h}, \boldsymbol{C})}$

$e' = (e'_0, e'_1) = Decode(sk, C)$

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Engineering DFR concept

- Real systems & ephemeral keys (CPA security):
  - DFR tolerance level is much more lenient than for CCA security.

- Engineering DFR: target system operational reliability

- 5 nines reliability (99.999%) gold standard of system availability
  - Translates to a DFR $\leq 2^{\log_2 10^{-5}} = 2^{-16.61}$
- 6 nines reliability (99.9999%) ➔ $2^{-19.93}$
- 7 nines reliability (99.99999%) ➔ $2^{-23.25}$

(Network errors occur at higher rates)

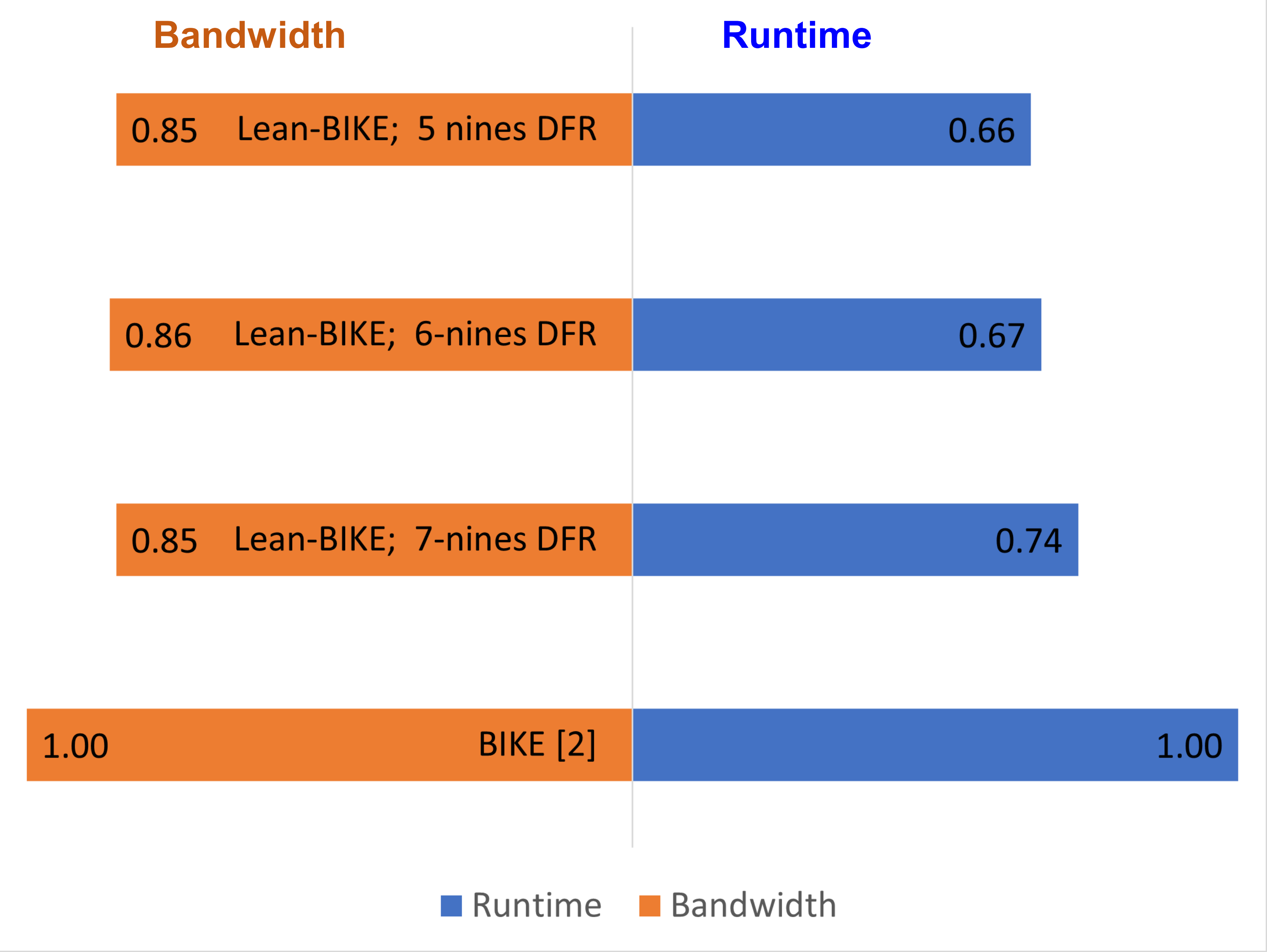
BIKE & Lean BIKE - numbers

Lean-BIKE vs. BIKE 5.1

(security Level 1)

Three levels of
Engineering DFR

And more savings are also possible



BIKE - Bit Flipping Key Encapsulation

Our concrete proposal

Standardize **both** BIKE **and** a Lean-BIKE version

Forward secrecy seeking (ephemeral key) usages

need not pay the toll

for trying to achieve CCA security

(when this is not really needed)

Lean-BIKE is available at

Drucker, Gueron, Kostic, “Additional implementation of BIKE”

https://github.com/awslabs/bike-kem

Thank you

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