NIST Cryptographic Standards for Trusted Platform in Quantum Era

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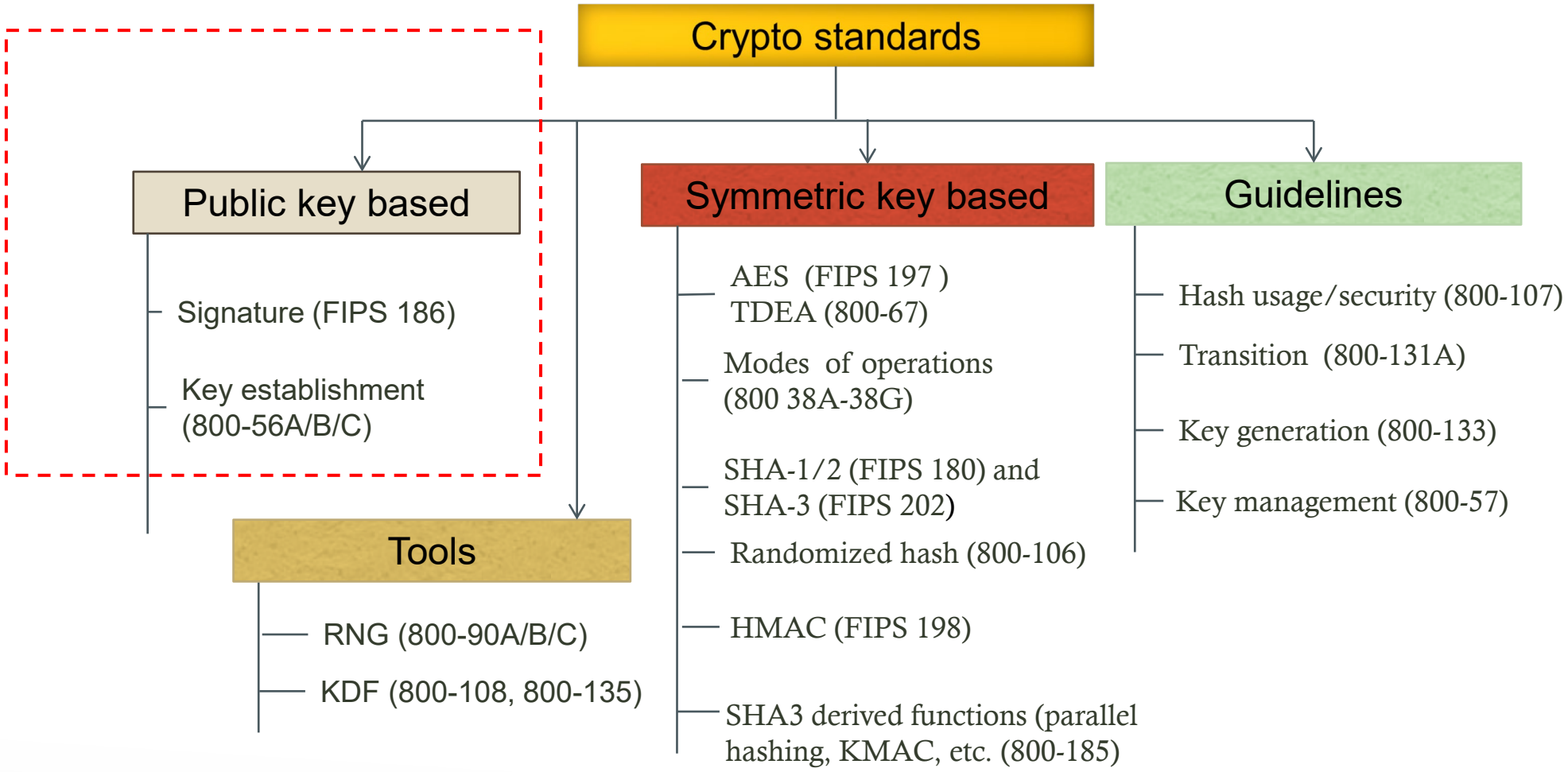
NIST Cryptographic Standards



NIST Public Key Cryptography Standards

- NIST standardized public key cryptographic schemes are based on two "hard problems" and some of these algorithms are used in today's TPM

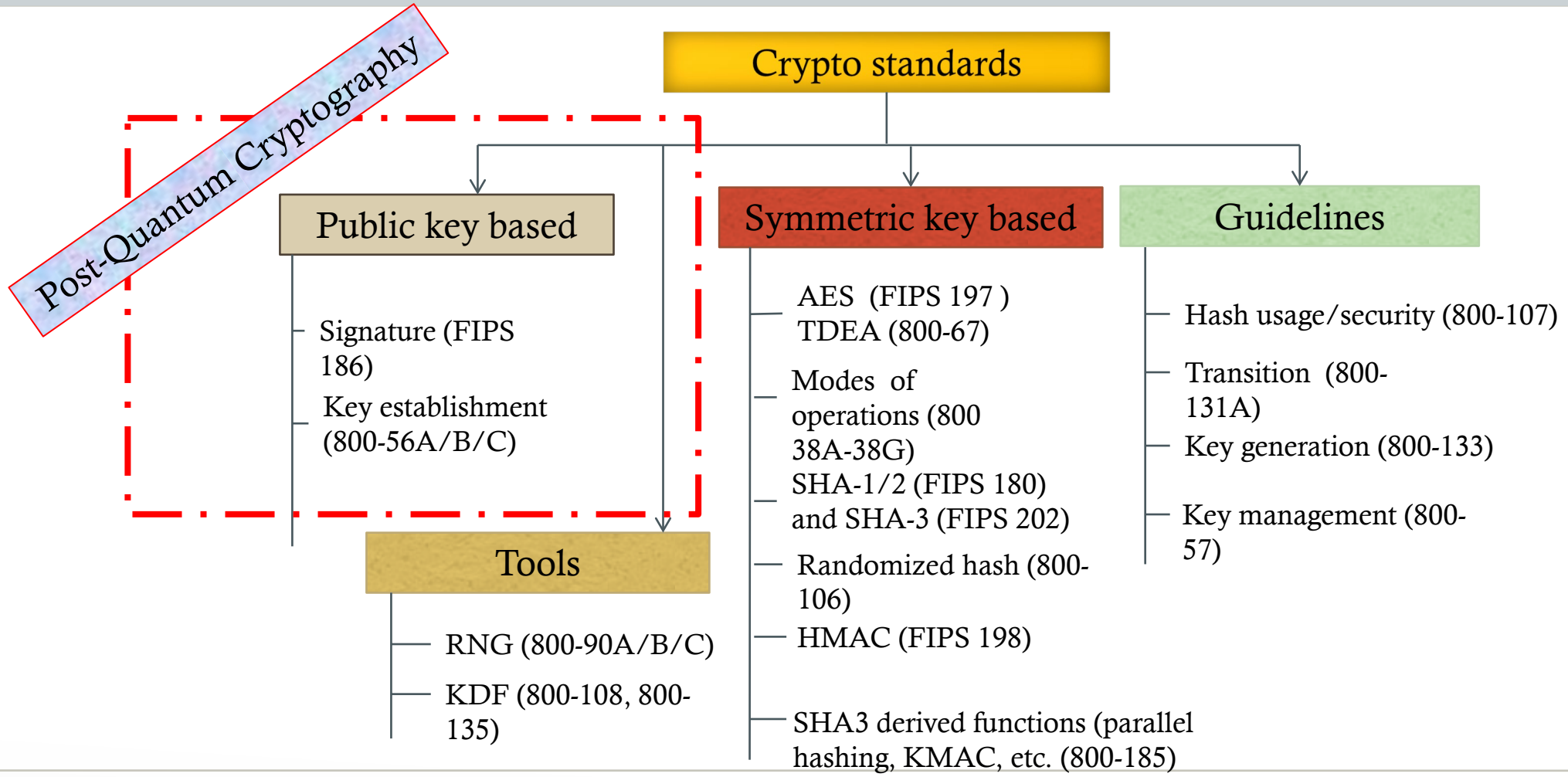
Integer Factorization
- RSA encryption (SP 800-56B) for key establishment)
- RSA signatures (FIPS 186)

Discrete Logarithm
- DH/ECDH and MQV/ECMQV (SP 800-56A for key establishment)
- DSA and ECDSA (FIPS 186)

Quantum Impact

- Emerging quantum computers changed what we have believed about the hardness of discrete log and factorization problems
  - Using quantum computers, an integer $N = p \cdot q$ can be factored in polynomial time using Shor's algorithm
  - The discrete logarithm problem, find x, given y can such that $g^x = y \; mod \; p$, also be solved by Shor's algorithm in polynomial time
- As a result, the public key cryptosystems deployed since the 1980s will need to be replaced
  - RSA signatures, DSA and ECDSA (FIPS 186-4)
  - Diffie-Hellman Key Agreement over finite fields and elliptic curves(NIST SP 800-56A)
  - RSA encryption (NIST SP 800-56B)
- We have to look for quantum-resistant counterparts for these cryptosystems
- Quantum computing also impacted security strength of symmetric key based cryptography algorithms
  - Grover's algorithm can find AES key with approximately $\sqrt{2^n}$ operations where n is the key length
  - Intuitively, we should double the key length, if 2^{64} quantum operations cost about the same as 2^{64} classical operations

Quantum Impact to NIST Standards



NIST PQC Initiative

- NIST Crypto program started to build a research team since 2012
  - Today NIST PQC team consists of a dozen of researchers with background in cryptography, quantum algorithms, crypto standards, etc.
- In 2015 -2016, we started to prepare for PQC standardization
  - The first workshop was held in April 2015
  - Published NIST IR 8105 in 2016
- NIST announced call for proposals in Dec. 2016

The Selection Criteria

- Security - against both classical and quantum attacks
- Performance - measured on various "classical" platforms
- Other properties
  - Drop-in replacements - Compatibility with existing protocols and networks
  - Perfect forward secrecy for key establishment
  - Resistance to side-channel attacks
  - Simplicity and flexibility
  - Misuse resistance, and
  - More
- The draft requirements and criteria were announced in August 2016 to call for public comments

Understand the Challenges

- Much broader scope – three crypto primitives
- Both classical and quantum attacks
  - Security strength assessment on specific parameter selections
- Consider various theoretical security models and practical attacks
  - Provably security and security against instantiation or implementation related security flaws and pitfalls
- Multiple tradeoff factors
  - Security, performance, key size, signature size, side-channel attack countermeasures
- Migrations into new and existing applications
  - TLS, IKE, TPM/code signing, PKI infrastructure, and much more
- Not exactly a competition – it is and it isn't

Differences with Past Competitions

- Post-quantum cryptography is far more complicated than AES/SHA-3
  - No silver bullet – not exact "drop in replacement"
  - Not enough research on quantum algorithms to ensure confidence on quantum security for some schemes
- We do not expect to "pick a single winner"
  - Ideally, several algorithms will emerge as "good choices"
- We will narrow our focus at some point
  - This does not mean algorithms are "out"
- Requirements/timeline could potentially change based on developments in the field

Submissions to NIST Call for Proposals

- 82 total submissions received from 26 Countries, 6 Continents
- 69 accepted as "complete and proper" (5 since withdrawn)
- 2 of them announced to "merge" to one (*)

	Signatures	KEM/Encryption	Overall
Lattice-based	5	20*	25
Code-based	2	17	19
Multi-variate	7	2	9
Stateless Hash-based/Symmetric based	3		3
Other	2	5	7
Total	**19**	**45**	**63**

Stateful Hash-Based Signatures

- Stateful hash-based signature is out of the scope of NIST call for proposals but it is in the scope for PQC standardization
- Two versions of stateful hash-based signatures have been proposed in IETF
  - XMSS – RFC 8391 "XMSS: eXtended Merkle Signature Scheme"
  - LMS – "Hash-Based Signatures" (draft-mcgrew-hash-sigs-13)
- Input/feedback was solicited on whether NIST shall standardize any or both hash-based signatures
  - About 20 responses were received and, in general, support NIST to standardize hash-based signatures
- NIST plans to initiate the project to develop a special publication on stateful hash-based signatures
- Further question will be how much to limit hash-based signature, e.g. for code signing only or also allowing for root/intermediate certificates
- Potential usage in TPM?
  - hash-based digital signature schemes are space-intensive, requiring trusted key state management and producing large signatures (some research appears in this area)

General on first round candidates

- Most submitted schemes (or early versions) have been published at the conferences or released through IACR eprint – In general, no big surprise
- Most submissions include proofs/discussions on the CCA/CPA security for Encryption/KEM and EUF-CMA for signatures
- Most submissions addressed the rationale for the selected parameters and mathematics structures as well as pros and cons of the schemes

Diversities and Tradeoffs

- Related to the security assumptions
  - Generic vs. structured (e.g. LWE vs. R-LWE) – Some submissions include both versions
- Auxiliary functions
  - Uniform sampling vs. Gaussian sampling
- Encryption/key exchange
  - Ciphertext size vs. public key size
  - Decryption failure vs. techniques to reduce the probability, including increase the module
- Signature
  - Signature size vs. public key size
  - Hash-and-sign vs. Fiat-Shamir
- etc.

Specific aspects for TPM

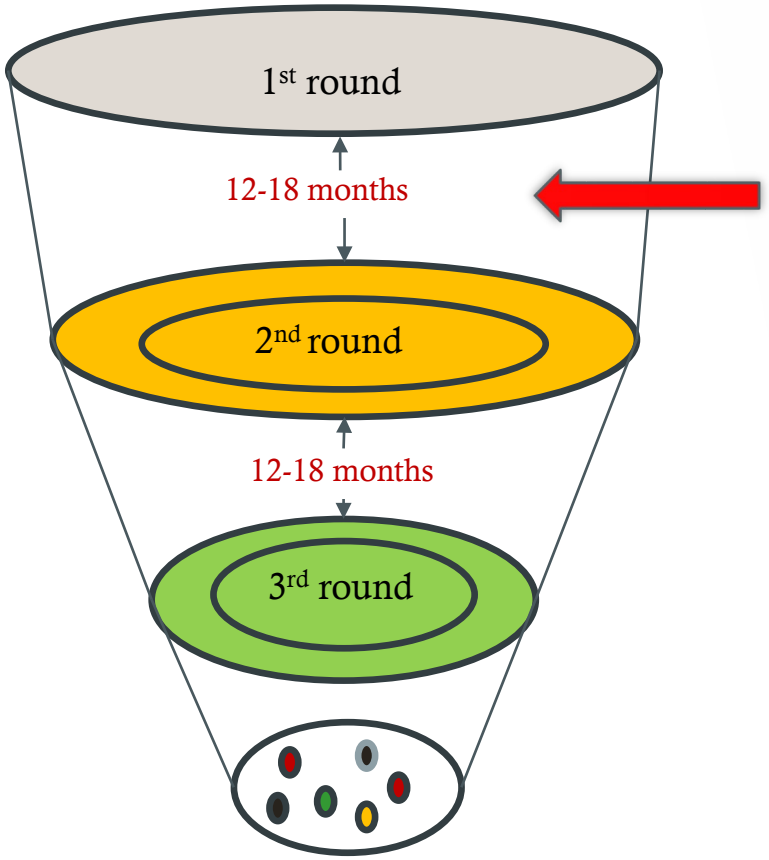
- Feedback from application community is important
  - Is there a limit on public key size, ciphertext size, signature size for TPM?
  - Is there a limit on internal memory?
  - Is decryption failure, even with 2^{-160} probability, an issue?
  - How important is it for encryption and signature to use the same primitive/operation (e.g. lattice, coding etc.)?
- Look into the first round candidates and voice application special needs
  - Tell what can potentially become a problem
- Which underlying operations among PQC primitives will be in favor of DAA?

Transition and Migration

- Is it a problem for TPM protocols between old and new, how to handle it?
- Is it possible to facilitate crypto agility?
- Is dual signature or hybrid mode a transition solution in TPM applications?

NIST Timeline (from April 2018)

- Initial analysis phase 12-18 months
- Narrow the pool and hold the second workshop in August 2019
- Second analysis phase 12-18 months
- May take third analysis phase if needed
- Expect draft standards in 2022-2023



Information on NIST PQC Standardization

- For NIST PQC project, please follow us at
  https://csrc.nist.gov/Projects/Post-Quantum-Cryptography
- To submit a comment, send e-mail to pqc-comments@nist.gov
- Join discussion mailing list pqc-forum@nist.gov