Update on the NIST Post-Quantum Cryptography Project

http://indianajones.wikia.com/wiki/Raiders_of_the_Lost_Ark

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Classical vs Quantum Computers

- The security of crypto relies on intractability of certain problems to modern computers
  - Example: RSA and factoring
- Quantum computers
  - Exploit quantum mechanics to process information
  - Use quantum bits = “qubits” instead of 0’s and 1’s
  - Superposition – ability of quantum system to be in multiples states at the same time
  - Potential to vastly increase computational power beyond classical computing limit

The Sky is Falling?

- If a large-scale quantum computer could be built then….

- Public key crypto:
  - RSA
  - ECDSA (and Elliptic Curve Cryptography)
  - DSA (and Finite Field Cryptography)
  - Diffie-Hellman key exchange

- Symmetric key crypto:
  - AES
  - Triple DES

- Hash functions:
  - SHA-2 and SHA-3

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- Vulnerable NIST standards
  - FIPS 186, *Digital Signature Standard*
    - Digital Signatures: RSA, DSA, ECDSA
  - SP 800-56A/B, *Recommendation for Pair-Wise Key Establishment Schemes*
    - Discrete Logs: Diffie-Hellman, MQV
    - Factorization based: RSA key transport

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- Symmetric key crypto:
  - AES — Need longer keys
  - Triple DES — Need longer keys

- Hash functions:
  - SHA-2 and SHA-3 — Use longer output

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How soon do we need to worry?

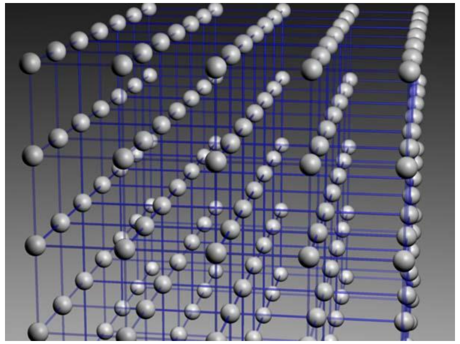
- Potentially as early as 15 years to break RSA-2048
  - 15 years, $1 billion USD, small nuclear power plant (Mariantoni, 2014)
  - 50% chance (Michele Mosca)

- PQC needs time to be ready for applications
  - Confidence – cryptanalysis
  - Implementations
  - Usability and interoperability (IKE, TLS, etc. … use public key crypto)
  - Standardization

- Transition has to be soon enough that any data compromised by quantum computers is no longer sensitive when compromise occurs

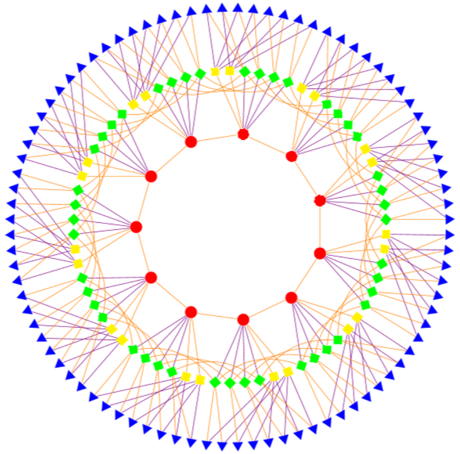
Possible Replacements

01010111 01101001 01101011
01101001 01110000 01100101
01100100 01101001 01100001



- Lattice-based
- Code-based
- Multivariate
- Others
  - Hash-based signatures
  - Isogeny-based signatures
  - Etc....

- All have their pros and cons



$$f_1(x_1,\ldots,x_n) = \sum_{1\le i\le j\le n} a_{ij}^{(1)} x_i x_j + \sum_{1\le i\le n} b_i^{(1)} x_i + c^{(1)} = d_1,$$

$$f_2(x_1,\ldots,x_n) = \sum_{1\le i\le j\le n} a_{ij}^{(2)} x_i x_j + \sum_{1\le i\le n} b_i^{(2)} x_i + c^{(2)} = d_2,$$

$$\vdots$$

$$f_m(x_1,\ldots,x_n) = \sum_{1\le i\le j\le n} a_{ij}^{(m)} x_i x_j + \sum_{1\le i\le n} b_i^{(m)} x_i + c^{(m)} = d_m,$$

Initial Observations

- For most of the potential PQC replacements, the times needed for encryption, decryption, signing, verification are acceptable
- Some key sizes are significantly increased
  - For most protocols, if the public keys do not need to be exchanged, it may not be a problem
- Some ciphertext and signature sizes are not quite plausible
- Key pair generation time for the encryption schemes is not bad at all
- **No easy "drop-in" replacements**
- Would be nice to have more benchmarks

Gathering Steam

- PQCrypto Workshop series
- ETSI workshops
- European PQCrypto project, Quantum flagship
- Japan's SAFECRYPTO project
- IETF hash-based signatures
- ISO/IEC JTC 1 SC 27 – study period on PQC
- Fall 2015: NSA announced it would be transitioning in the "not too distant" future https://www.iad.gov/iad/programs/iad-initiatives/cnsa-suite.cfm

The NIST PQC Project http://www.nist.gov/pqcrypto

- Biweekly seminars since 2012
- Guest researchers and invited speakers
- Research: publications and presentations
  - PQCrypto, AWACS, ICICS, CRYPTO, Qcrypt, Eurocrypt, ETSI Quantum-safe workshops, etc.
- Out Reach
  - PKI community, Automotive industry talks

- 2015: NIST PQC workshop http://www.nist.gov/itl/csd/ct/post-quantum-crypto-workshop-2015.cfm
- Feb 2016: NIST report on PQC- http://csrc.nist.gov/publications/drafts/nistir-8105/nistir_8105_draft.pdf
- Feb 2016: NIST announced preliminary standardization plan at PQCrypto https://pqcrypto2016.jp/data/pqc2016_nist_announcement.pdf

Collaboration

- IETF – CFRG
- ISO/IEC JTC 1 SC 27
- ETSI
  - Workshops, white papers
- Universities
  - University of Maryland (QuiCS)
  - University of Waterloo (Cryptoworks 21)
- Guest Researchers and Speaker
  - Lyubachevsky, Ding, Takagi, Petzoldt, Faugere, Gligoroski, Perret, etc…

Timeline

- June 2016 – Draft Call For Proposals released for public comment
- Fall 2016 – formal Call For Proposals finalized
- Nov 2017 – Deadline for submissions
- 3-5 years – Analysis phase
    - NIST will report its findings
- 2 years later - Draft standards ready (2023-2025)

- Workshops
    - Early 2018 – submitter's presentations
    - One or two during the analysis phase

Call for Proposals

- NIST is calling for quantum-resistant cryptographic algorithms for new public-key crypto standards
  - Digital signatures
  - Encryption/key-establishment
- We see our role as managing a process of achieving community consensus in a **transparent** and timely manner
- We do not expect to “pick a winner”
  - Ideally, several algorithms will emerge as ‘good choices’
- We may pick one (or more) for standardization
  - Only algorithms publicly submitted considered

Differences with AES/SHA-3 competitions

- Post-quantum cryptography is more complicated than AES or SHA-3
  - No silver bullet - each candidate has some disadvantage
  - Not enough research on quantum algorithms to ensure confidence for some schemes
- We do not expect to “pick a winner”
  - Ideally, several algorithms will emerge as “good choices”
- We may narrow our focus at some point
  - This does not mean algorithms are “out”
- Requirements/timeline could potentially change based on developments in the field

Minimal acceptability requirements

- Publicly disclosed and available with no IPR
  - Signed statements, disclose patent info
- Implementable in wide range of platforms
- Provides at least one of: signature, encryption, or key exchange
- Theoretical and empirical evidence providing justification for security claims
- Concrete values for parameters meeting target security levels

Specification

- Implementation
  - Reference version
  - Optimized version
- Cryptographic API will be provided
  - Can call approved hash functions, block ciphers, modes, etc…
- Known Answer tests
- Optional – constant time implementation

Evaluation criteria

- To be detailed in the formal Call
    - Security
    - Cost (computational and memory)
    - Algorithm and implementation characteristics

- Draft criteria will be open for public comment

- We strongly encourage public evaluation and publication of results concerning submissions

- NIST will summarize the evaluation results and report publicly

Security Analysis

- Security definitions
  - IND-CCA2 for encryption, EUF-CMA for signatures, CK best for key exchange?
  - Used to judge whether an attack is relevant
- Quantum/classical algorithm complexity
  - Stability of best known attack complexity
  - Precise security claim against quantum computation
  - Parallelism?
- Security proofs (not required but considered as support material)
- Quality and quantity of prior cryptanalysis

Target Security Levels

	Classical Security	Quantum Security	Examples
I	128 bits	64 bits	AES128 (brute force key search)
II	128 bits	80 bits	SHA256/SHA3-256 (collision)
III	192 bits	96 bits	AES128 (brute force key search)
IV	192 bits	128 bits	SHA256/SHA3-256 (collision)
V	256 bits	128 bits	AES128 (brute force key search)

Cost

- Computational efficiency
  - Hardware and software
    - Key generation
    - Encryption/Decryption
    - Signing/Verification
    - Key exchange

- Memory requirements
  - Concrete parameter sets and key sizes for target security levels
  - Ciphertext/signature size

- May need more than one algorithm for each function to accommodate different application environments

Algorithm and Implementation Characteristics

- Ease of implementation
  - Tunable parameters
  - Implementable on wide variety of platforms and applications
  - Parallelizable
  - Resistance to side-channel attacks

- Ease of use
  - How does it fit in existing protocols (such as TLS or IKE)
  - Misuse resistance

- Simplicity

The Evaluation Process

- Initial evaluation phase (12-18 months)
  - No tweaks/modifications allowed
  - Workshops at beginning and end of initial evaluation phase
- Report findings and narrow candidate pool
- Second evaluation phase (12-18 months)
  - Small modifications allowed
  - Workshop towards end of second phase
- Report findings and narrow candidates
- Select algorithms for standardization or decide more evaluation needed

Call for Feedback

- How is the timeline?
  - Do we need an ongoing process, or is one time enough?
- How to determine if a candidate is mature enough for standardization?
  - hash-based signatures for code signing
- We are focusing on signatures and encryption/key-establishment. Should we also consider other functionalities?
- How can we encourage people to study practical impacts on the existing protocols?
  - For example, key sizes may be too big

Conclusion

- NIST is calling for quantum-resistant algorithms
  - We see our role as managing a process of achieving community consensus in a transparent and timely manner
  - Different from (but similar to) AES/SHA-3 competitions
- PQC Standardization is going to be a long journey
- We don’t have all the answers
- Be prepared to transition to new (public-key) algorithms in 10 years
  - The transition will not be painless
    - NIST will provide transition guideline when PQC standards are developed
  - Prepare the application designers
    - Focus on crypto-agility