Reduction of Key Sizes on Rainbow-like Multivariate Signature Schemes

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INE410111 — Research Methodology in Computer Science

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Context

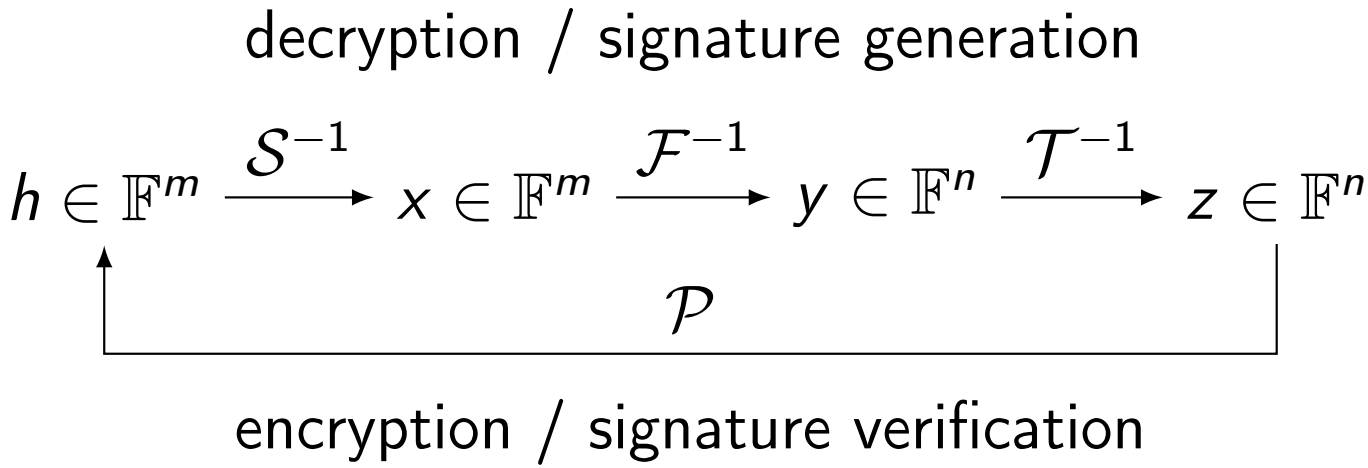
- Guarantee protection and privacy of messages sent digitally
- Security of digital signature schemes is based on problems from number theory
- There exist quantum algorithms [Sho97] that solve these problems efficiently
- Post-quantum cryptography aims to create cryptosystems based on problems immune to quantum speedups

Motivation

- Imminent threat from quantum computers
- Several active branches of post-quantum cryptography
  - Focus on cryptosystems that are based on the difficulty of solving systems of equations
- Standardization calls by institutions such as NIST and IRTF
- Development of quantum computers by corporations, such as Google and Intel

Multivariate cryptography

- Cryptography based on systems of multivariate quadratic equations over finite fields

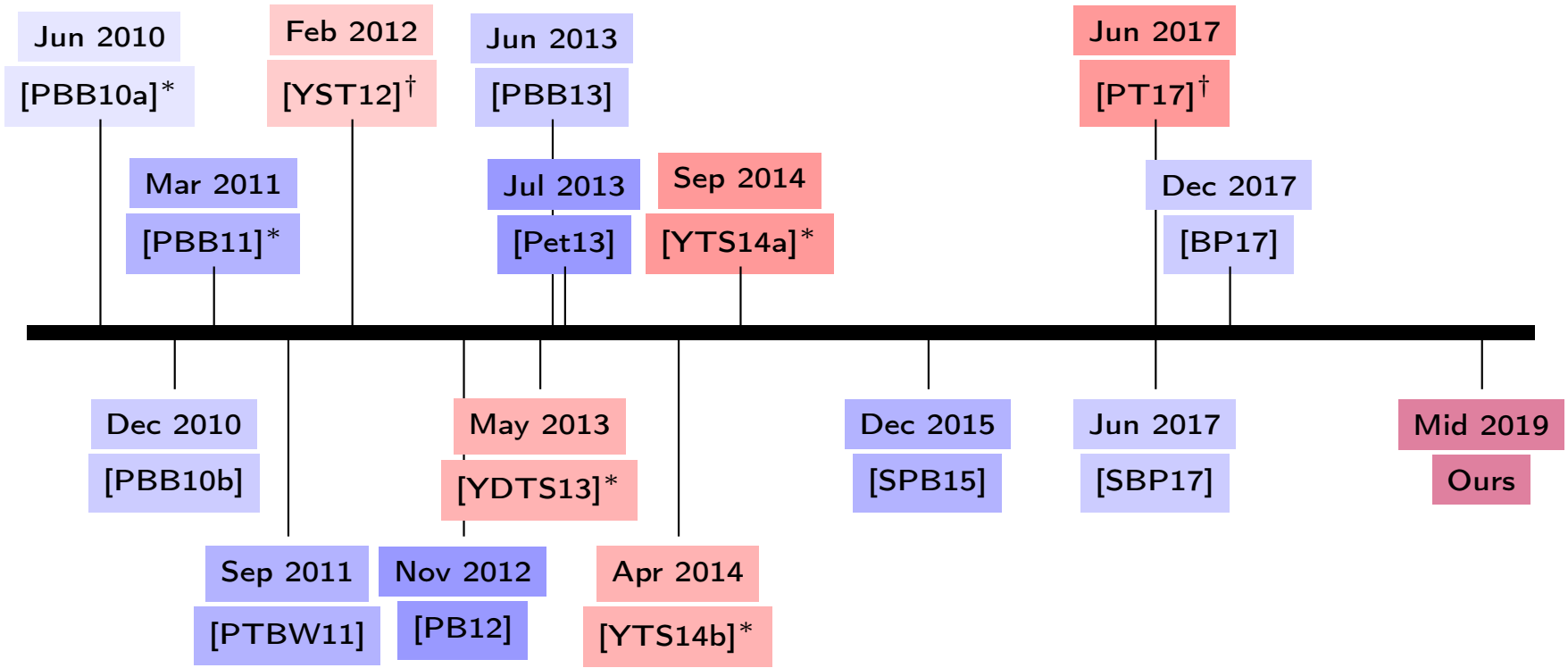


- Fast operations, small signature sizes and large keys, compared to classical schemes

Underlying issue

- Focus on the Rainbow signature scheme, due to Ding and Schmidt [DS05], submitted to NIST for standardization
- Easy description, good balance between signature and key sizes
- Keys in the order of 10 KB, while classical schemes feature sub-1 KB
- Introduction of structures in the keys may lower security

Related works



Schemes in blue optimise public keys, while red ones reduce private keys. Darker tones mean greater success. Asterisks denote reparametrized works and crosses denote broken schemes.

Hypothesis

- To the best of our knowledge, works have reduced either private or public keys
- Do there exist any restrictions in doing both at the same time?
- Is it possible to generate a structured public key from a similarly composed private key?
- Introduction of matrix symmetries as possible arrangements may lower security

Objectives

- Establishment of fit matrix structures to be introduced
- Measurement of security achieved by keys created with those matrices
- Development of a method in which private and public keys are structurally related
- Description of a new signature scheme with carefully chosen parameters for devices with distinct requirements

Methodology

- Review schemes that reduce key sizes, cryptanalysis of these, and study matrix-like symmetric structures
- Create an algorithm to generate a compact private-public key pair
- Apply currently known cryptanalytic methods to test security of signatures created by these keys
- Compare performance and security with related works
- Publish and present results through papers, dissertation etc.

Expected results

- Identify the relationship between matrix types and their effect on security
- Deep analysis on how to maintain structure when generating a key pair
- Present a Rainbow-like signature scheme that features reduction of private and public key sizes
- International collaboration and scientific contributions

References I

W. Beullens and B. Preneel.

Field Lifting for Smaller UOV Public Keys.

In A. Patra and N. Smart, editors, *Progress in Cryptology – INDOCRYPT 2017*, volume 10698 of *Lecture Notes in Computer Science*, December 2017.

J. Ding and D. Schmidt.

Rainbow, a New Multivariable Polynomial Signature Scheme.

In J. Ioannidis, A. Keromytis, and M. Yung, editors, *Applied Cryptography and Network Security*, volume 3531 of *Lecture Notes in Computer Science*, pages 164–175, June 2005.

A. Petzoldt and S. Bulygin.

Linear Recurring Sequences for the UOV Key Generation Revisited.

In T. Kwon, M.-K. Lee, and D. Kwon, editors, *Information Security and Cryptology – ICISC 2012*, volume 7839 of *Lecture Notes in Computer Science*, pages 441–455, November 2012.

A. Petzoldt, S. Bulygin, and J. Buchmann.

A Multivariate Signature Scheme with a Partially Cyclic Public Key.

In J.-C. Faugère and C. Cid, editors, *International Conference on Symbolic Computation and Cryptography*, pages 229–235, June 2010.

A. Petzoldt, S. Bulygin, and J. Buchmann.

CyclicRainbow – A Multivariate Signature Scheme with a Partially Cyclic Public Key.

In G. Gong and K. C. Gupta, editors, *Progress in Cryptology – INDOCRYPT 2010*, volume 6498 of *Lecture Notes in Computer Science*, pages 33–48, December 2010.

A. Petzoldt, S. Bulygin, and J. Buchmann.

Linear Recurring Sequences for the UOV Key Generation.

In D. Catalano, N. Fazio, R. Gennaro, and A. Nicolosi, editors, *Public Key Cryptography – PKC 2011*, volume 6571 of *Lecture Notes in Computer Science*, pages 335–350, March 2011.

References II

A. Petzoldt, S. Bulygin, and J. Buchmann.

Fast Verification for Improved Versions of the UOV and Rainbow Signature Schemes.
In P. Gaborit, editor, *Post-Quantum Cryptography*, volume 7932 of *Lecture Notes in Computer Science*, pages 188–202, June 2013.

A. Petzoldt.

Selecting and Reducing Key Sizes for Multivariate Cryptography.
PhD thesis, Technische Universität Darmstadt, July 2013.

Z. Peng and S. Tang.

Circulant Rainbow: A New Rainbow Variant With Shorter Private Key and Faster Signature Generation.
IEEE Access, 5:11877–11886, June 2017.

A. Petzoldt, E. Thomae, S. Bulygin, and C. Wolf.

Small Public Keys and Fast Verification for $\mathcal{M}$ultivariate $\mathcal{Q}$uadratic Public Key Systems.
In B. Preneel and T. Takagi, editors, *Cryptographic Hardware and Embedded Systems – CHES 2011*, volume 6917 of *Lecture Notes in Computer Science*, pages 475–490, September 2011.

A. Szepieniec, W. Beullens, and B. Preneel.

MQ Signatures for PKI.
In T. Lange and T. Takagi, editors, *Post Quantum Cryptography*, volume 10346 of *Lecture Notes in Computer Science*, pages 224–240, June 2017.

P. W. Shor.

Polynomial-Time Algorithms for Prime Factorization and Discrete Logarithms on a Quantum Computer.
SIAM Journal on Computing, 26(5):1484–1509, October 1997.

References III

K.-A. Shim, C.-M. Park, and Y.-J. Baek.

Lite-Rainbow: Lightweight Signature Schemes Based on Multivariate Quadratic Equations and Their Secure Implementations.
In A. Biryukov and V. Goyal, editors, *Progress in Cryptology – INDOCRYPT 2015*, volume 9462 of *Lecture Notes in Computer Science*, pages 45–63, December 2015.

T. Yasuda, J. Ding, T. Takagi, and K. Sakurai.

A Variant of Rainbow with Shorter Secret Key and Faster Signature Generation.
In K. Chen, Q. Xie, W. Qiu, S. Xu, and Y. Zhao, editors, *ACM Workshop on Asia Public-Key Cryptography*, pages 57–62, May 2013.

T. Yasuda, K. Sakurai, and T Takagi.

Reducing the Key Size of Rainbow Using Non-commutative Rings.
In O. Dunkelman, editor, *Topics in Cryptology – CT-RSA 2012*, volume 7178 of *Lecture Notes in Computer Science*, pages 68–83, February 2012.

T. Yasuda, T. Takagi, and K. Sakurai.

Efficient variant of Rainbow using sparse secret keys.
Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 5(3):3–13, September 2014.

T. Yasuda, T. Takagi, and K. Sakurai.

Efficient Variant of Rainbow without Triangular Matrix Representation.
In M. S. Mahendra, E. J. Neuhold, M. A. Tjoa, and I. You, editors, *Information and Communication Technology*, volume 8407 of *Lecture Notes in Computer Science*, pages 532–541, April 2014.