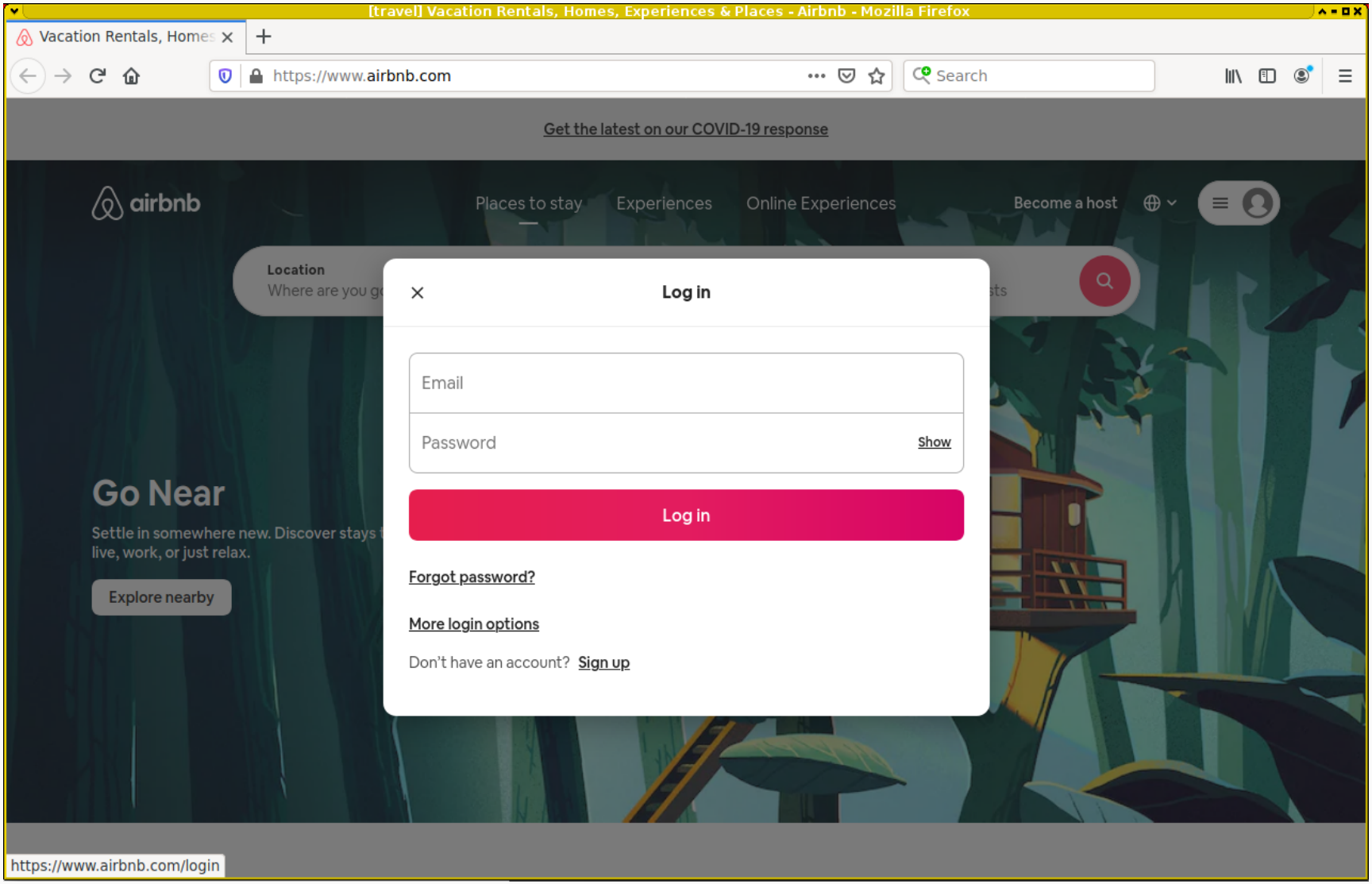
MAX PLANCK INSTITUTE
FOR SECURITY AND PRIVACY

The transition to post-quantum cryptography: challenge and chance

Peter Schwabe

November 14, 2020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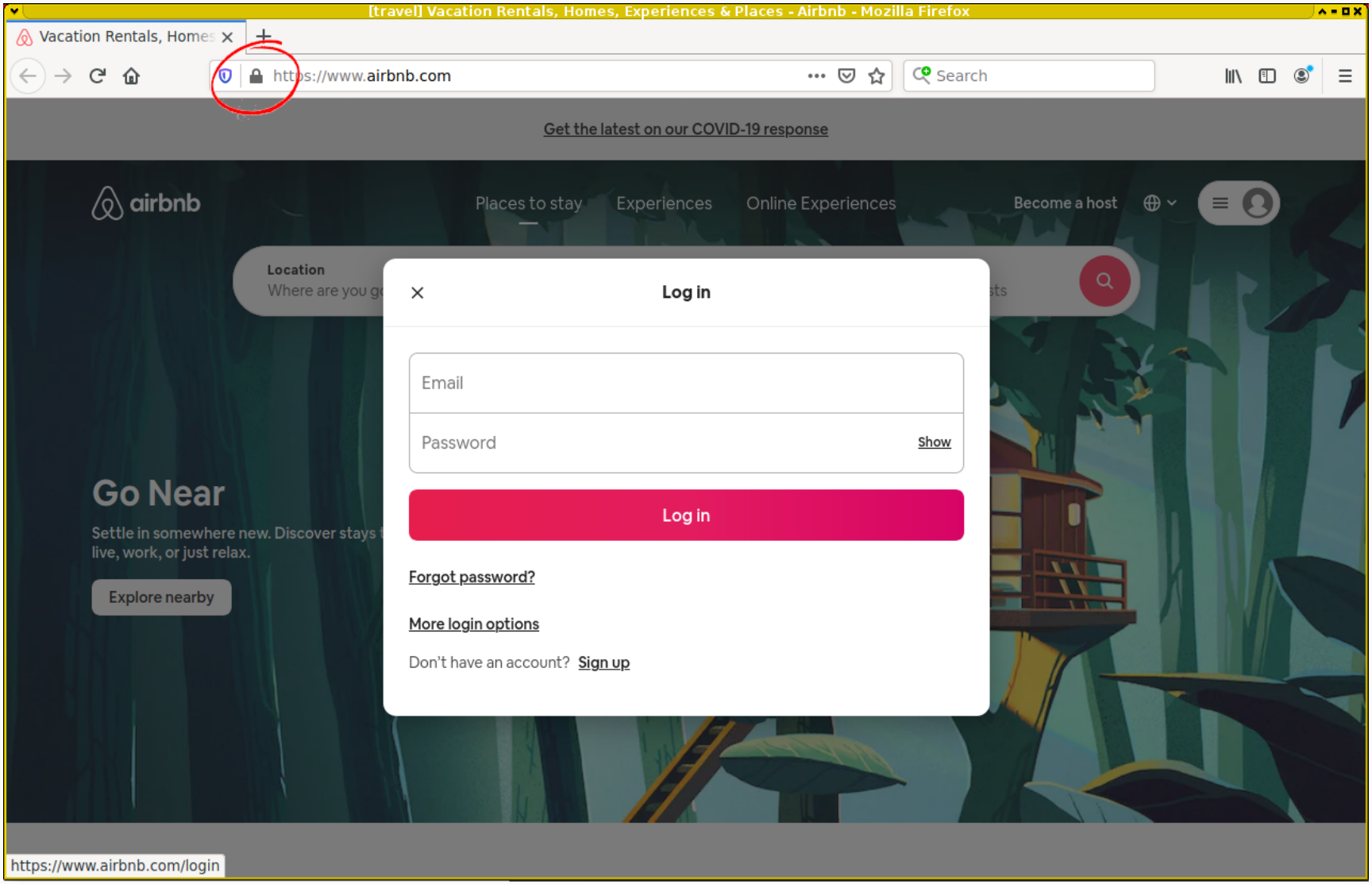
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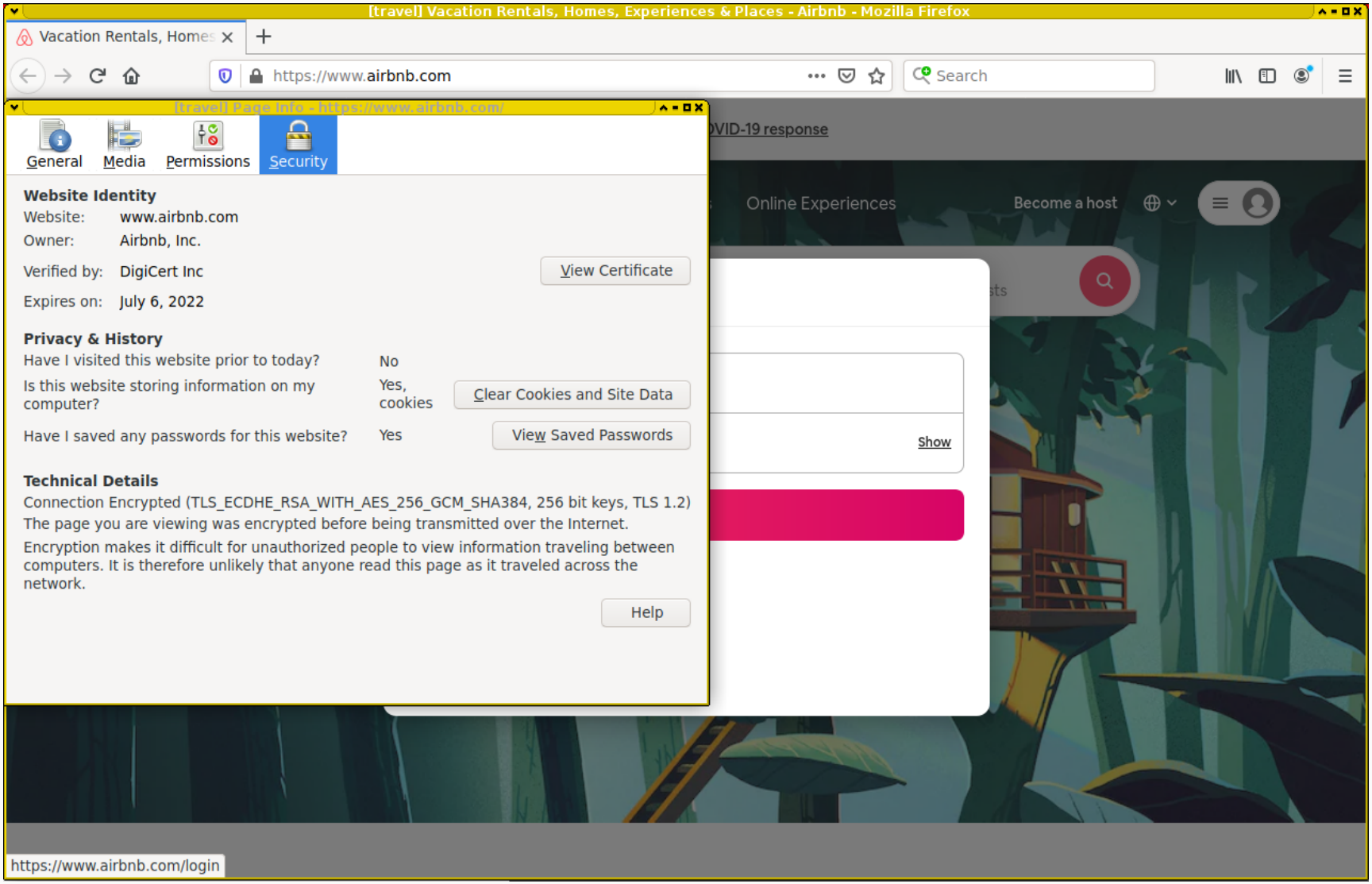
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Have I visited this website prior to today? No
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Clear Cookies and Site Data
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Connection Encrypted (TLS_ECDHE_RSA_WITH_AES_256_GCM_SHA384, 256 bit keys, TLS 1.2)
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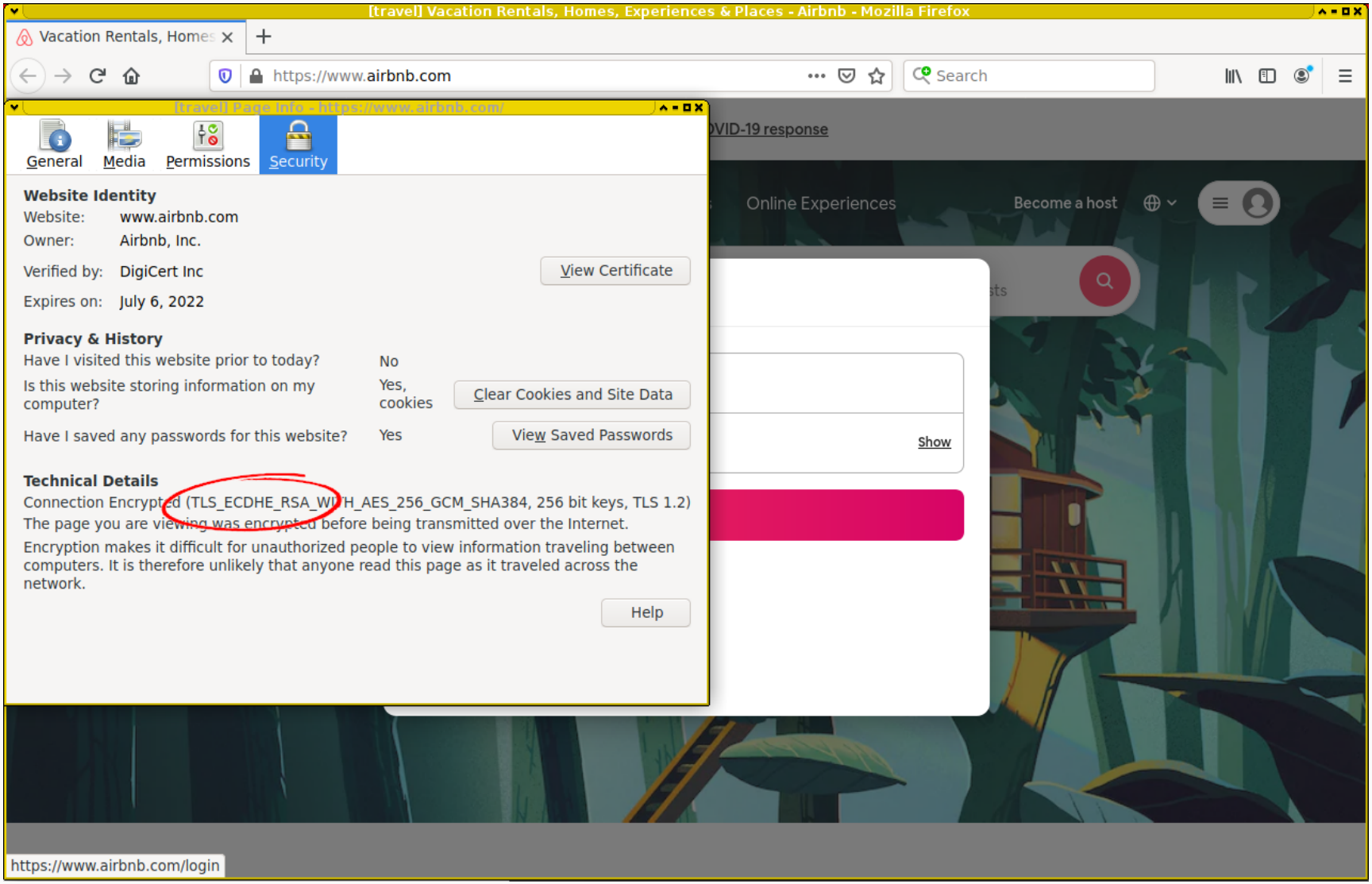
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Verified by: DigiCert Inc
View Certificate
Expires on: July 6, 2022
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Have I visited this website prior to today? No
Is this website storing information on my computer? Yes, cookies
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Polynomial-Time Algorithms for Prime Factorization and Discrete Logarithms on a Quantum Computer*

Peter W. Shor†

Abstract

A digital computer is generally believed to be an efficient universal computing device; that is, it is believed able to simulate any physical computing device with an increase in computation time by at most a polynomial factor. This may not be true when quantum mechanics is taken into consideration. This paper considers factoring integers and finding discrete logarithms, two problems which are generally thought to be hard on a classical computer and which have been used as the basis of several proposed cryptosystems. Efficient randomized algorithms are given for these two problems on a hypothetical quantum computer. These algorithms take a number of steps polynomial in the input size, e.g., the number of digits of the integer to be factored.

“In the past, people have said, maybe it’s 50 years away, it’s a dream, maybe it’ll happen sometime. I used to think it was 50. Now I’m thinking like it’s 15 or a little more. It’s within reach. It’s within our lifetime. It’s going to happen.”

—Mark Ketchen (IBM), Feb. 2012, about quantum computers

Post-quantum crypto

Definition

Post-quantum crypto is (asymmetric) crypto that resists attacks using classical *and quantum* computers.

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5 main directions

- Lattice-based crypto (PKE and Sigs)
- Code-based crypto (mainly PKE)
- Multivariate-based crypto (mainly Sigs)
- Hash-based signatures (only Sigs)
- Isogeny-based crypto (so far, mainly PKE)

The NIST PQC “not-a-competition”

- Inspired by two earlier NIST crypto competitions:
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- PQC project:
  - Announcement: Feb 2016
  - Call for proposals: Dec 2016 (based on community input)
  - Deadline for submissions: Nov 2017

The NIST competition: initial overview

Count of Problem Category	Column Labels		
Row Labels	Key Exchange	Signature	Grand Total
?	1		1
Braids	1	1	2
Chebychev	1		1
Codes	19	5	24
Finite Automata	1	1	2
Hash		4	4
Hypercomplex Numbers	1		1
Isogeny	1		1
Lattice	24	4	28
Mult. Var	6	7	13
Rand. walk	1		1
RSA	1	1	2
Grand Total	**57**	**23**	**80**

4 31 27

Overview tweeted by Jacob Alperin-Sheriff on Dec 4, 2017.

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Signature schemes

- 3 lattice-based
- 2 symmetric-crypto based
- 4 MQ-based

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- 4 key-agreement schemes
  - 3 lattice-based
  - 1 code-based
- 3 signature schemes
  - 2 lattice-based
  - 1 MQ-based

Alternate schemes

- 5 key-agreement schemes
  - 2 lattice-based
  - 2 code-based
  - 1 isogeny-based
- 3 signature schemes
  - 2 symmetric-crypto based
  - 1 MQ-based

What now?

- NIST is expected to announce winners in late 2021
- $\approx$ one year later get standards

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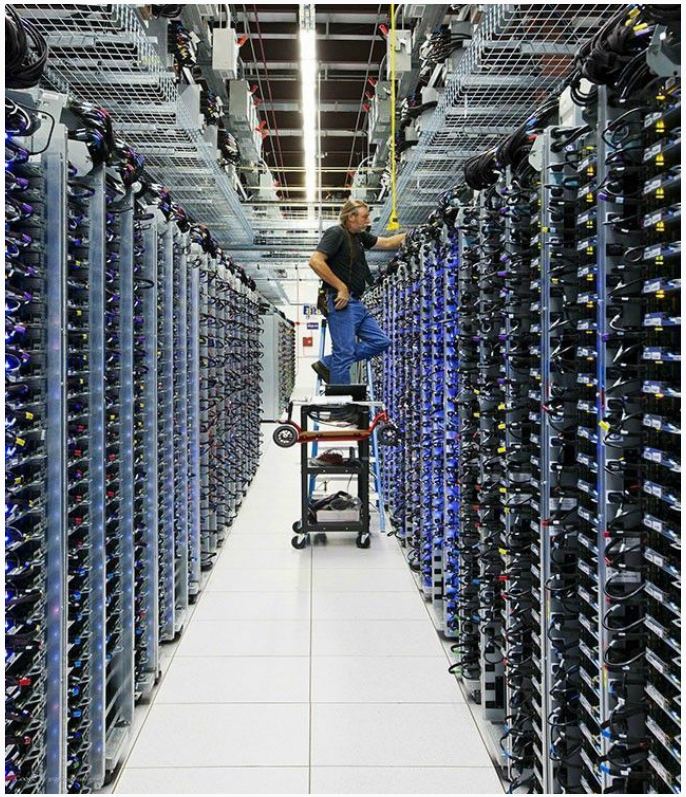
Replacing MD5 was “easy”!

Challenge 1: Performance



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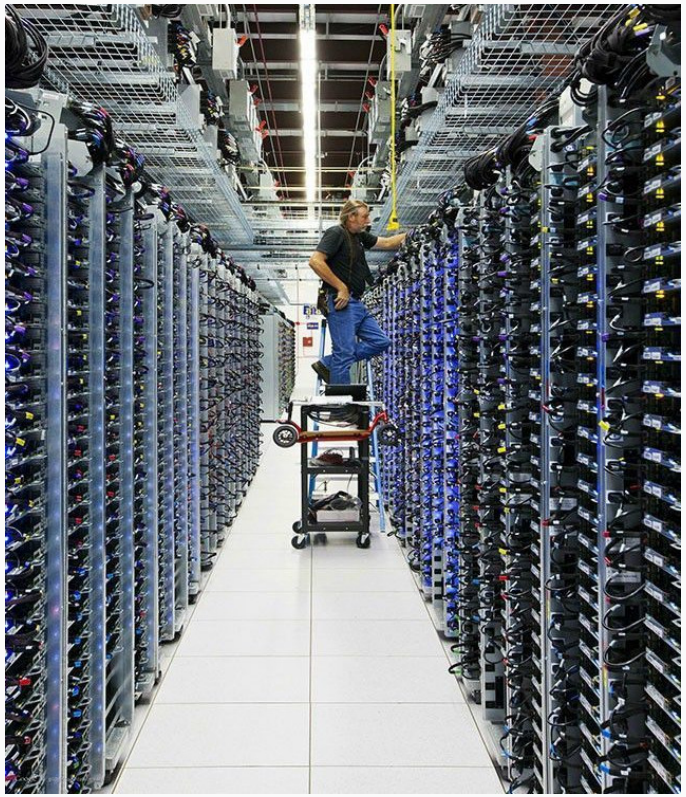

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  - Reduce cost for busy servers
  - Fit into constrained devices
- Small routines executed many times
- Often hand-optimized on assembly level

Challenge 1: Performance (ctd.)

Elliptic-curve cryptography

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- SPHINCS$^+$ signing: ≈3 billion cycles
- Kyber (all ops): <80 kcycles
- Kyber data sent: <1.2 KB

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Security reductions

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- "hard problem" may turn out to be easier than expected
- proofs may be wrong

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The case of OCB2

- 2004: Rogaway proposes OCB2
  - Security reduction guaranteeing confidentiality and authenticity
- 2009: OCB2 is standardized by ISO
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- Round-2 qTesla proof wrong (?) $\Rightarrow$ devastating attack

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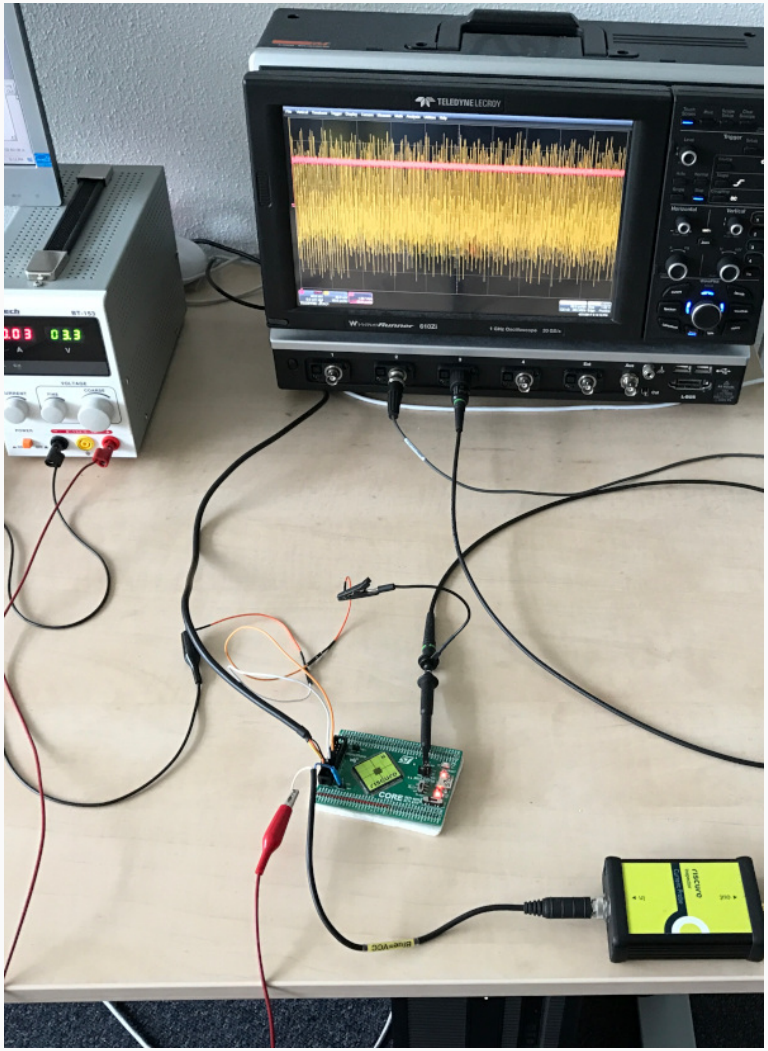

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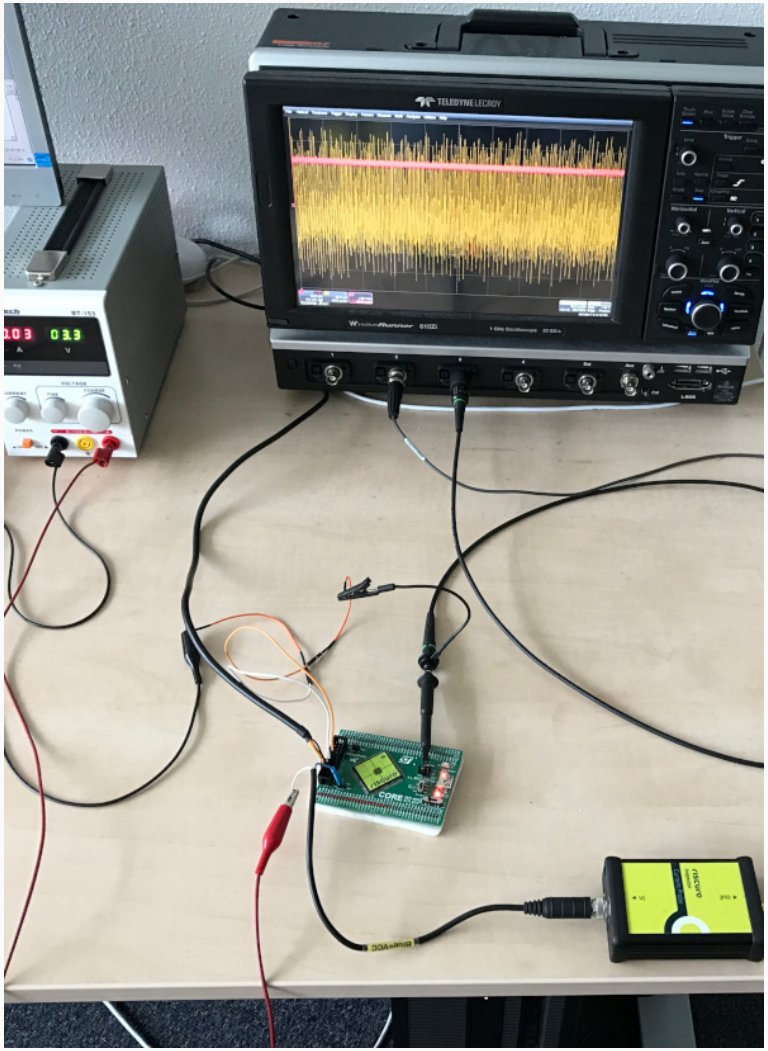

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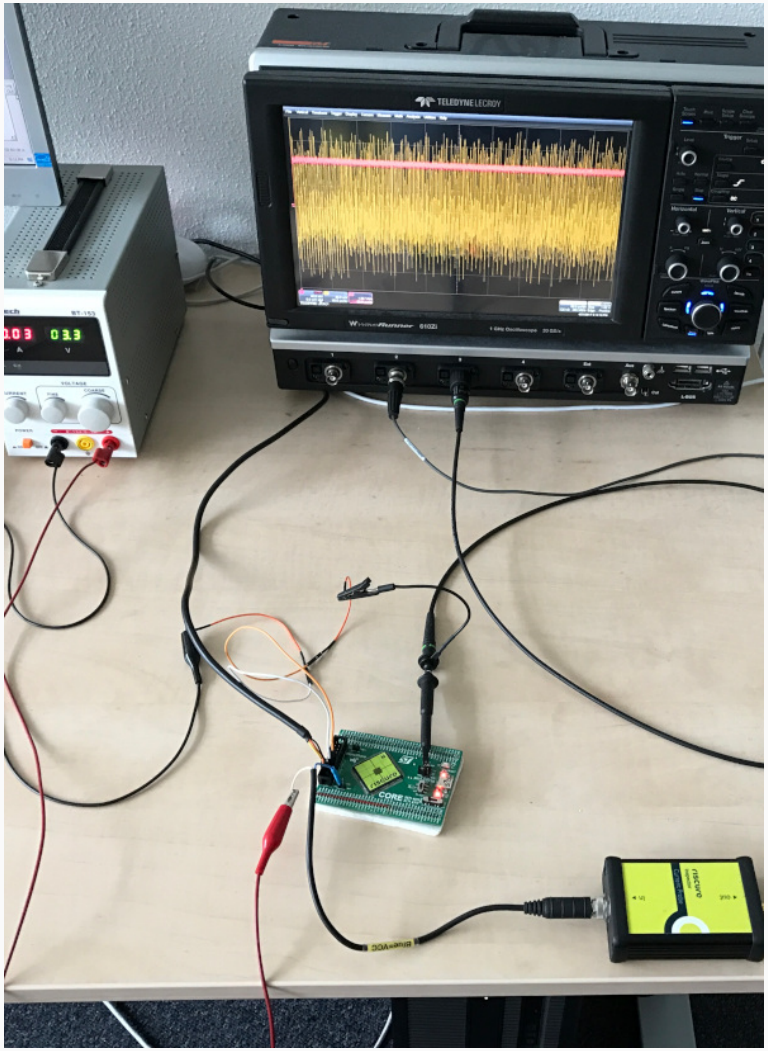

- Attackers see more than input/output:
  - Power consumption
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- **Side-channel attacks:**
  - Measure information
  - Use to obtain secret data
- Timing attacks can be done **remotely**
- Cost of countermeasures heavily depends on the scheme

Challenge 3: Implementation Security (ctd.)

“the implementation security aspect of lattice-based cryptography is still a vastly unexplored and open topic”

— Primas, Pessl, Mangard, 2017.

Challenge 3: Implementation Security (ctd.)

"…this isn't very different for any of the other areas of post-quantum crypto"

— Schwabe, 2020.

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- Baseline: *“constant-time”* implementations
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For many applications, implementations are not ready.

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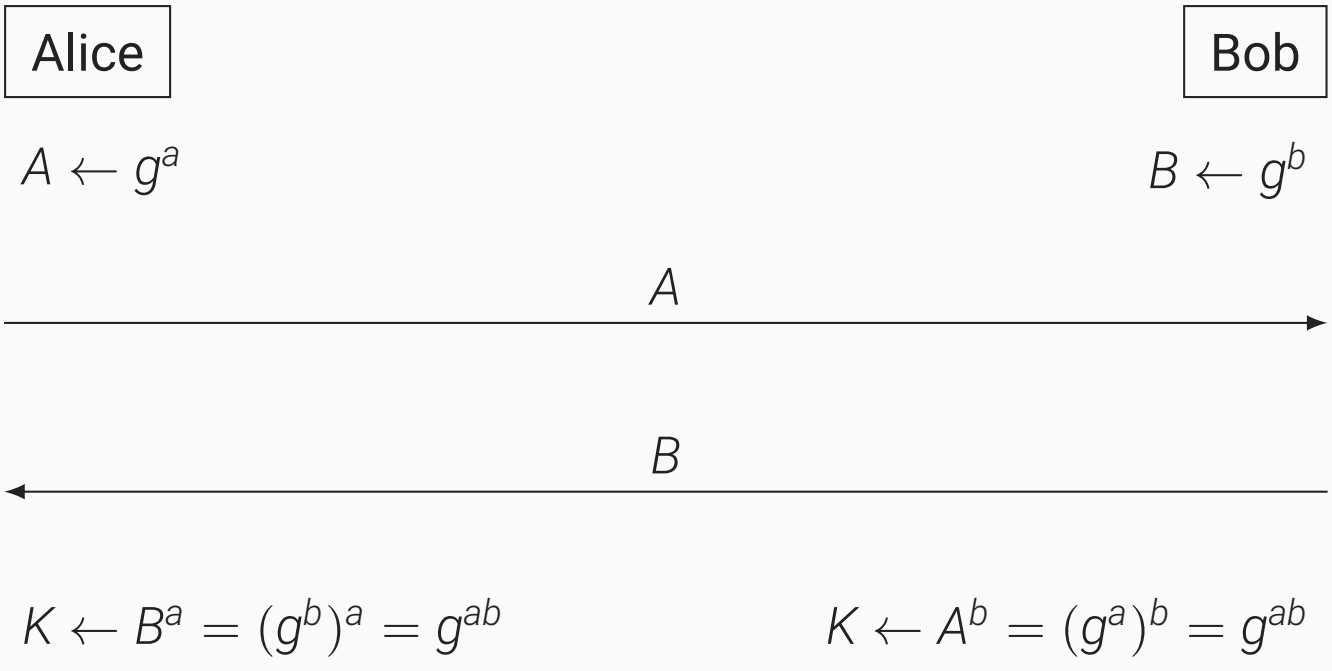
“It’s a huge foot cannon” — Adam Langley

Challenge 5: The curious case of Diffie-Hellman



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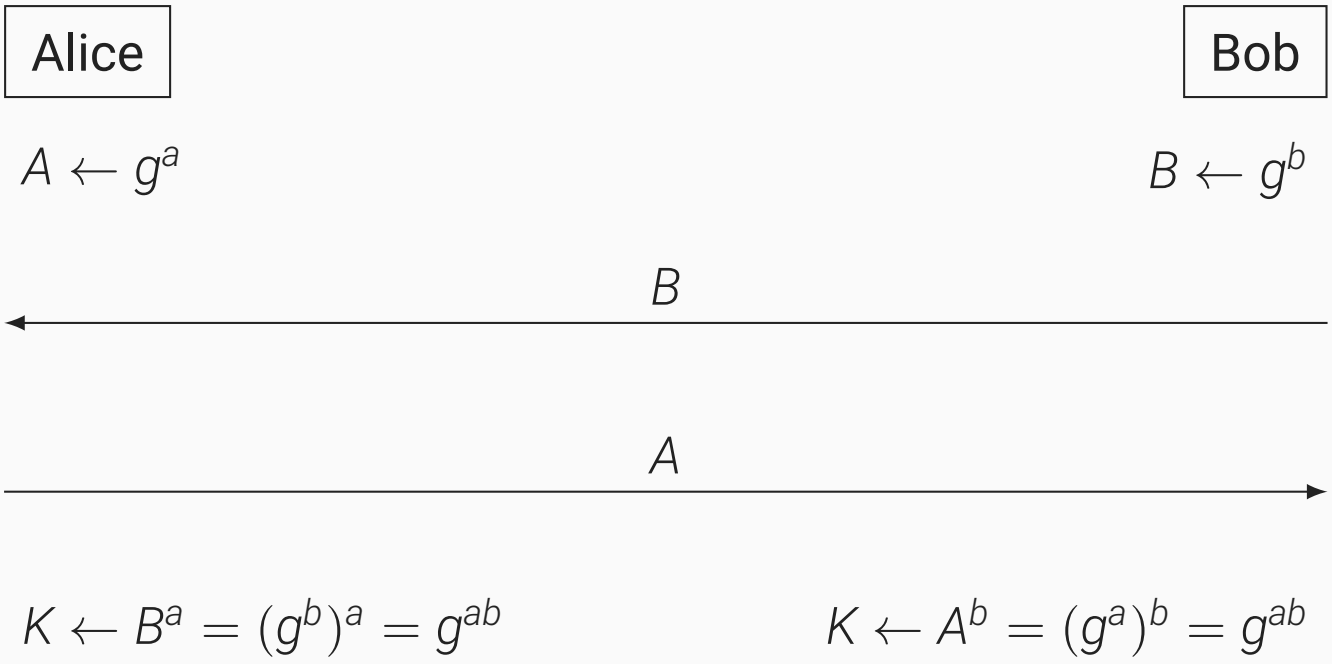

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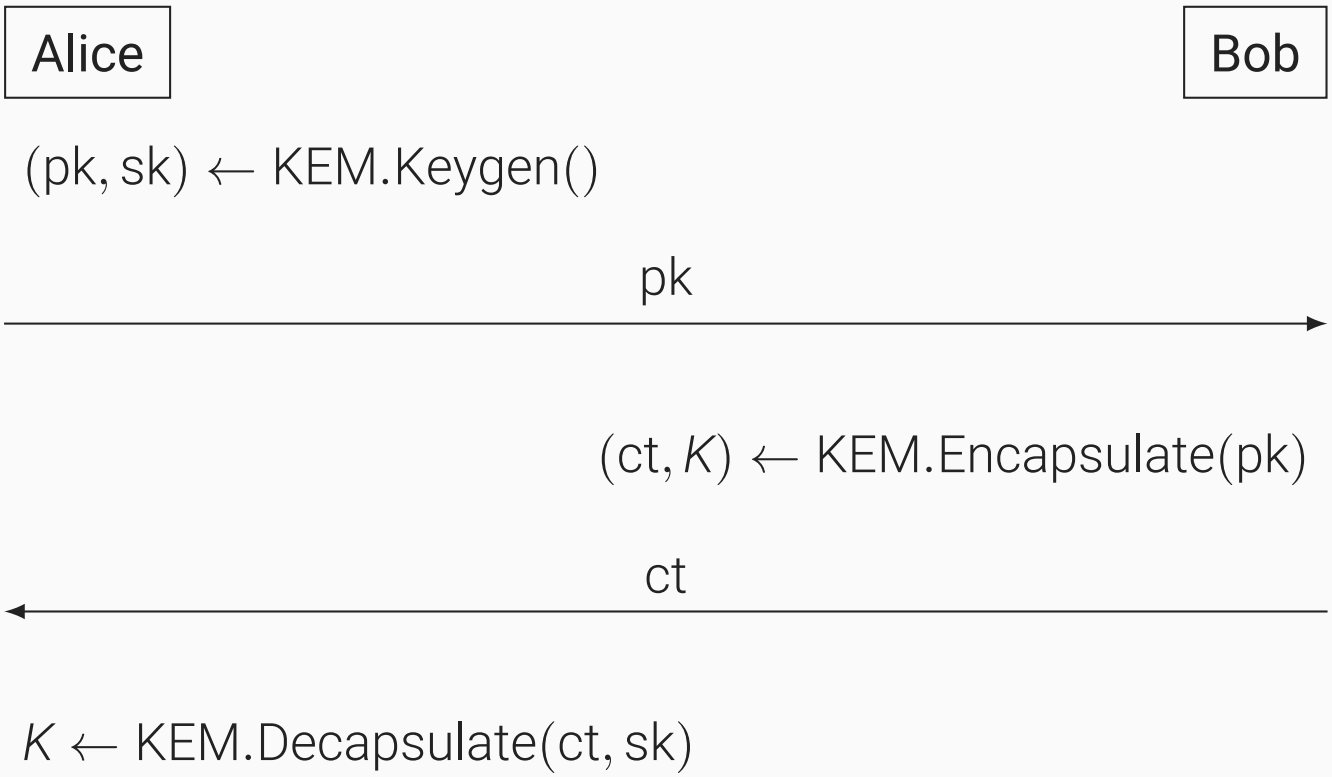
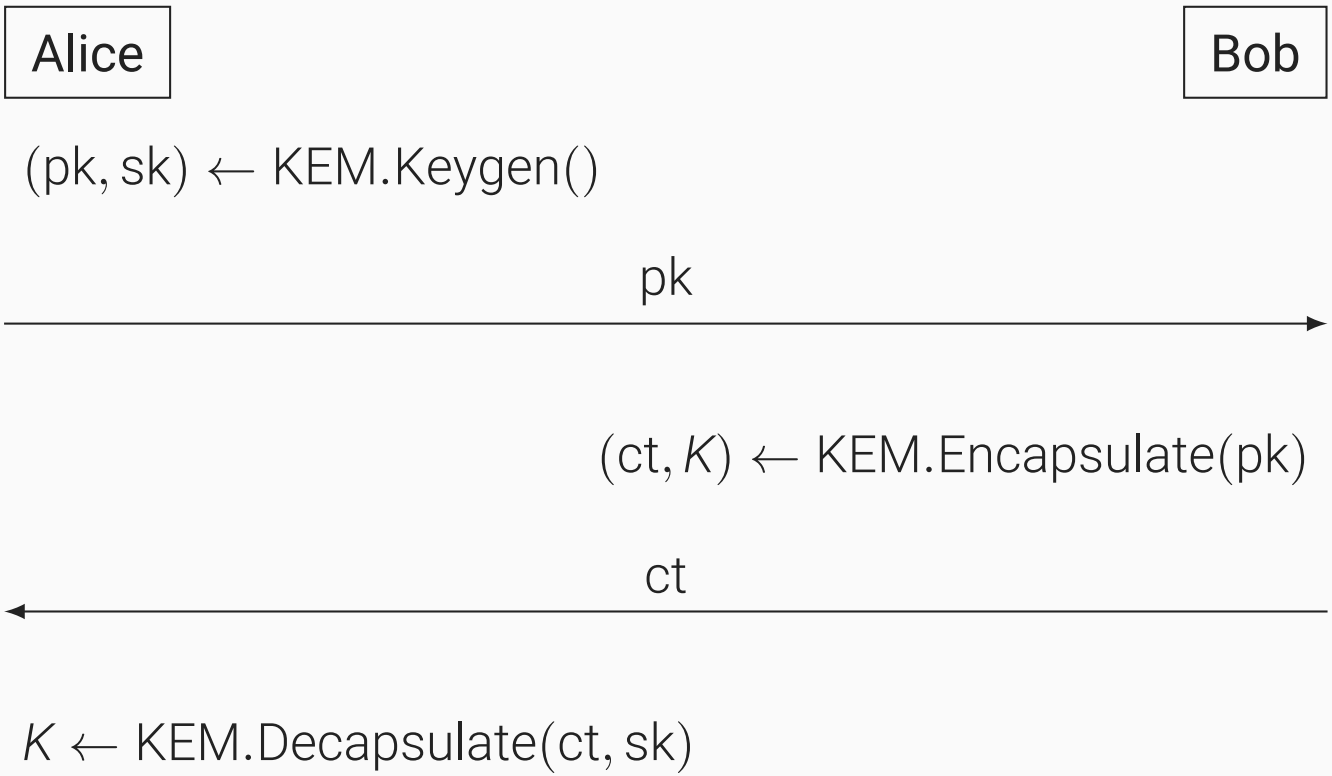


KEMs: as close as you'll get to DH*



*Except with CSIDH (Castryck, Lange, Martindale, Renes, Panny, 2018)

Is it already too late?

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- When do we need to start migrating?

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How long do we need today's communication to be secure?

How long does it take us to migrate?

But for signatures we have time, right?

- Signatures provide authentication
- Cannot retroactively “decrypt” anything
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But for signatures we have time, right?

- Signatures provide authentication
- Cannot retroactively “decrypt” anything
- Stop accepting pre-quantum signatures once there is a quantum computer
- May need to prepare devices today!
- Signatures are used for, e.g., software updates
- What if I cannot update anymore in 15 years?
  - What’s the lifetime of a car?
  - What’s the lifetime of smart-home appliances?

A chance?

How can this migration be a *chance*?

Crypto (software) today

PlayStation 3 hack – how it happened and what it means

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A New Wireless Hack Can Unlock 100 Million Volkswagens

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Malware and Vulnerabilities • October 04, 2019 • Cyware Hacker News

New 'Minerva attack' Can Recover Private Keys From Cryptographic Libraries

Crypto (software) today

High-assurance crypto software

- Use formal methods to improve crypto (software):

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Careful: high-assurance does not mean “unbreakable”

HACS success stories

moz://a

Internet Health Technology

Mozilla Security Blog

FIREFOX SECURITY TLS

Verified cryptography for Firefox 57

Benjamin Beurdouche | September 13, 2017

Traditionally, software is produced in this way: write some code, maybe do some code review, run unit-tests, and then hope it is correct. Hard experience shows that it is very hard for programmers to write bug-free software. These bugs are sometimes caught in manual testing, but many bugs still are exposed to users, and then must be fixed in patches or subsequent versions. This works for most software, but it's not a great way to write cryptographic software; users expect and deserve assurances that the code providing security and privacy is well written and bug free.

HACS success stories

MIT News
ON CAMPUS AND AROUND THE WORLD

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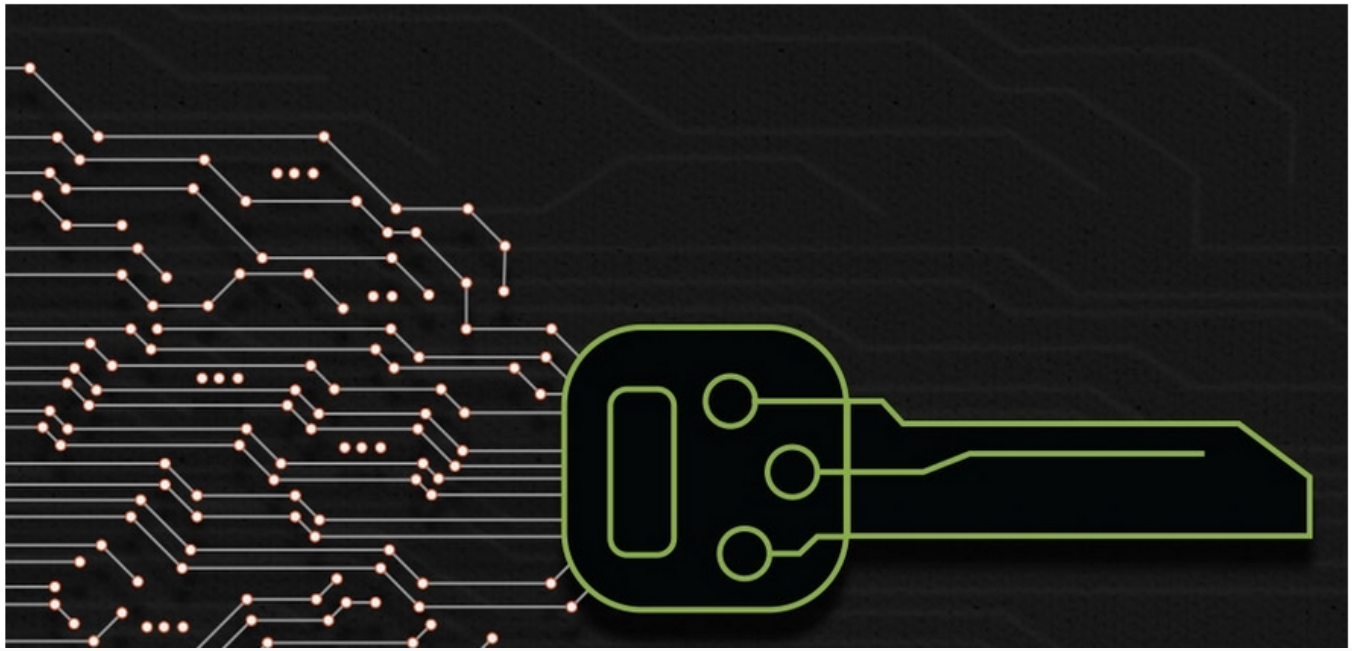
Automated cryptocode generator is helping secure the web

System automatically writes optimized algorithms to encrypt data in Google Chrome browsers and web applications.

Rob Matheson | MIT News Office
June 17, 2019



HACS success stories

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Provably-secure code incorporated into Linux kernel

Daniel Tkacik

APR 29, 2020

An overly optimistic outlook

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- All security reductions are computer verified
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. . . let's see it as an ambitious goal!

Some pointers

PQC resources

- NIST PQC website:
  `https://csrc.nist.gov/Projects/Post-Quantum-Cryptography`
- NIST mailing list:
  `https://csrc.nist.gov/projects/post-quantum-cryptography/email-list`
  `https://groups.google.com/a/list.nist.gov/g/pqc-forum`
- Open Quantum Safe `https://openquantumsafe.org/`
- PQC Wiki: `https://pqc-wiki.fau.edu`

HACS resources

- HACS workshop: `https://www.hacs-workshop.org/`