Ch13: Quantum-Safe Security

Random numbers

Applications:

→ Cryptography
→ Numerical simulations
→ Statistical sampling

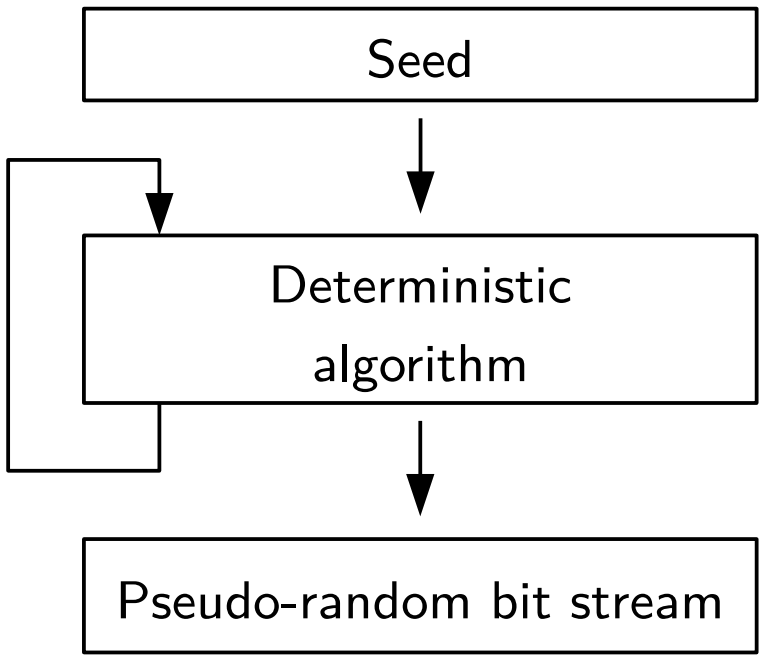
Critical that these values be:

→ Uniformly distributed
→ Independent

There are two main classes of generators: software and physical.

Pseudo random number generators (PRNG)

They consist of an algorithm into which some initial value – called the seed – is fed, and which produces by iteration a sequence of pseudo-random numbers:



Pseudo random number generators (PRNG)

In a well-designed algorithm, this sequence may have most of the properties of a random sequence, and thus pass statistical randomness tests.

However, it is important to note that computers are deterministic systems: given a certain input, a program will always produce the same output.

Because of this very fundamental property, it is impossible for a program to produce a sequence of truly random numbers

By knowing the seed, it is always possible to reproduce the sequence.

Pseudo random number generators (PRNG)

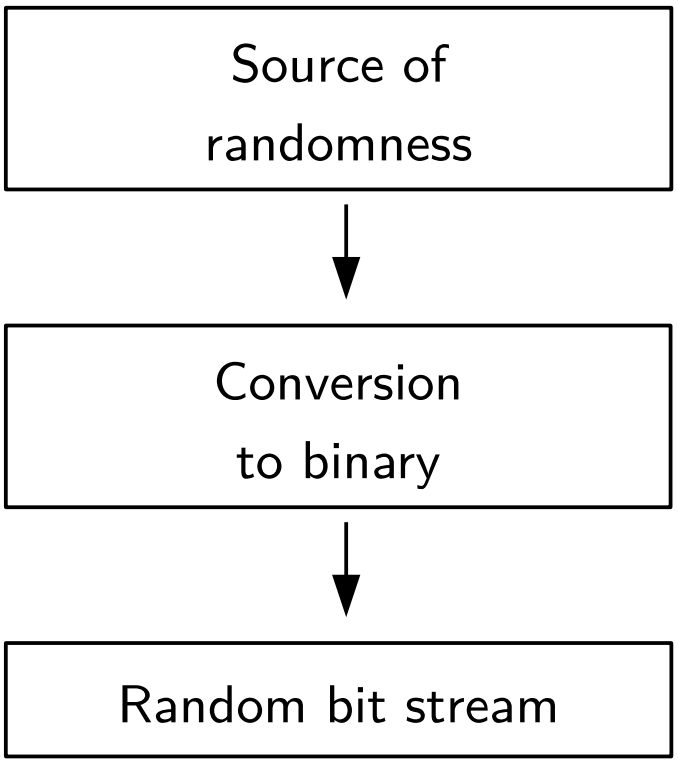
PRNG is a single point of failure for many real-world cryptosystems. If random numbers are insecure – likely to be predictable – then the entire application is insecure.

Topic	Summary	Additional Information
Dual_EC_DRBG	This algorithm was officially recommended by NIST, until it was discovered that it may contain a backdoor, potentially implanted by NSA.	http://www.wired.com/2013/09/nsa-backdoor/
Low entropy in Linux servers	Initially reported in a Black-Hat conference in 2015.	http://www.bbc.com/news/technology-33839925
Untrusted physical RNGs	FreeBSD developers recommend against using the physical RNGs in the processors manufactured by Intel and Via for fear of a backdoor.	http://arstechnica.com/security/2013/12/we-cannot-trust-intel-and-vias-chip-based-crypto-freebsd-developers-say/
Weak keys	There are now well-documented examples, showing how badly chosen or re-used keys damage encryption systems.	https://freedom-to-tinker.com/blog/haldermanheninger/how-is-nsa-breaking-so-much-crypto/ https://factorable.net/weakkeys12.conference.pdf

Source: *Cloud Security Alliance*

Hardware random number generators (HRNG)

For security or other applications where high quality randomness is needed, physical approaches are taken to generate random bits.



Hardware random number generators (HRNG)

A HRNG typically consists of:

→ A transducer to convert some aspect of the physical phenomena to an electrical signal;
→ An amplifier and other electronic circuitry to increase the amplitude of the random fluctuations to a measurable level;
→ Some type of analog to digital converter to convert the output into a digital number, often a simple binary digit 0 or 1.

By repeatedly sampling the randomly varying signal, a series of random numbers is attained.

Hardware random number generators (HRNG)

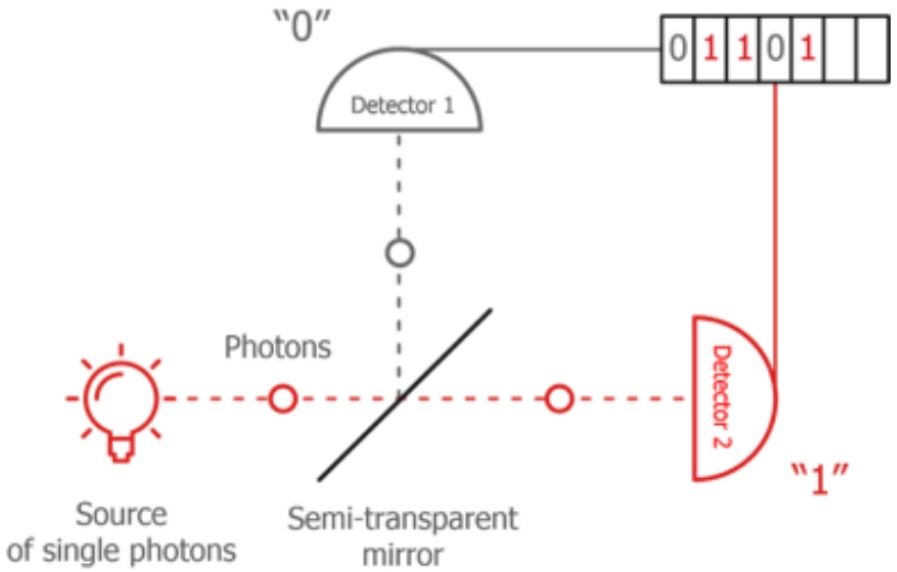
While processes described by classical physics such as clock jitter, chaotic behaviour, *etc* can be used to deliver entropy, classical physics is fundamentally deterministic, i.e. predictable for a given set of conditions.

In addition, although random numbers generated by classical physical processes are likely to pass randomness tests, it can be impossible to verify that they are not influenced by their environment, reducing the output quality.

Quantum random number generators (QRNG)

Generators based on quantum physical processes deliver the highest quality random data. Contrary to classical physics, quantum physics is fundamentally random.

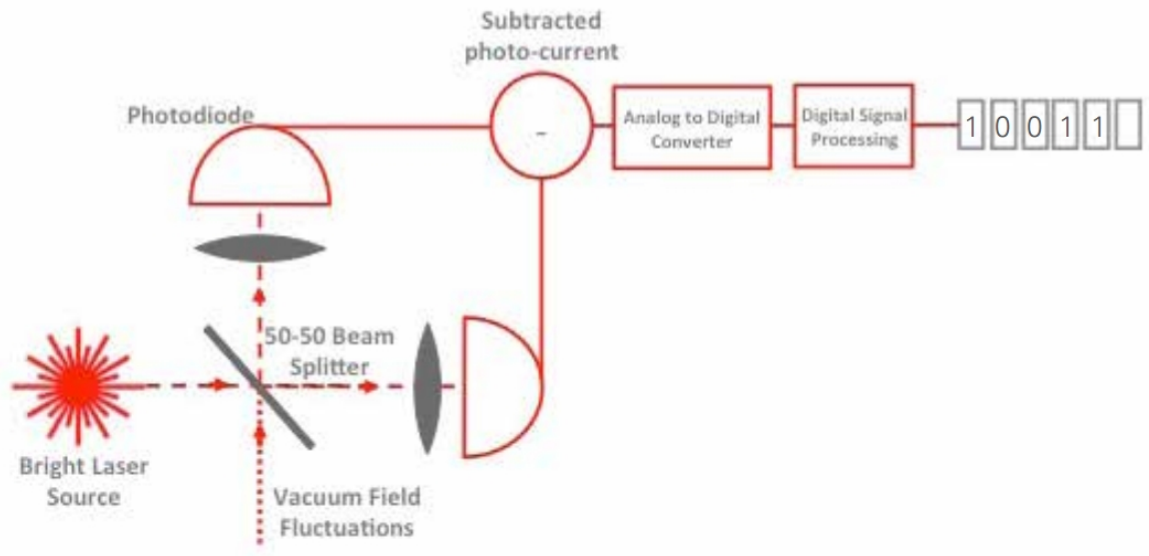
- QRNG based on single-photon splitting:

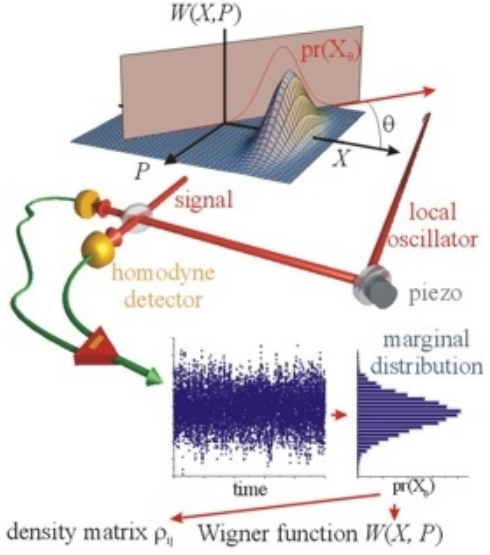


Quantum random number generators (QRNG)

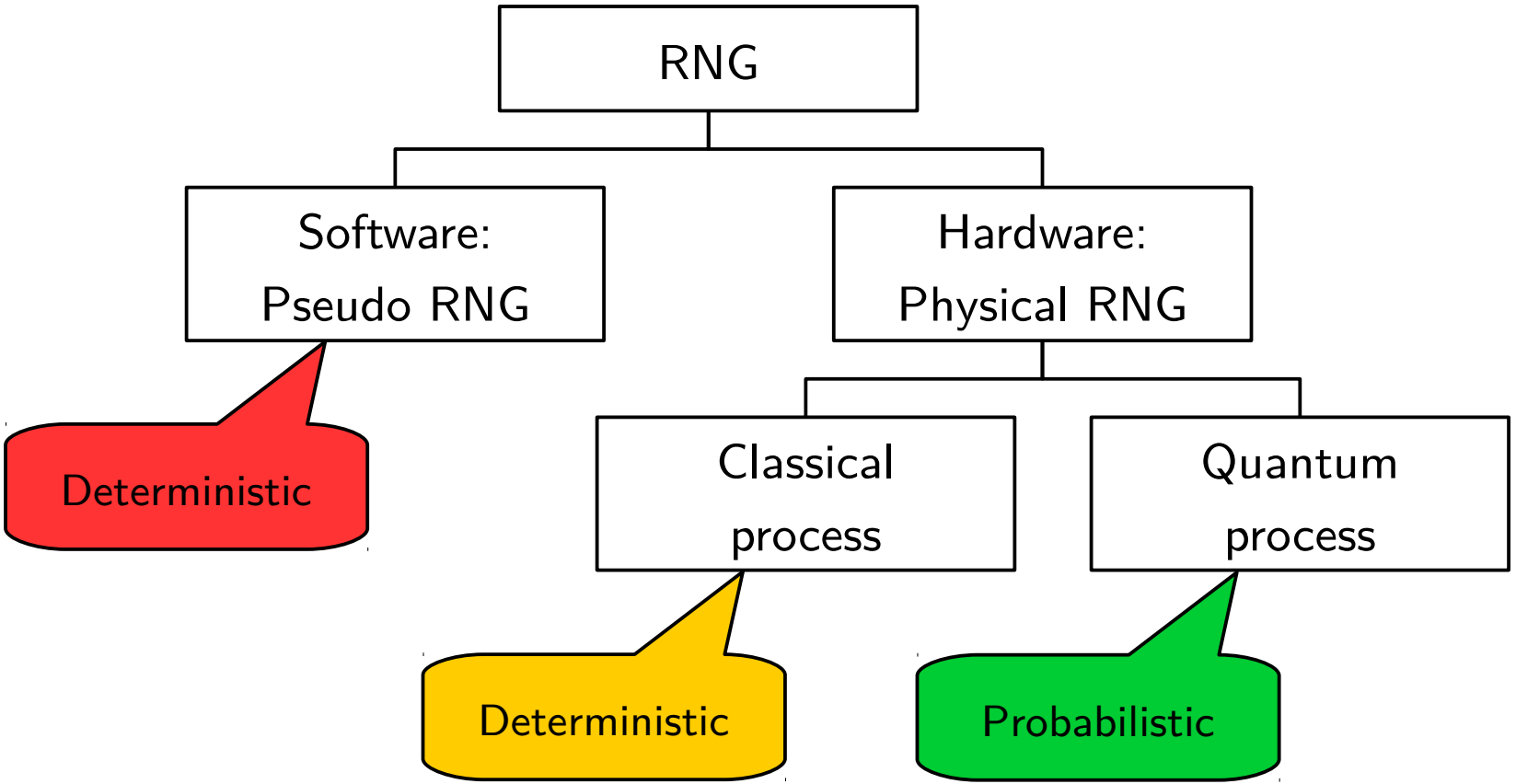
Generators based on quantum physical processes deliver the highest quality random data. Contrary to classical physics, quantum physics is fundamentally random.

- QRNG based on quantum vacuum noise measurements:

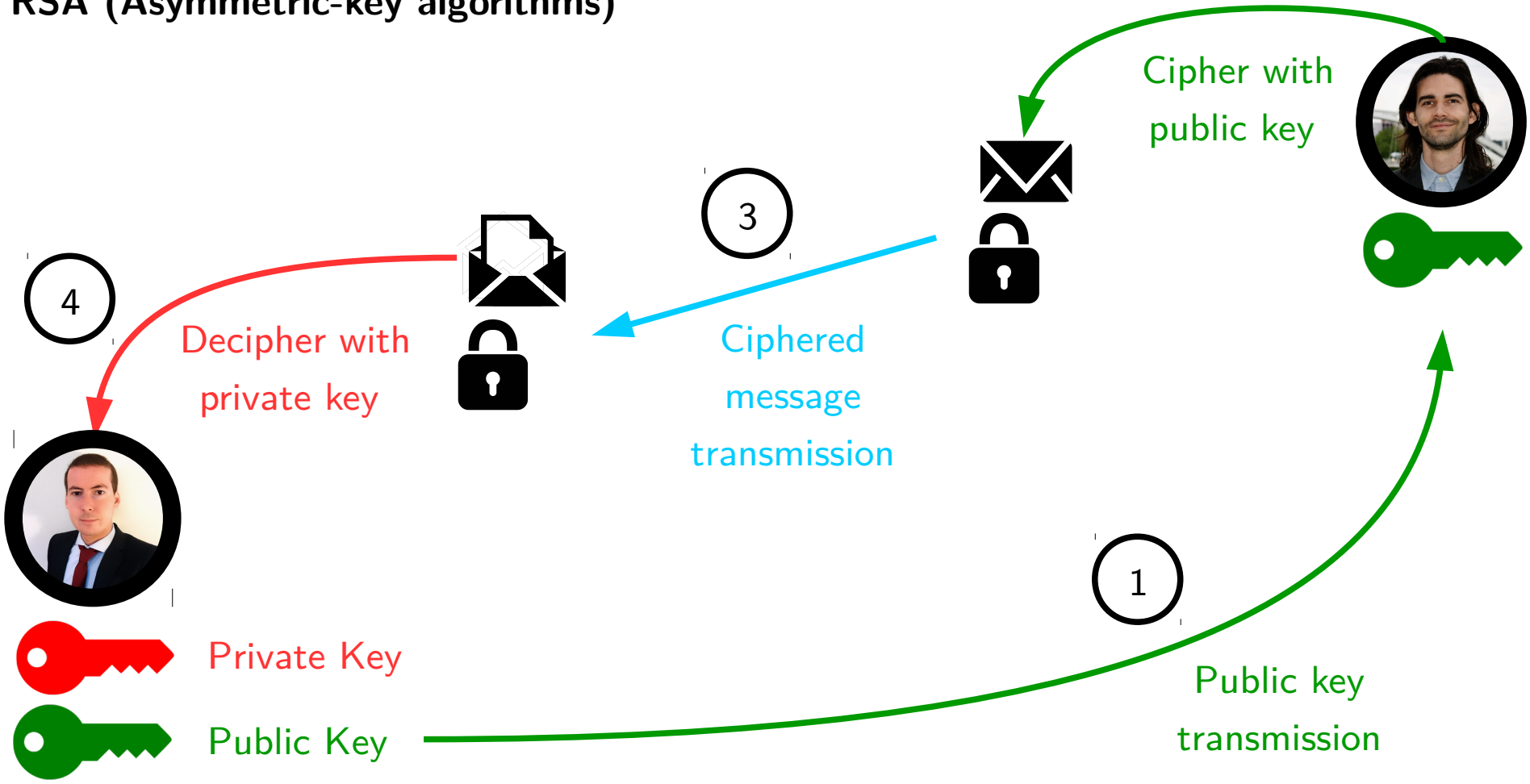




Summary


RNG
Software:
Pseudo RNG
Hardware:
Physical RNG
Deterministic
Classical
process
Quantum
process
Deterministic
Probabilistic

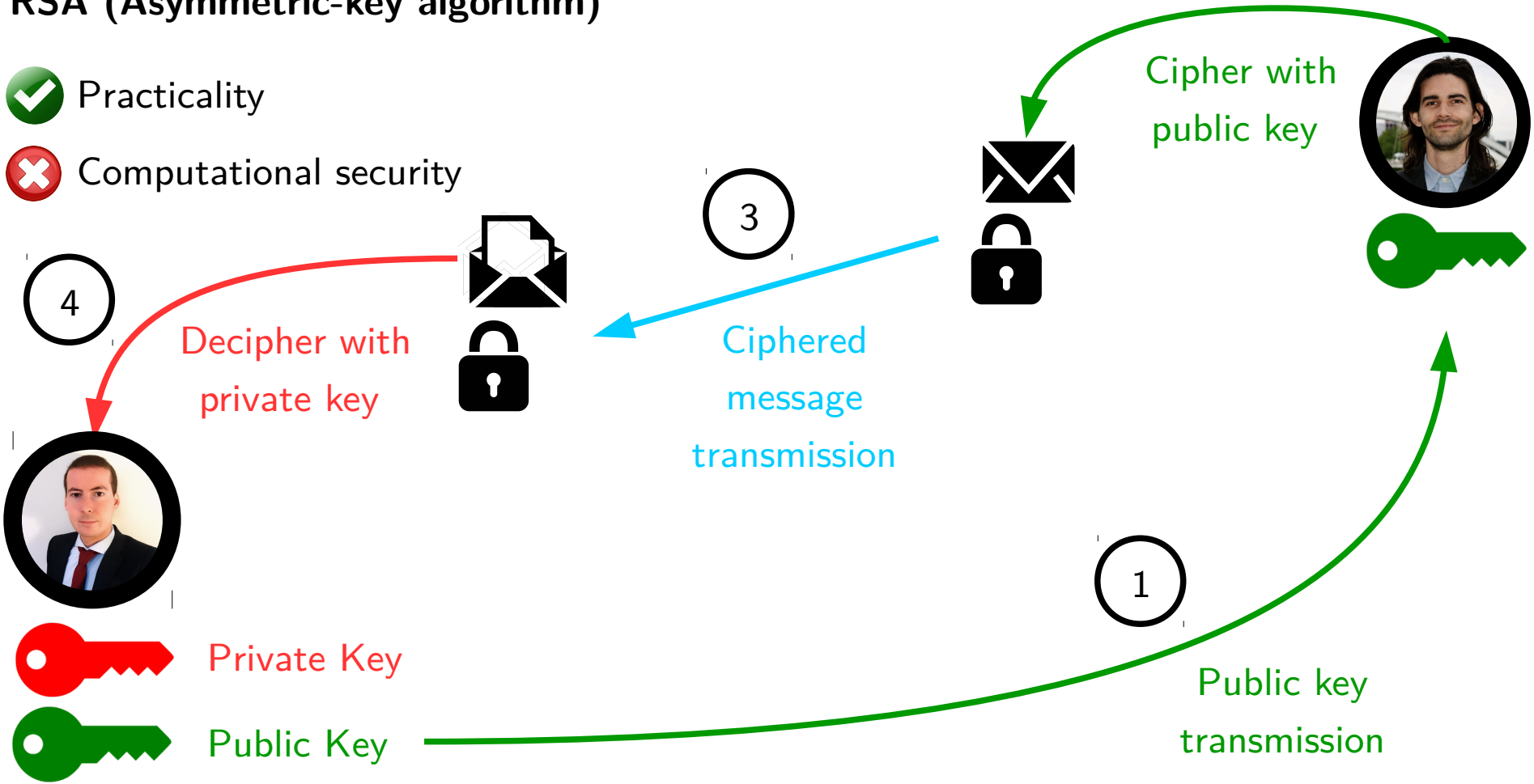
RSA (Asymmetric-key algorithms)



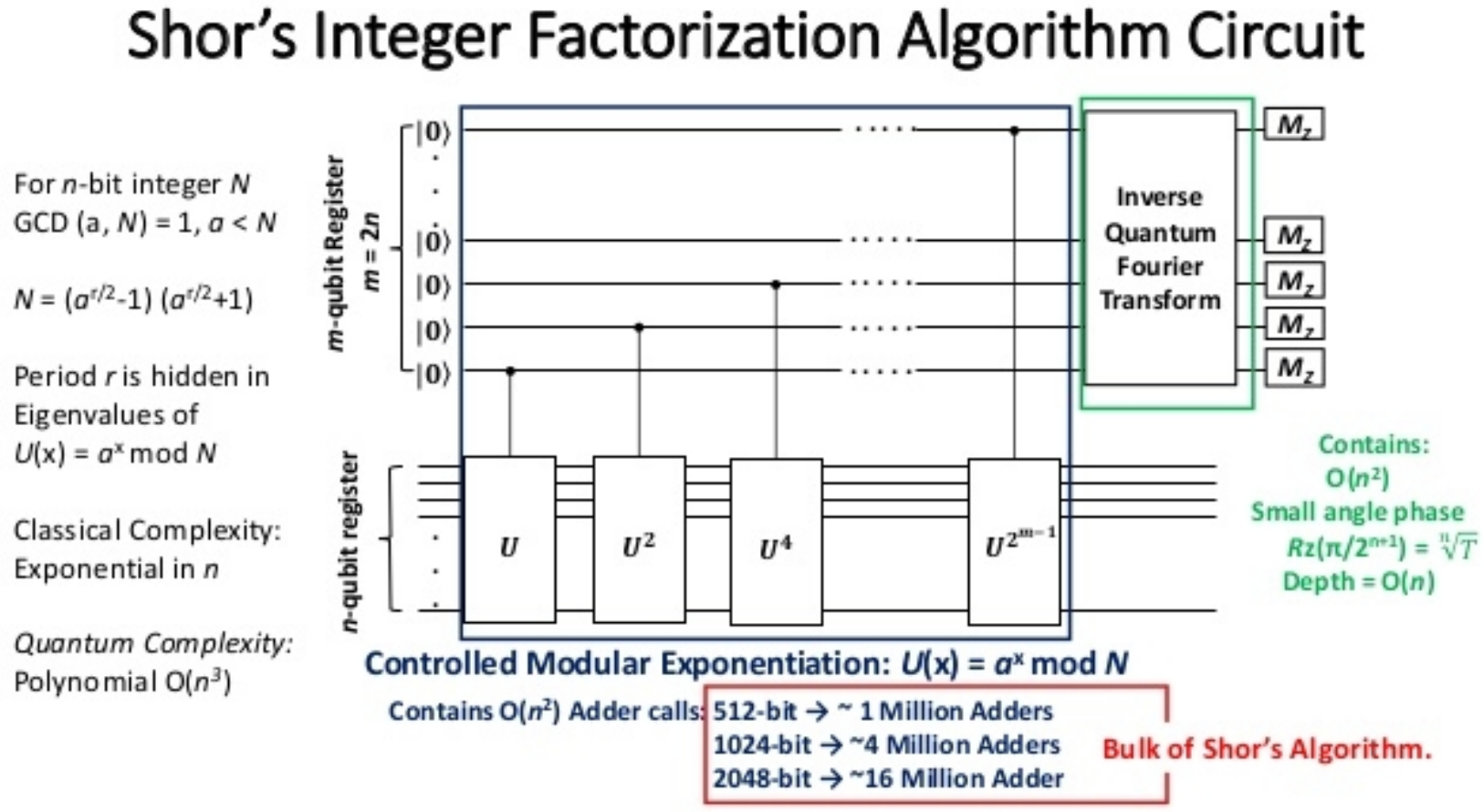
RSA (Asymmetric-key algorithm)

Practicality

Computational security



Shor's quantum factoring algorithm



Shor's quantum factoring algorithm

Quantum Physics

[Submitted on 23 May 2019 (v1), last revised 5 Dec 2019 (this version, v2)]

How to factor 2048 bit RSA integers in 8 hours using 20 million noisy qubits

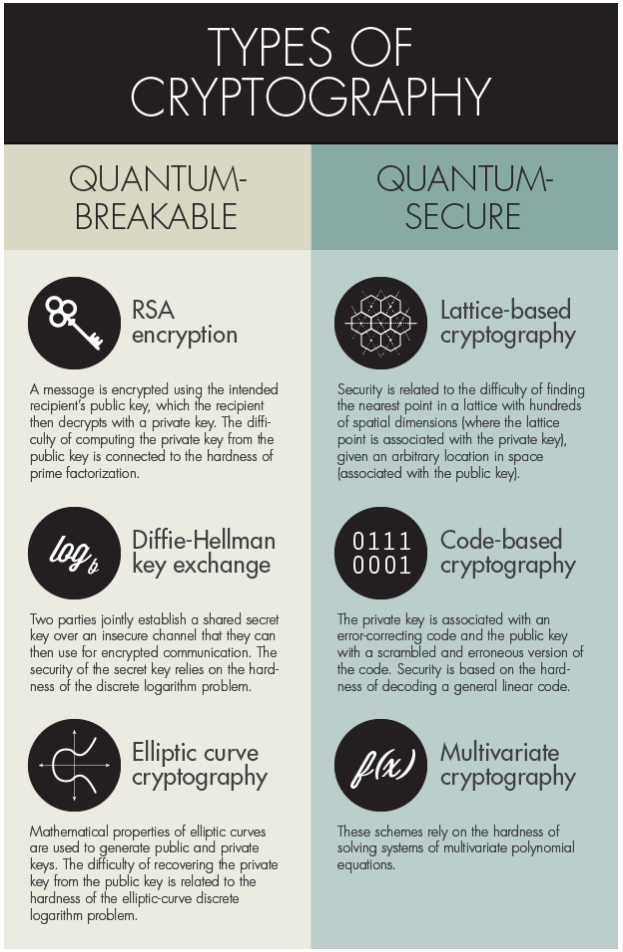
Craig Gidney, Martin Ekerå

We significantly reduce the cost of factoring integers and computing discrete logarithms in finite fields on a quantum computer by combining techniques from Shor 1994, Griffiths-Niu 1996, Zalka 2006, Fowler 2012, Ekerå-Håstad 2017, Ekerå 2017, Ekerå 2018, Gidney-Fowler 2019, Gidney 2019. We estimate the approximate cost of our construction using plausible physical assumptions for large-scale superconducting qubit platforms: a planar grid of qubits with nearest-neighbor connectivity, a characteristic physical gate error rate of 10^{-3}, a surface code cycle time of 1 microsecond, and a reaction time of 10 microseconds. We account for factors that are normally ignored such as noise, the need to make repeated attempts, and the spacetime layout of the computation. When factoring 2048 bit RSA integers, our construction's spacetime volume is a hundredfold less than comparable estimates from earlier works (Fowler et al. 2012, Gheorghiu et al. 2019). In the abstract circuit model (which ignores overheads from distillation, routing, and error correction) our construction uses $3n + 0.002n \lg n$ logical qubits, $0.3n^3 + 0.0005n^3 \lg n$ Toffolis, and $500n^2 + n^2 \lg n$ measurement depth to factor n-bit RSA integers. We quantify the cryptographic implications of our work, both for RSA and for schemes based on the DLP in finite fields.

Comments: 26 pages, 10 figures, 5 tables

Subjects: **Quantum Physics (quant-ph)**

Post-quantum algorithms



NIST

Information Technology Laboratory

COMPUTER SECURITY RESOURCE CENTER

PROJECTS

Post-Quantum Cryptography

Project Overview

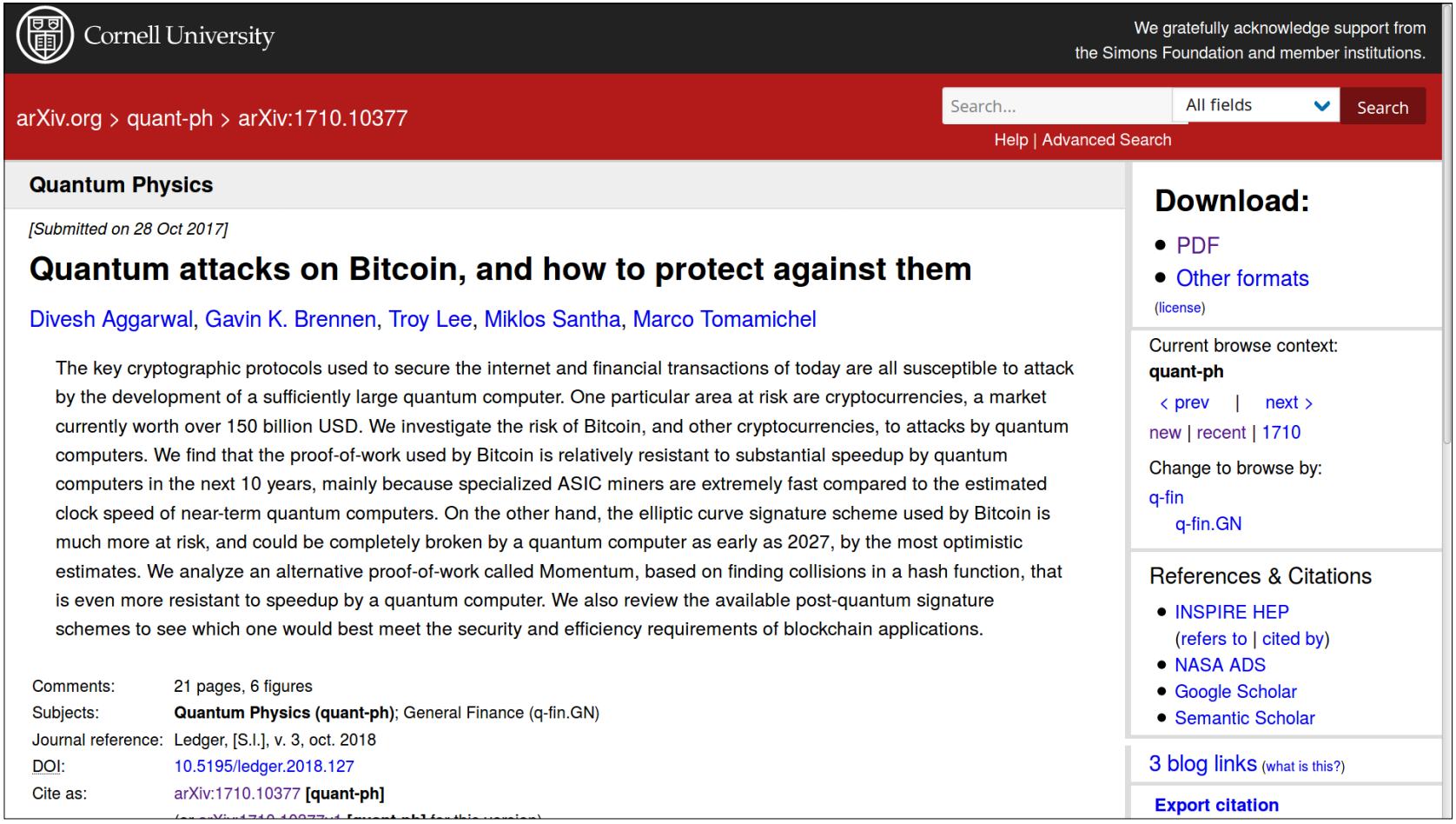
NIST has initiated a process to solicit, evaluate, and standardize one or more quantum-resistant public-key cryptographic algorithms. **Full details can be found in the Post-Quantum Cryptography Standardization page.**

The Round 2 candidates were announced January 30, 2019. NISTIR 8240, Status Report on the First Round of the NIST Post-Quantum Cryptography Standardization Process is now available.

Background

In recent years, there has been a substantial amount of research on quantum computers – machines that exploit quantum mechanical phenomena to solve mathematical problems that are difficult or intractable for conventional computers. If large-scale quantum computers are ever built, they will be able to break many of the public-key cryptosystems currently in use. This would seriously compromise the confidentiality and integrity of digital communications on the Internet and elsewhere. The goal of *post-quantum cryptography* (also called quantum-resistant cryptography) is to develop cryptographic systems that are secure against both quantum and classical computers, and can interoperate with existing communications protocols and networks.

Post-quantum algorithms



Cornell University

We gratefully acknowledge support from the Simons Foundation and member institutions.

arXiv.org > quant-ph > arXiv:1710.10377

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Quantum Physics

[Submitted on 28 Oct 2017]

Quantum attacks on Bitcoin, and how to protect against them

Divesh Aggarwal, Gavin K. Brennen, Troy Lee, Miklos Santha, Marco Tomamichel

The key cryptographic protocols used to secure the internet and financial transactions of today are all susceptible to attack by the development of a sufficiently large quantum computer. One particular area at risk are cryptocurrencies, a market currently worth over 150 billion USD. We investigate the risk of Bitcoin, and other cryptocurrencies, to attacks by quantum computers. We find that the proof-of-work used by Bitcoin is relatively resistant to substantial speedup by quantum computers in the next 10 years, mainly because specialized ASIC miners are extremely fast compared to the estimated clock speed of near-term quantum computers. On the other hand, the elliptic curve signature scheme used by Bitcoin is much more at risk, and could be completely broken by a quantum computer as early as 2027, by the most optimistic estimates. We analyze an alternative proof-of-work called Momentum, based on finding collisions in a hash function, that is even more resistant to speedup by a quantum computer. We also review the available post-quantum signature schemes to see which one would best meet the security and efficiency requirements of blockchain applications.

Comments: 21 pages, 6 figures
Subjects: **Quantum Physics (quant-ph)**; General Finance (q-fin.GN)
Journal reference: Ledger, [S.l.], v. 3, oct. 2018
DOI: 10.5195/ledger.2018.127
Cite as: arXiv:1710.10377 **[quant-ph]**

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- NASA ADS
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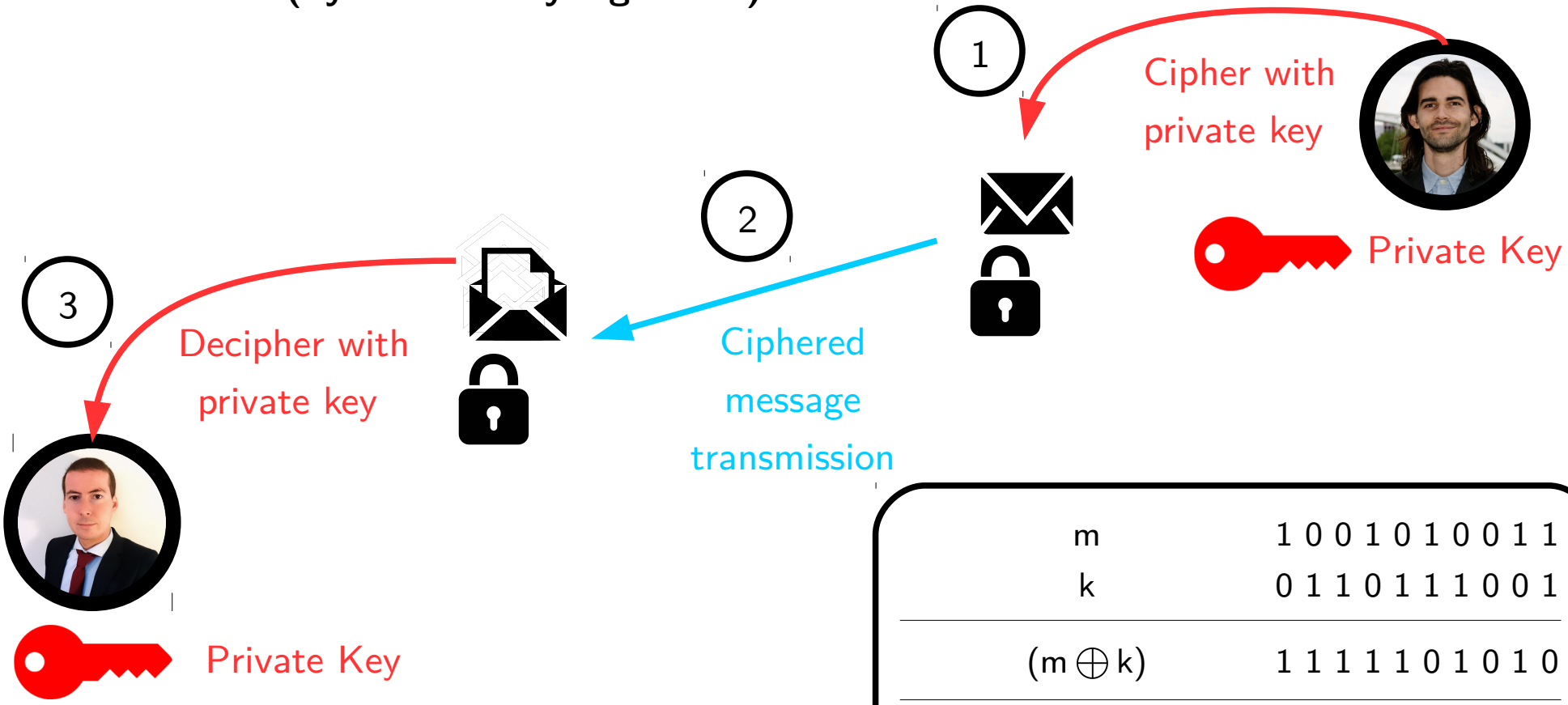
- Semantic Scholar

3 blog links (what is this?)

Export citation

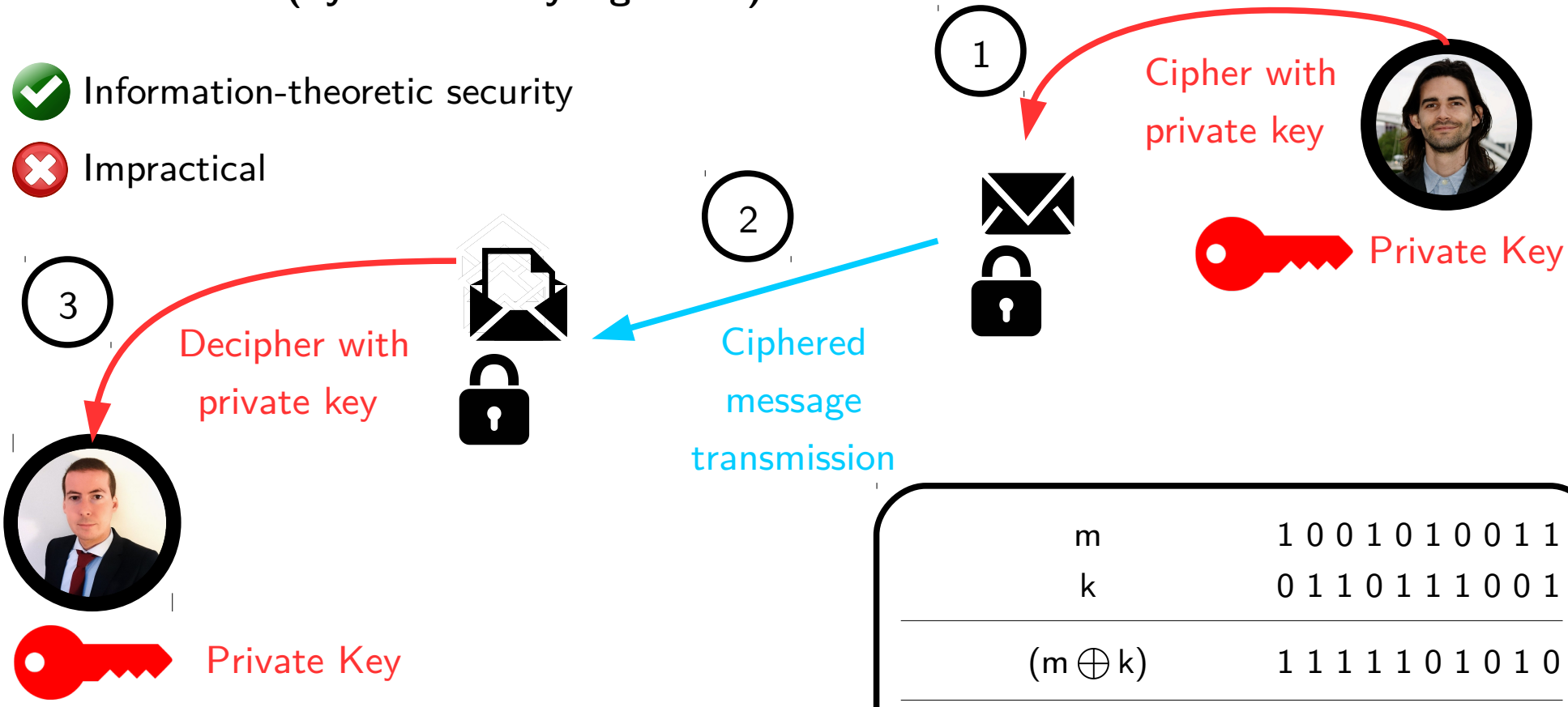
One-Time Pad (Symmetric-key algorithm)



m	1 0 0 1 0 1 0 0 1 1
k	0 1 1 0 1 1 1 0 0 1
$(m \oplus k)$	1 1 1 1 1 0 1 0 1 0
$(m \oplus k) \oplus k = m$	1 0 0 1 0 1 0 0 1 1

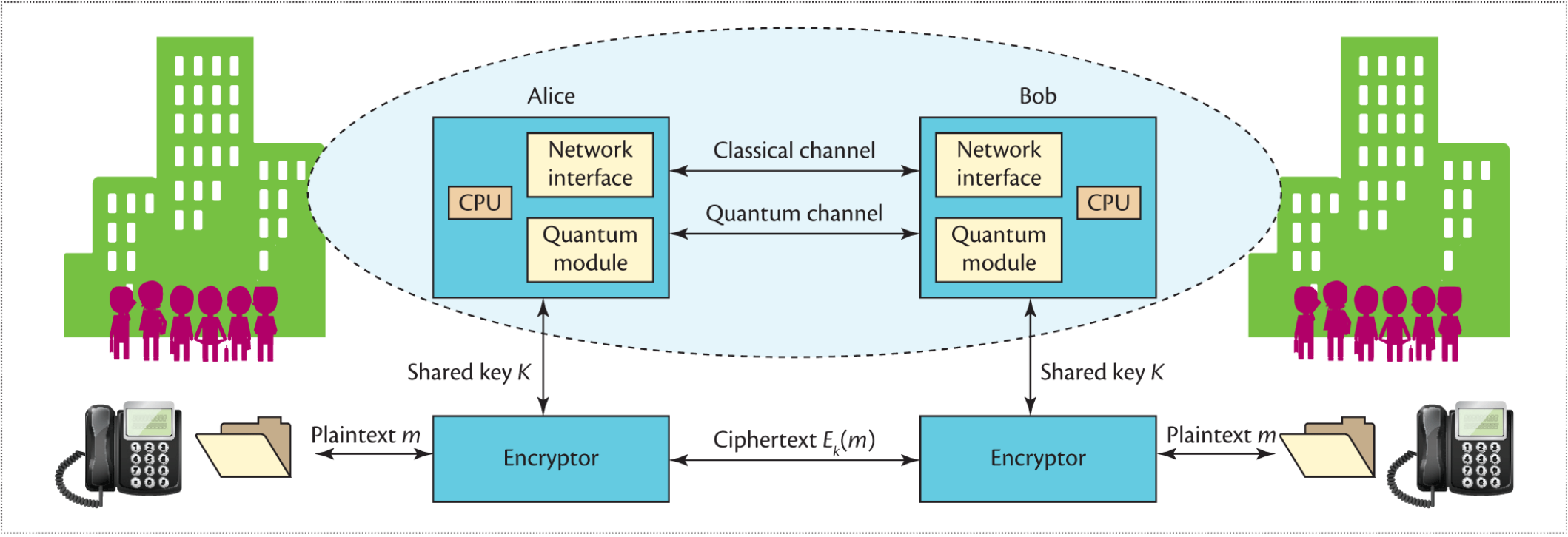
One-Time Pad (Symmetric-key algorithm)

- Information-theoretic security
- Impracticall

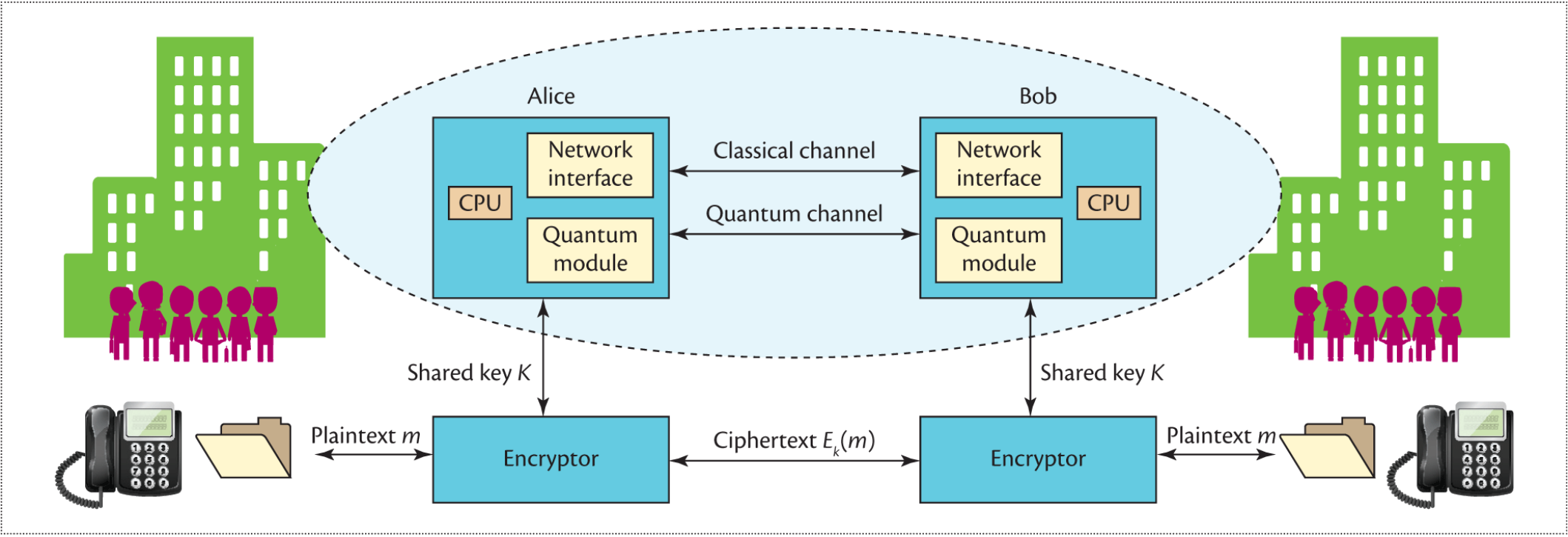


m	1 0 0 1 0 1 0 0 1 1
k	0 1 1 0 1 1 1 0 0 1
$(m \oplus k)$	1 1 1 1 1 0 1 0 1 0
$(m \oplus k) \oplus k = m$	1 0 0 1 0 1 0 0 1 1

QKD + One Time Pad

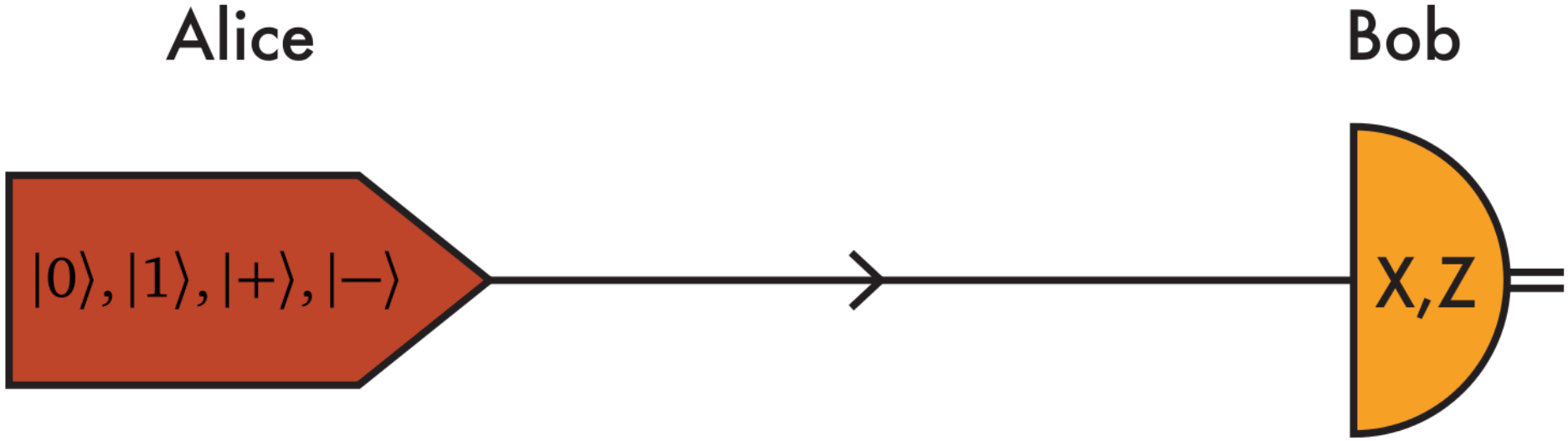


QKD + One Time Pad



- Information-theoretic security
- Practicality

BB84 QKD protocol

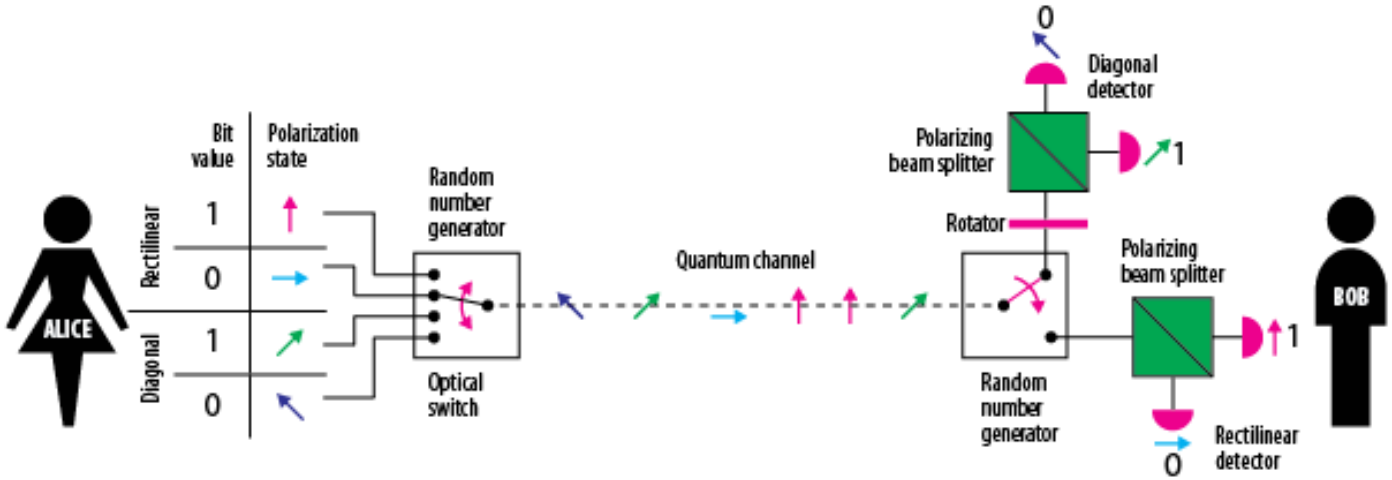


The Hello World of quantum key distribution

Security is provided by:

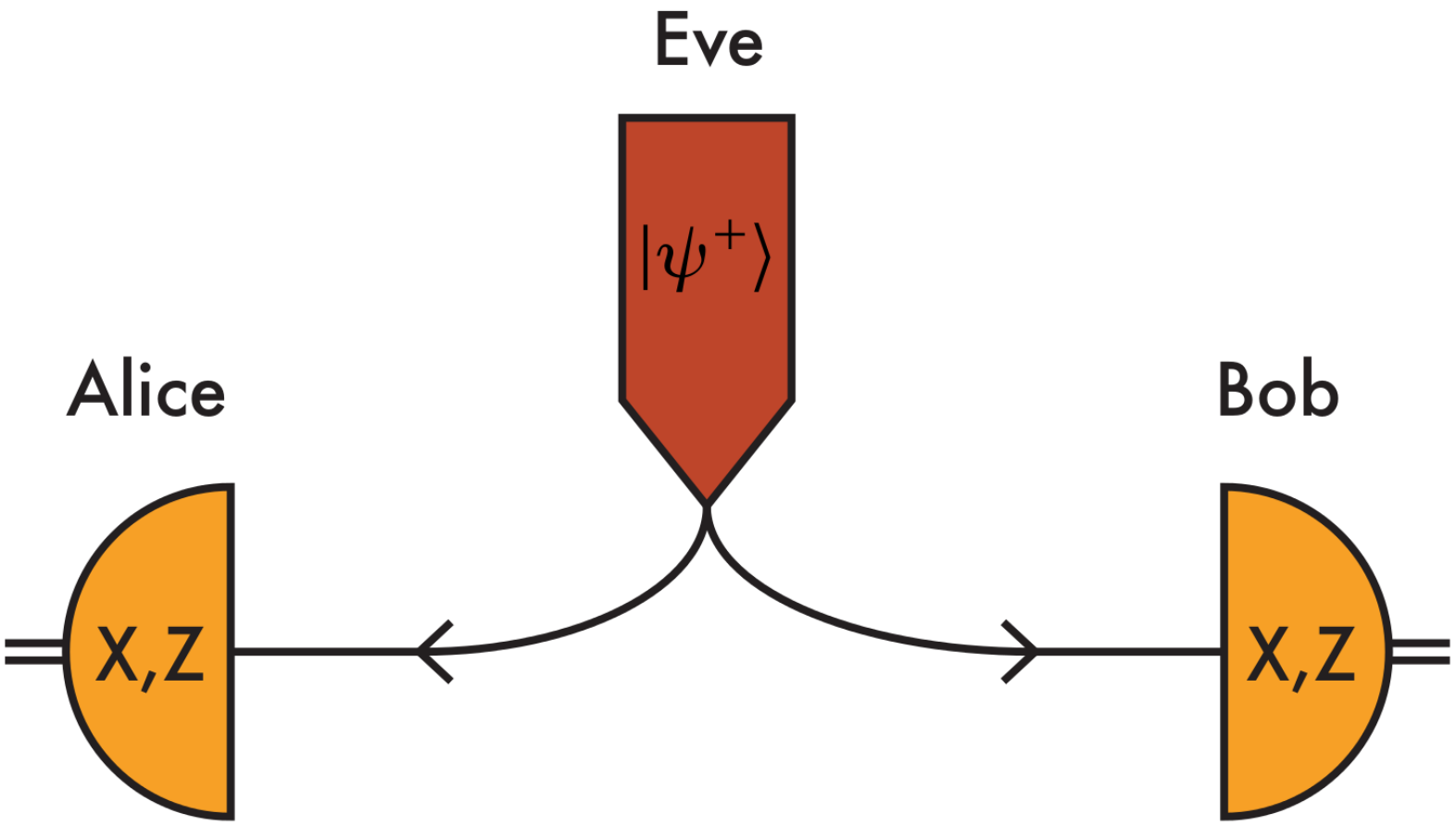
- Heisenberg uncertainty principle (no commutating operators)
- No cloning theorem

BB84 QKD protocol

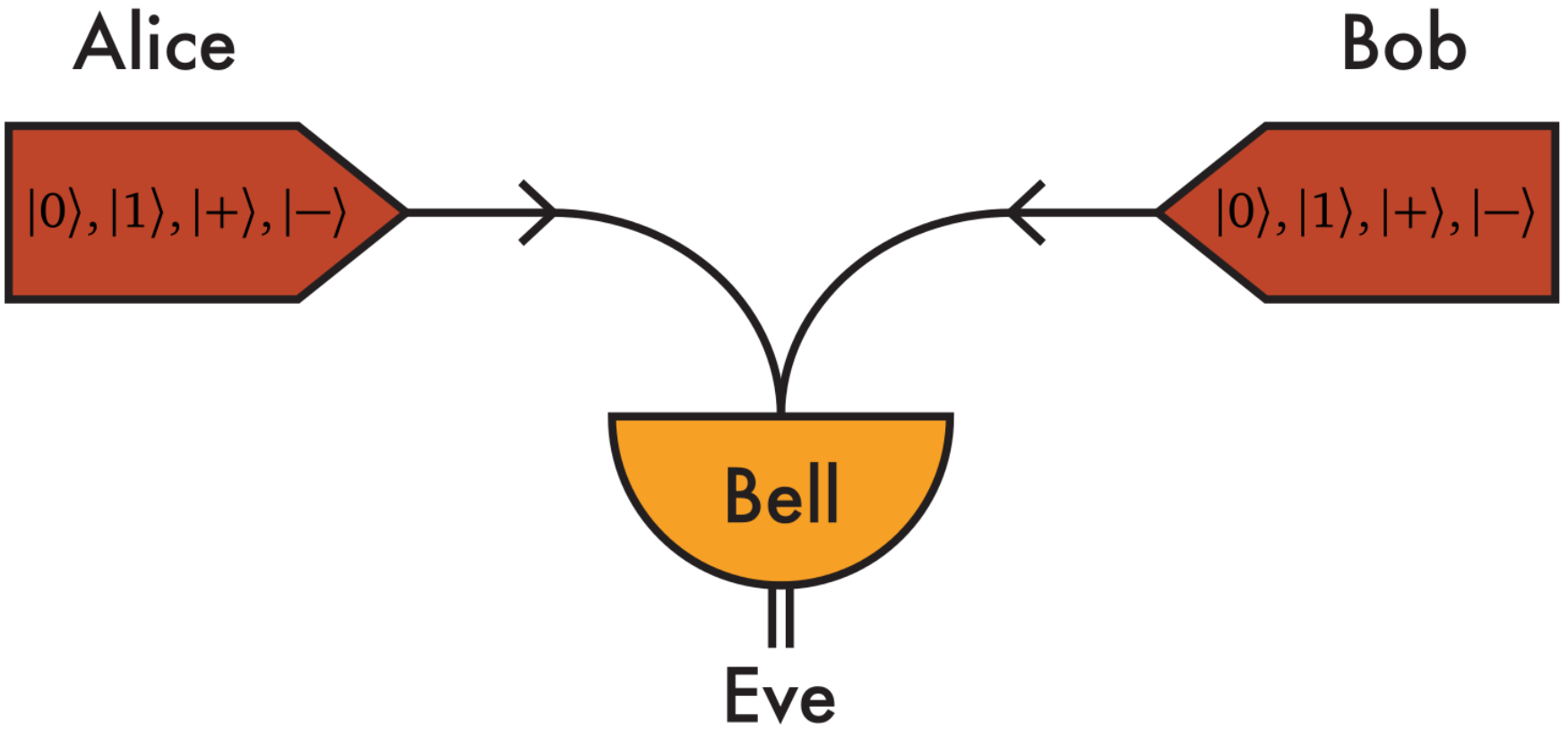


Quantum transmission & detection	ALICE sends photons	↖	↗	→	↑	↑	↗	↖	↑
	ALICE's random bits	0	1	0	1	1	1	0	1
	BOB's detection events	↑	↗	↖	↑	↗	↗	↖	↖
	BOB's detected bit values	1	1	0	1	1	1	0	0
Public discussion (i.e., sifting)	BOB tells ALICE the basis choices he made	Rect	Diag	Diag	Rect	Diag	Diag	Diag	Diag
	ALICE tells BOB which bits to keep		✔		✔		✔	✔	
	ALICE and BOB's shared sifted key	–	1	–	1	–	1	0	–

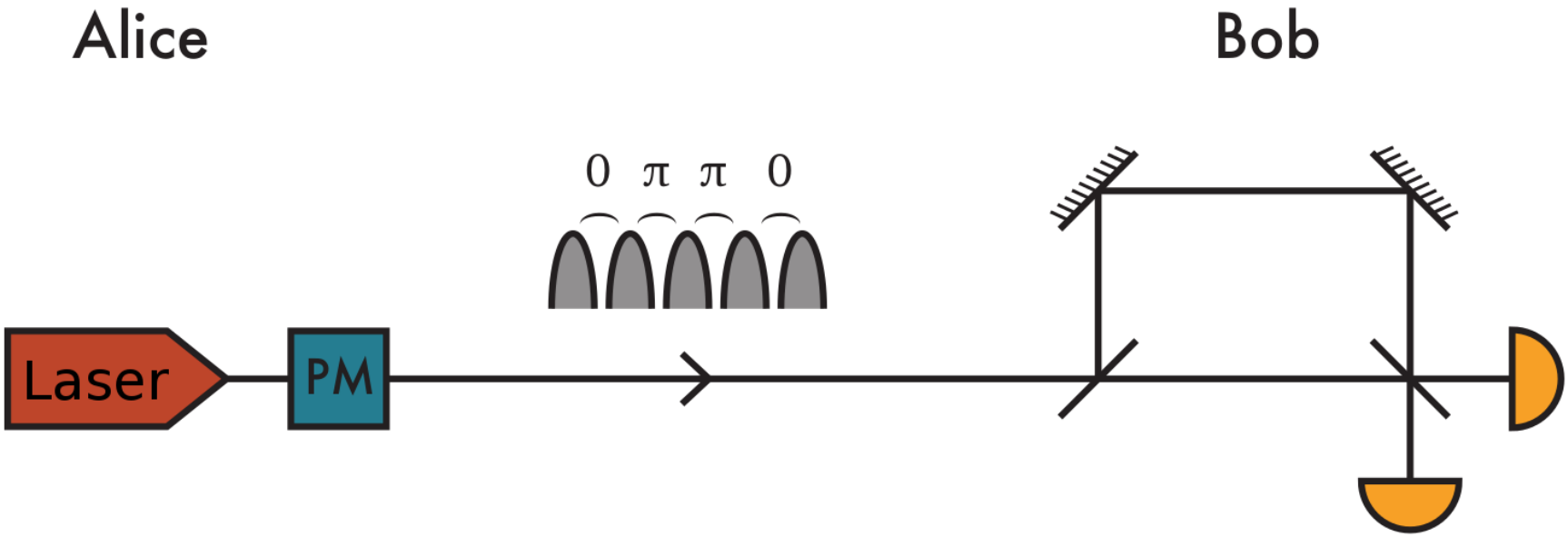
E91 QKD protocol



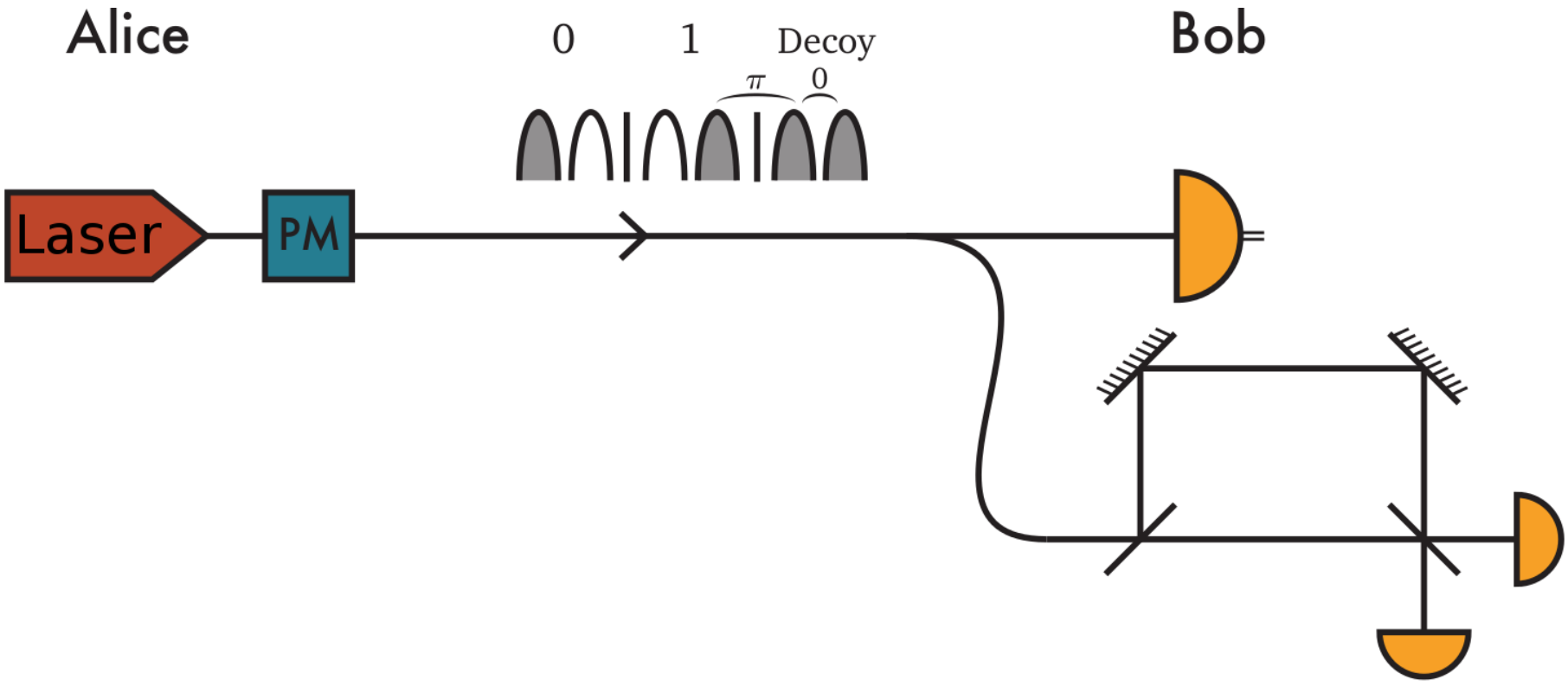
MDI QKD protocol



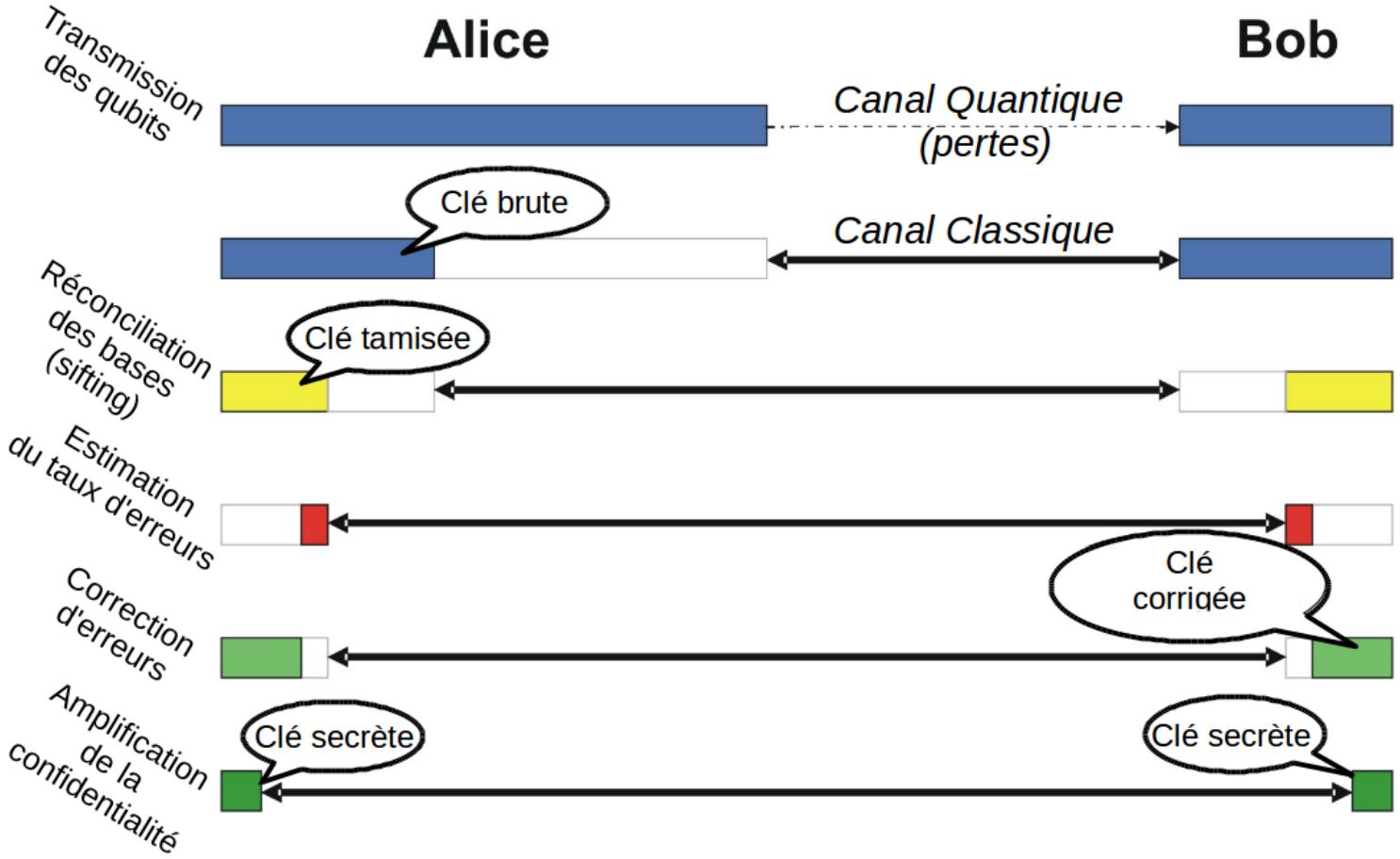
DPS QKD protocol



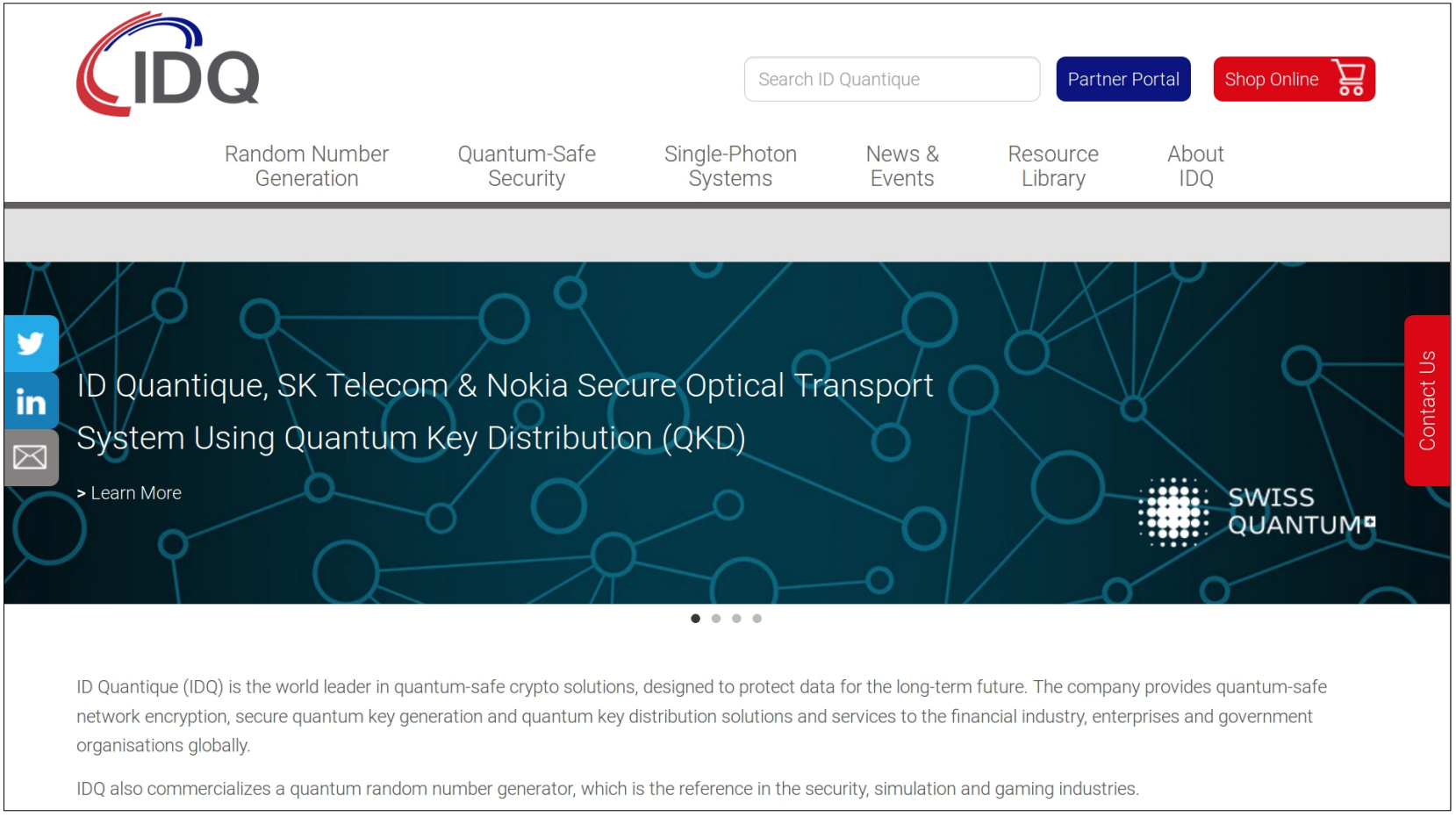
COW QKD protocol



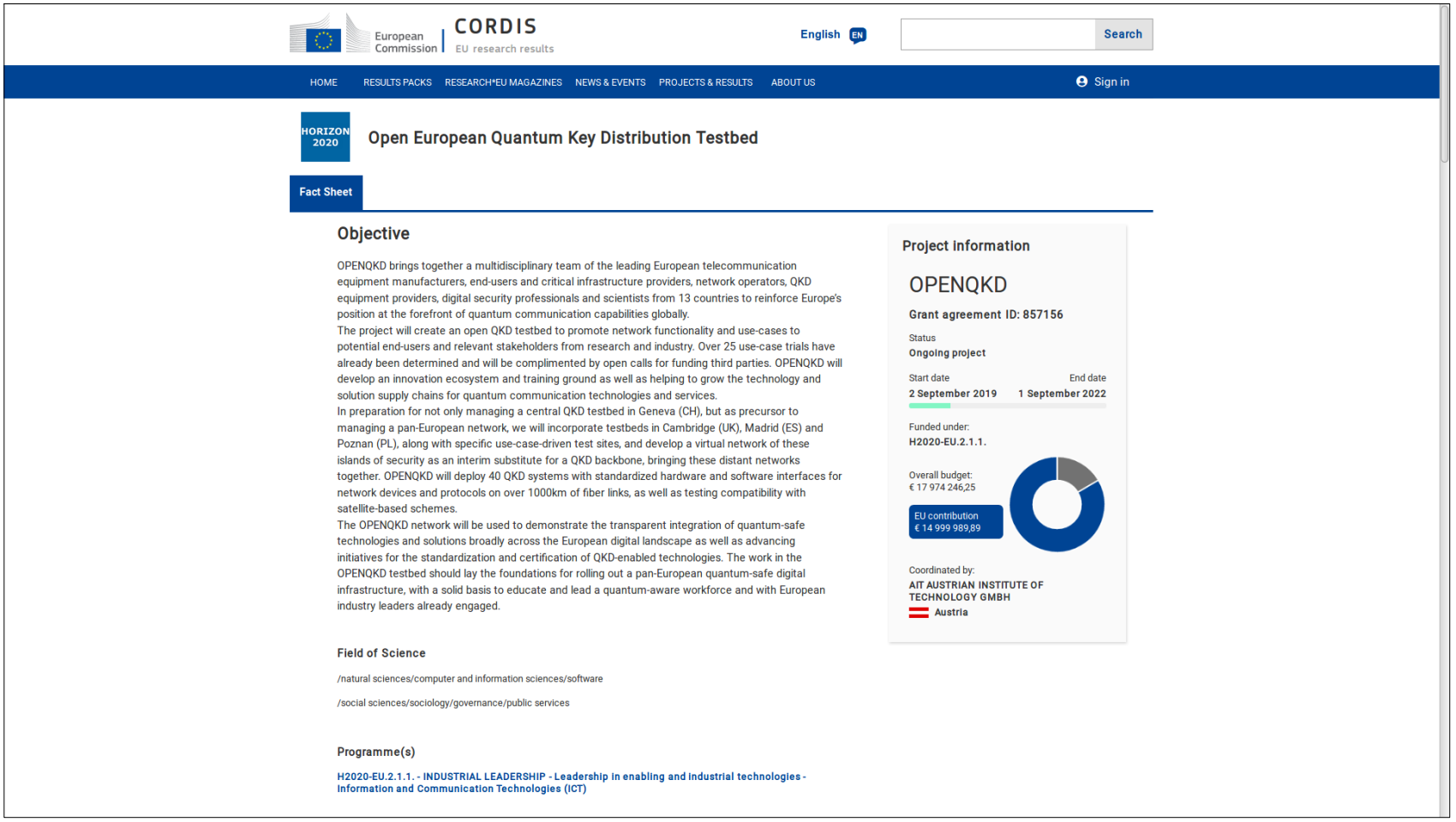
Post-processing steps



Field implementations



Field implementations



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HORIZON 2020

Open European Quantum Key Distribution Testbed

Fact Sheet

Objective

OPENQKD brings together a multidisciplinary team of the leading European telecommunication equipment manufacturers, end-users and critical infrastructure providers, network operators, QKD equipment providers, digital security professionals and scientists from 13 countries to reinforce Europe's position at the forefront of quantum communication capabilities globally.
The project will create an open QKD testbed to promote network functionality and use-cases to potential end-users and relevant stakeholders from research and industry. Over 25 use-case trials have already been determined and will be complimented by open calls for funding third parties. OPENQKD will develop an innovation ecosystem and training ground as well as helping to grow the technology and solution supply chains for quantum communication technologies and services.
In preparation for not only managing a central QKD testbed in Geneva (CH), but as precursor to managing a pan-European network, we will incorporate testbeds in Cambridge (UK), Madrid (ES) and Poznan (PL), along with specific use-case-driven test sites, and develop a virtual network of these islands of security as an interim substitute for a QKD backbone, bringing these distant networks together. OPENQKD will deploy 40 QKD systems with standardized hardware and software interfaces for network devices and protocols on over 1000km of fiber links, as well as testing compatibility with satellite-based schemes.
The OPENQKD network will be used to demonstrate the transparent integration of quantum-safe technologies and solutions broadly across the European digital landscape as well as advancing initiatives for the standardization and certification of QKD-enabled technologies. The work in the OPENQKD testbed should lay the foundations for rolling out a pan-European quantum-safe digital infrastructure, with a solid basis to educate and lead a quantum-aware workforce and with European industry leaders already engaged.

Field of Science

/natural sciences/computer and information sciences/software

/social sciences/sociology/governance/public services

Programme(s)

H2020-EU.2.1.1. - INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Information and Communication Technologies (ICT)

Project information

OPENQKD

Grant agreement ID: 857156

Status
Ongoing project

Start date **2 September 2019** End date **1 September 2022**

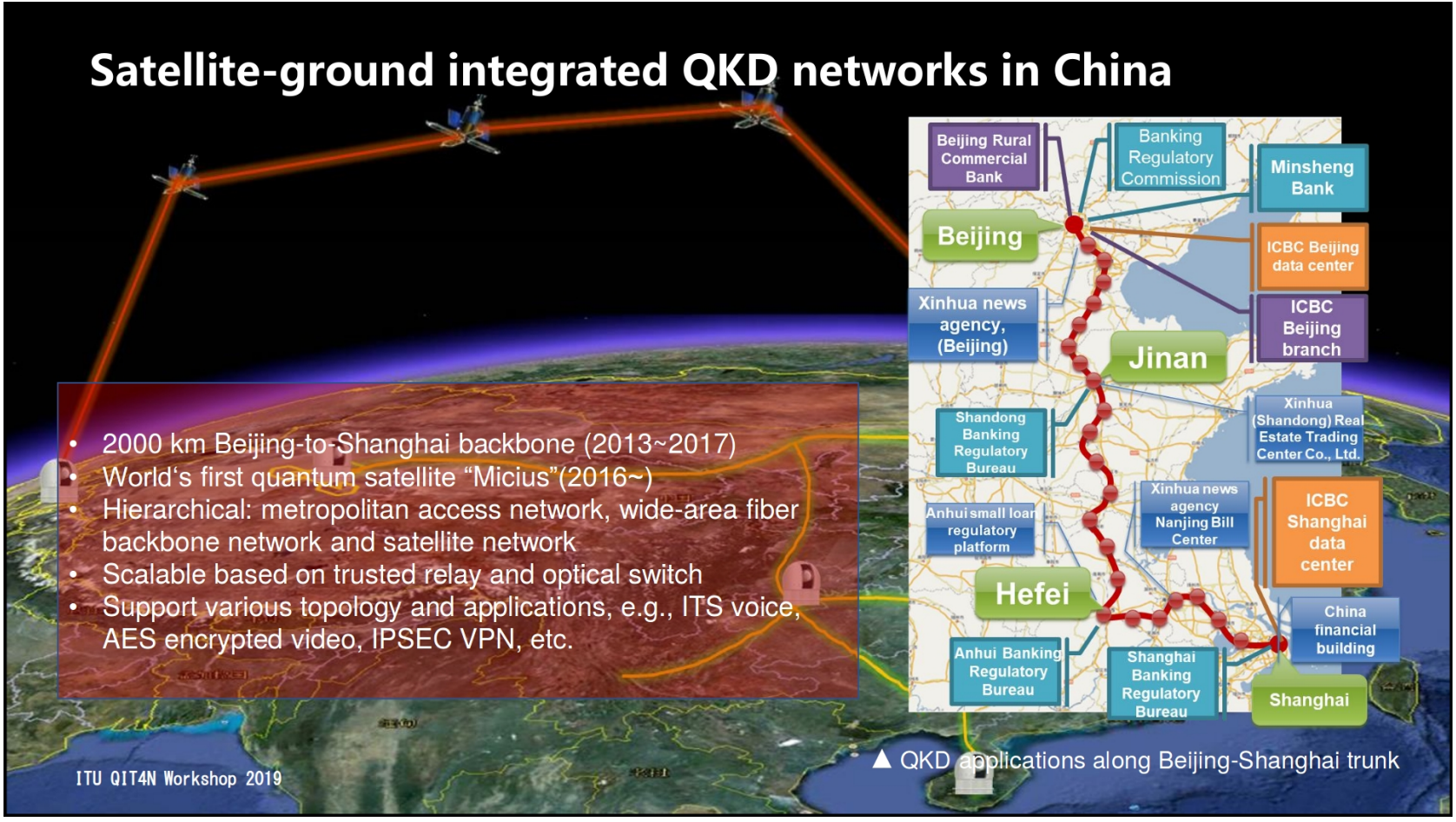
Funded under:
H2020-EU.2.1.1.

Overall budget:
€ 17 974 246,25

EU contribution
€ 14 999 989,89

Coordinated by:
AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH
Austria

Field implementations



▲ QKD applications along Beijing-Shanghai trunk