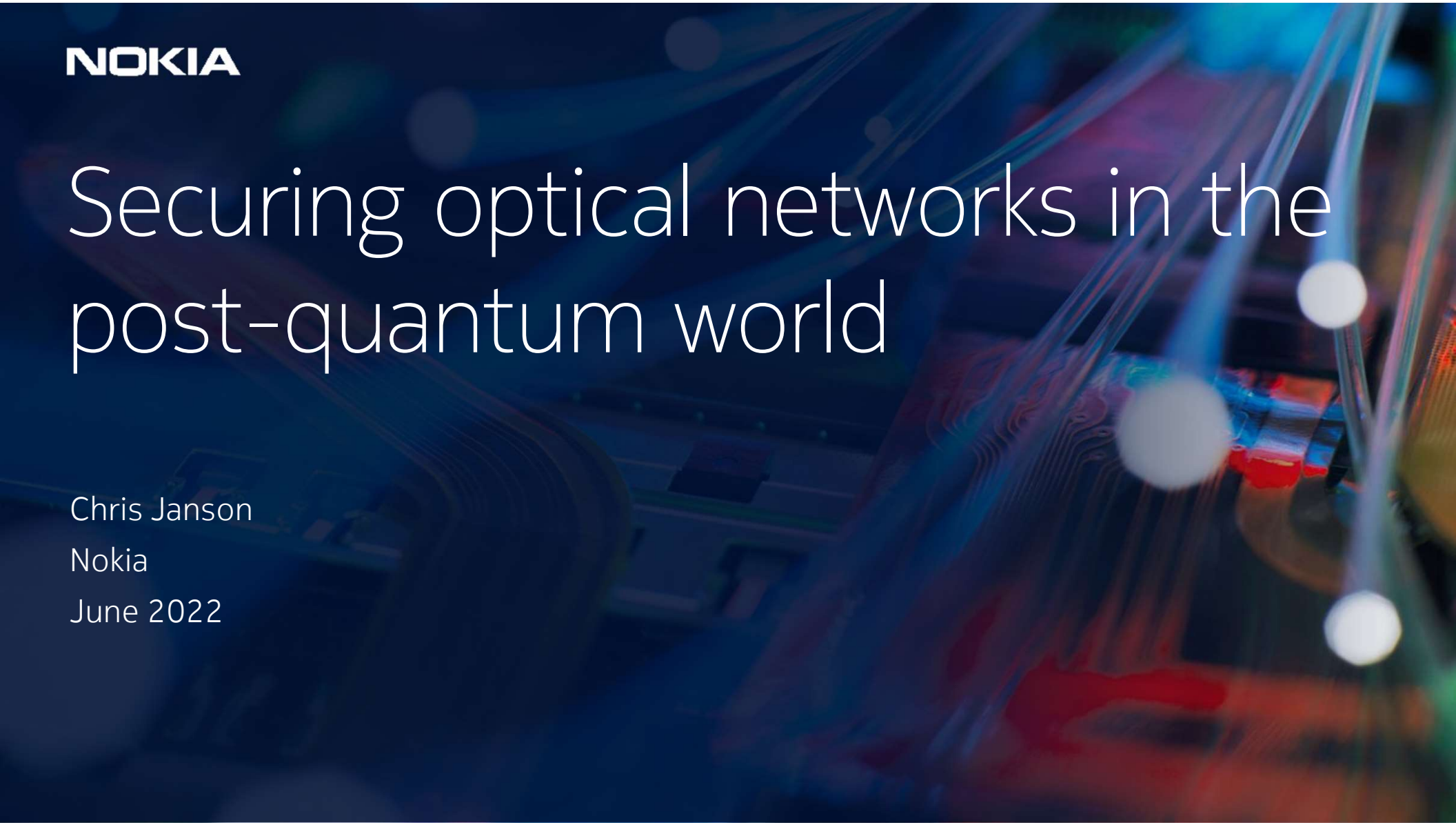

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Securing optical networks in the post-quantum world

Chris Janson
Nokia
June 2022

Agenda

1 Introductory context

2 Current cryptography and Quantum-safe security

3 Emerging standards

4 Secure optical transport

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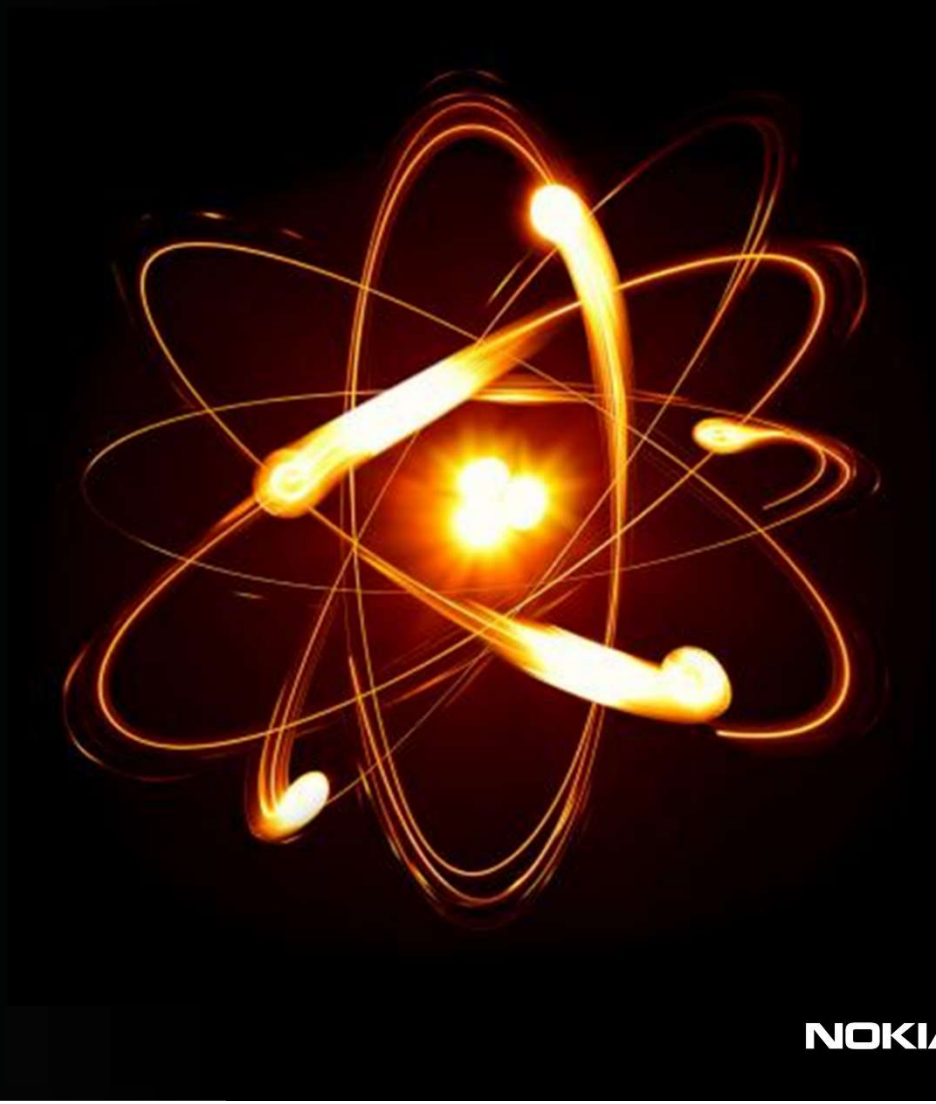
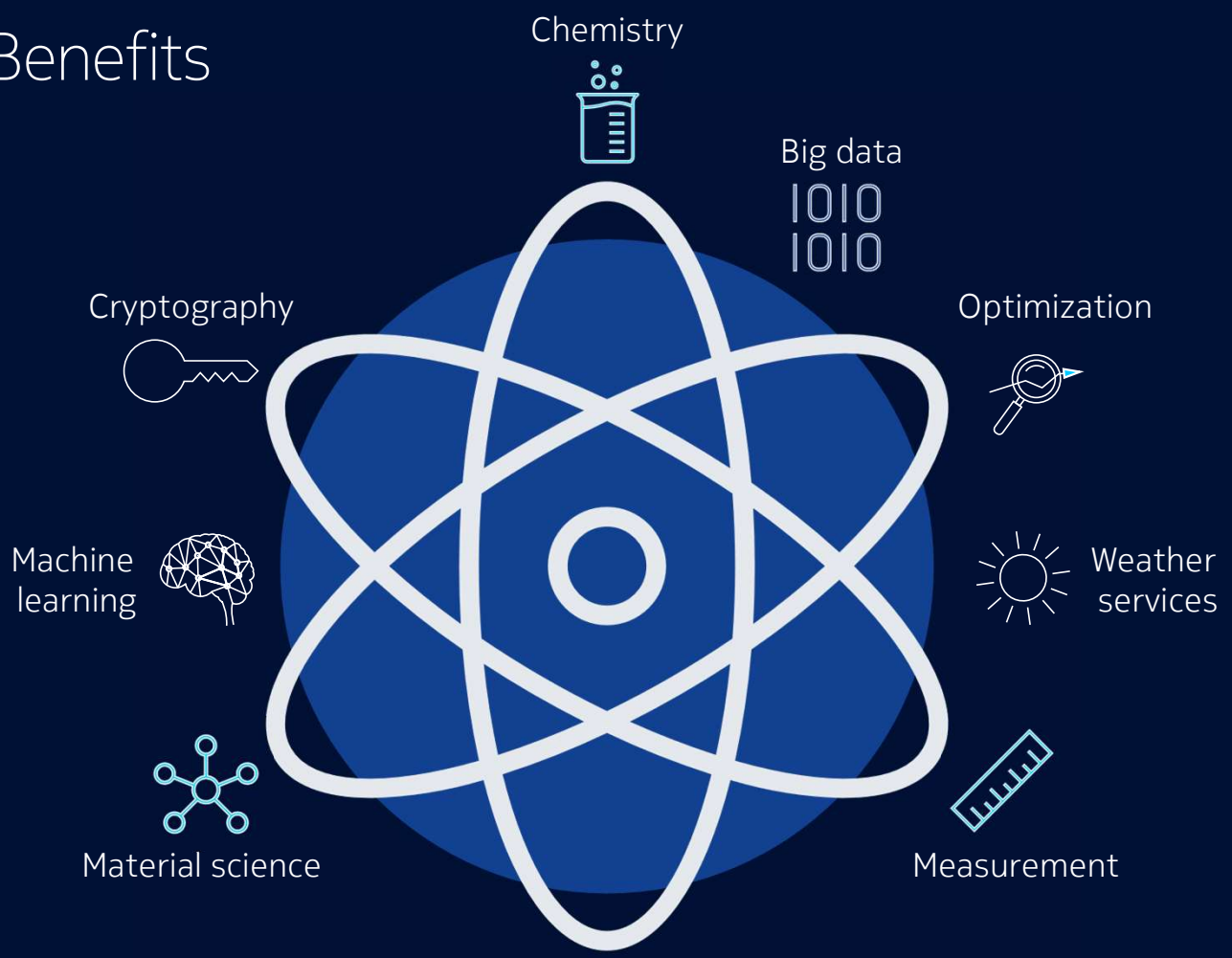
Quantum Mechanics

> “If you think you understand quantum mechanics, you don’t understand quantum mechanics.”
>
> Richard P. Feynman



Quantum vs. Classic Computing

Quantum Computing Benefits



Quantum Computer Types

Analog Quantum Computer

Noisy Quantum Computer

Universal Quantum Computer

Quantum Computing Race

Many countries have well defined quantum programs

Canada

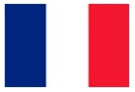
- National strategy established in 2016
- Canadian Space Agency Quantum Encryption and Science Satellite (QEYSSat) mission
- National Research Council of Canada's Security and Disruptive Technologies Research Centre: Quantum Sensors and Security program

China

- Chinese Academy of Sciences Center for Excellence in Quantum Information and Quantum Physics
- Quantum Experiments at Space Scale (QUESS) project (the Micius satellite)
- Beijing–Shanghai Quantum Secure Communication Backbone
- National Quantum Laboratory—backed by a massive **US$10 billion** in funding over five years

EU

- EuroQCI Declaration
- QTEdu
- Quantum Industry Consortium
- QuantERA
- OpenQKD
- European Quantum Communication Infrastructure (EuroQCI)



France

- National Strategy for Quantum Technologies, with some **US$1.8 billion** promised the sector
- Grand Challenge on first-generation NISQ quantum accelerators

Germany

- National strategy established in 2018 with **US$3.1 billion** in fudging
- Quantum Technologies—From Basic Research to Market supports quantum technology research
- Grand Challenge competition in quantum communication
- QuNET initiative set up in 2018 to develop a quantum network for secure data transmission between federal authorities

Russia

- Quantum Technologies Roadmap established in 2019 backed by **US$663 million** over five years
- National Quantum Laboratory

UK

- National Quantum Technologies Programme with **US$540 million in** funding for the first phase covering the period from 2014–2019, and **US$473 million** the second phase
- National Quantum Computing Centre
- Rigetti Computing, a leading quantum computing company, has partnered with the government and leads a consortium to develop the UK's first quantum computer by 2023

US

- National Quantum Initiative set up in 2018 with **US$1.275 billion** allocated
- National Quantum Coordination Office, part of the White House Office of Science and Technology Policy
- National Science Foundation, within it three Quantum Leap Challenges Institutes
- Quantum Foundry, a Center for Quantum Networks
- Five Quantum Information Science Centers backed by the DoE
- Quantum Economic Development Consortium (QED-C)

Source: https://thequantumdaily.com/2021/04/29/15-countries-with-national-quantum-initiatives/

Symmetric vs. Asymmetric Cryptography

Symmetric Algorithms

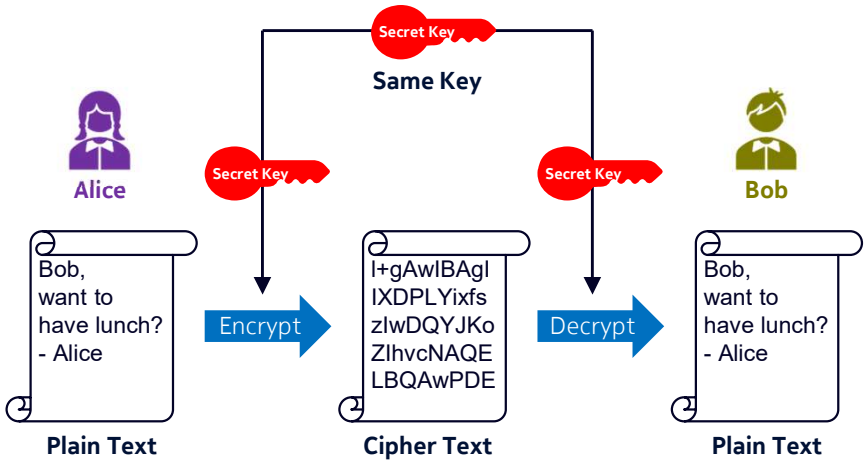
- Block ciphers (require chaining)
- Stream ciphers

Asymmetric Algorithms

- Digital Signatures
- Key Agreement
- Public Key Encryption
- Key Encapsulation

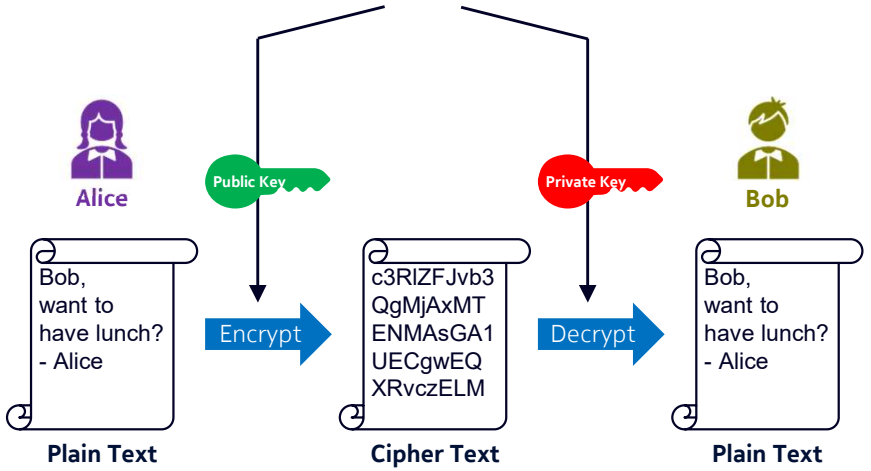
Symmetric Encryption

The same key is use for encryption and decryption.



Asymmetric (Public Key) Encryption

The keys are different but are mathematically linked.



Quantum Computing Impact on Today's Cryptography

Some algorithms we rely on today will be completely broken

- **Shor's** algorithm discovered in 1994 by Peter Shor that can find prime factors of an integer and find discrete logs
- **Grover's** is a quantum search algorithm devised in 1996 by Lov Grover that improves search by a quadratic root factor

Type	Algorithm	Key Length	Effective Key Length		Quantum Attack
			Classic Computing	Quantum Computing	
Asymmetric	RSA-1024	1024 bits	80 bits	**0 bits**	**Shor's**
	RSA-2048	2048 bits	112 bits		
	ECC-256	256 bits	128 bits		
	ECC-384	384 bits	256 bits		
Symmetric	AES-128	128 bits	128 bits	64 bits	**Grover's**
	AES-256	256 bits	256 bits	128 bits	

Quantum Acronyms

Not all technologies imply quantum-safe

Quantum Computing (QC)

Machines that use the properties of quantum physics to store data and perform computations

Quantum Random Number Generator (QRNG)

Quantum random number generators create randomness by measuring quantum processes

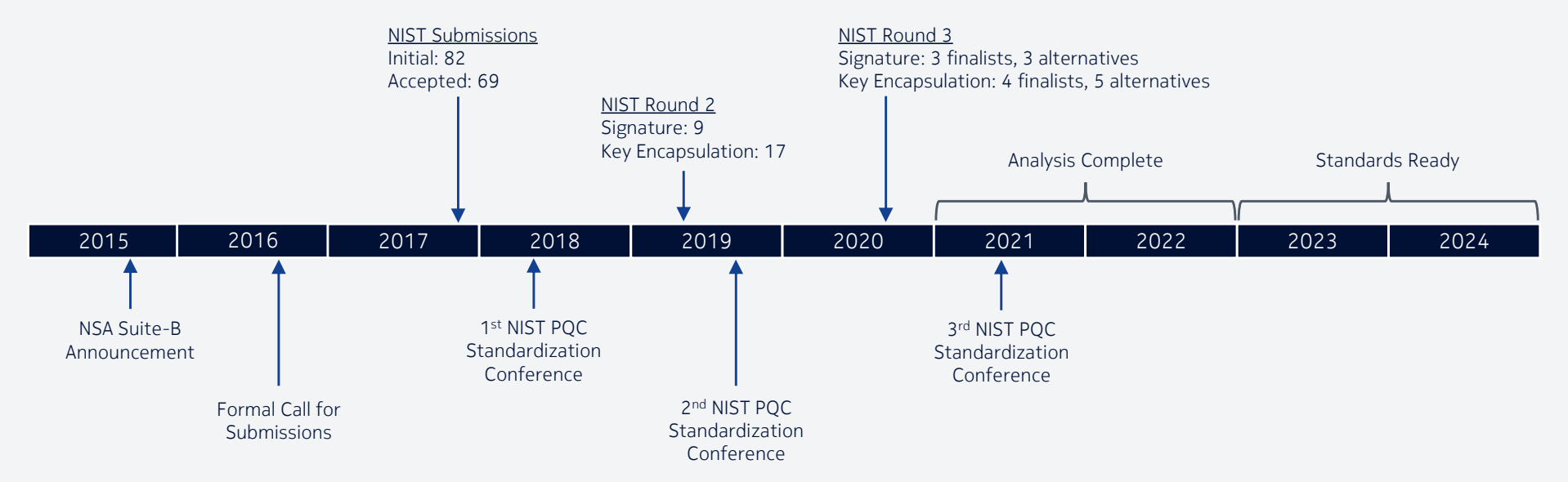
Quantum-safe Cryptography (QSC) / Post-quantum Cryptography (PQC)

Algorithms resistant to attacks by both classical and quantum computers because they are based on hard math problems for which an efficient solution using a quantum algorithm does not exist

Quantum Key Distribution (QKD)

Distribution using properties found in quantum physics to exchange cryptographic keys in such a way that is provable and guarantees security

US NIST Post-Quantum Cryptography Standardization



"As the replacements for currently standardized public key algorithms are not yet ready, a focus on maintaining crypto agility is imperative. Until new quantum-resistant algorithms are standardized, agencies should continue to use the recommended algorithms currently specified in NIST standards."

NIST Report on Post-Quantum Cryptography, April 2016

Types of Post-Quantum Cryptography

Codes

- Introduced by McEliece in 1978
- Relies on hardness of decoding unknown codes
- Very large public keys
- Fast encryption and decryption

Lattices

- First commercial version was NTRU (1996)
- Two most important hard problems:
  - Shortest Integer Solution (SIS)
  - Learning With Errors (LWE)
- Competitive key sizes and fast operations

Multivariate

- Introduced by Matsumoto and Imai in 1998
- Based on the fact that solving n randomly chosen non-linear equations in n variables is NP-complete
- Trade offs between key sizes and operation time

Supersingular Isogenies

- Introduced by Jao in 2009
- Relies on difficulty of finding isogenies (mappings) between Elliptic Curves
- Competitive key sizes, but slower operations

Secure Optical Transport Options

		Handshake		Data Encryption	
		Authentication	**Key Establishment**	**Encryption**	**Overall Security**
1	Classic	**Asymmetric** (RSA/ECDSA) **Quantum-vulnerable**	**Asymmetric** (EC)DH **Quantum-vulnerable**	**Symmetric** (AES 256) **Quantum-safe**	**Quantum-vulnerable**
2	Classic	**Pre-shared Key** **Quantum-safe**	**Symmetric** (AES 256) **Quantum-safe**	**Symmetric** (AES 256) **Quantum-safe**	**Quantum-safe**
3	Quantum Key Distribution (QKD)	**Pre-shared Key** **Quantum-safe** or **Asymmetric** (Dilithium/Rainbow) **Quantum-safe but not standardized**	**QKD** **Quantum-safe**	**Symmetric** (AES 256) **Quantum-safe**	**Quantum-safe** or **Quantum-safe but not standardized**
4	Post-quantum Cryptography (PQC)	**Asymmetric** (Dilithium/Rainbow) **Quantum-safe but not standardized**	**Asymmetric** (KIBER/SIKE/McEliece) **Quantum-safe but not standardized**	**Symmetric** (AES 256) **Quantum-safe**	**Quantum-safe but not standardized**
5	Hybrid	**Asymmetric** (RSA/ECDSA) **Quantum-vulnerable**	**Asymmetric** (EC)DH **Quantum-vulnerable** + **Asymmetric** (KIBER/SIKE/McEliece) **Quantum-safe but not standardized**	**Symmetric** (AES 256) **Quantum-safe**	**Quantum-safe but not standardized**

Preparing for Quantum-safe Migration

Symmetric encryption and pre-shared keys are quantum-safe

Global government agencies will transition to quantum-safe algorithms

Until new algorithms are available, we need to rely on current algorithms

Existing safety mitigations:

- Use larger key sizes in encryption algorithms
- Use key agreement schemes that leverage **large, symmetric, pre-shared keys**

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Summary

Quantum Computing & Quantum-safe Security

- Quantum computing is no longer a theoretical idea
- Billions are being invested around the world in quantum computer development
- It is possible we won't immediately learn about the first universal quantum computer
- Governments indicate that systems will be migrated to a suite of algorithms to mitigate the quantum threat (QKD and QRNG are not the solution)
- Global standards bodies are working on new quantum-safe algorithms and new encryption protocol specifications
- Some information is already vulnerable today to the future quantum-threat
- While hybrid mechanisms using asymmetric cryptography can help mitigate the quantum threat, the only 100% certain approach is to use **large symmetric encryption keys** and key establishment schemes that rely on **large pre-shared symmetric keys**

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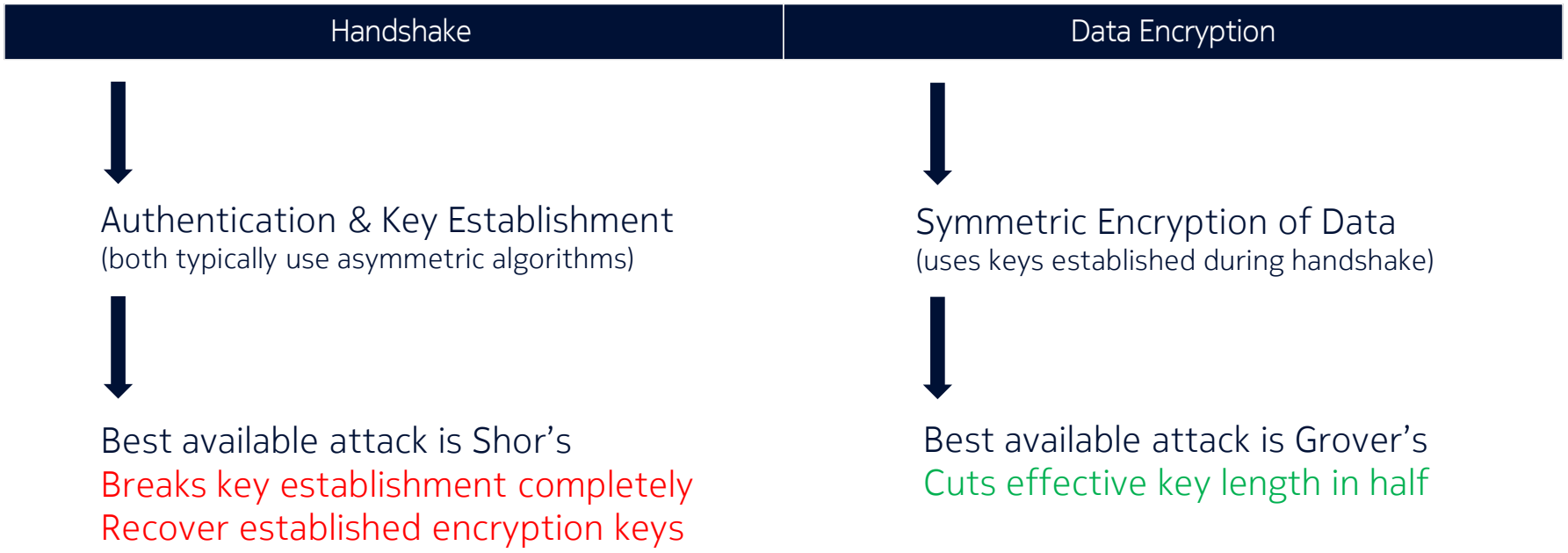
Back-up materials

Threat to Encryption

Information we transmit today is already vulnerable

An encryption protocol session, like TLS, consists of the handshake and the data encryption part



Threat to Encryption vs Authentication

The threat might be different, but the migration urgency is the same

- While both asymmetric encryption and authentication are vulnerable to quantum-enabled attacks, the threats are different
- Asymmetric encryption used today to encrypt information makes this encrypted information already vulnerable to the harvest & decrypt attack
- In the case of authentication in encryption protocol, the authenticity of information is only useful during a very short time – during handshake to authenticate the key establishment keys
- In the case of authentication in document signing, the signatures can be invalidated and replaced with quantum-safe ones
- In the case of code signing, we really need to look at long-lived devices that are expected to last more than a decade and where replacing trust anchors can be challenging

Global Quantum-safe Cryptographic Standards

NIST Round 3 PQC Algorithms

	Type	Name	Math
Finalists	Key Encapsulation	Classic McEliece	Codes
		CRYSTALS-KYBER	Lattices
		NTRU	Lattices
		SABER	Lattices
	Digital Signature	CRYSTALS-DILITHIUM	Lattices
		FALCON	Lattices
		Rainbow	Multivariate
Alternate Candidates	Key Encapsulation	BIKE	Codes
		FrodoKEM	Lattices
		HQC	Codes
		NTRU Prime	Lattices
		SIKE	Supersingular Isogenies
	Digital Signature	GeMSS	Multivariate
		Picnic	Other
		SPHINCS+	Stateless Hashes

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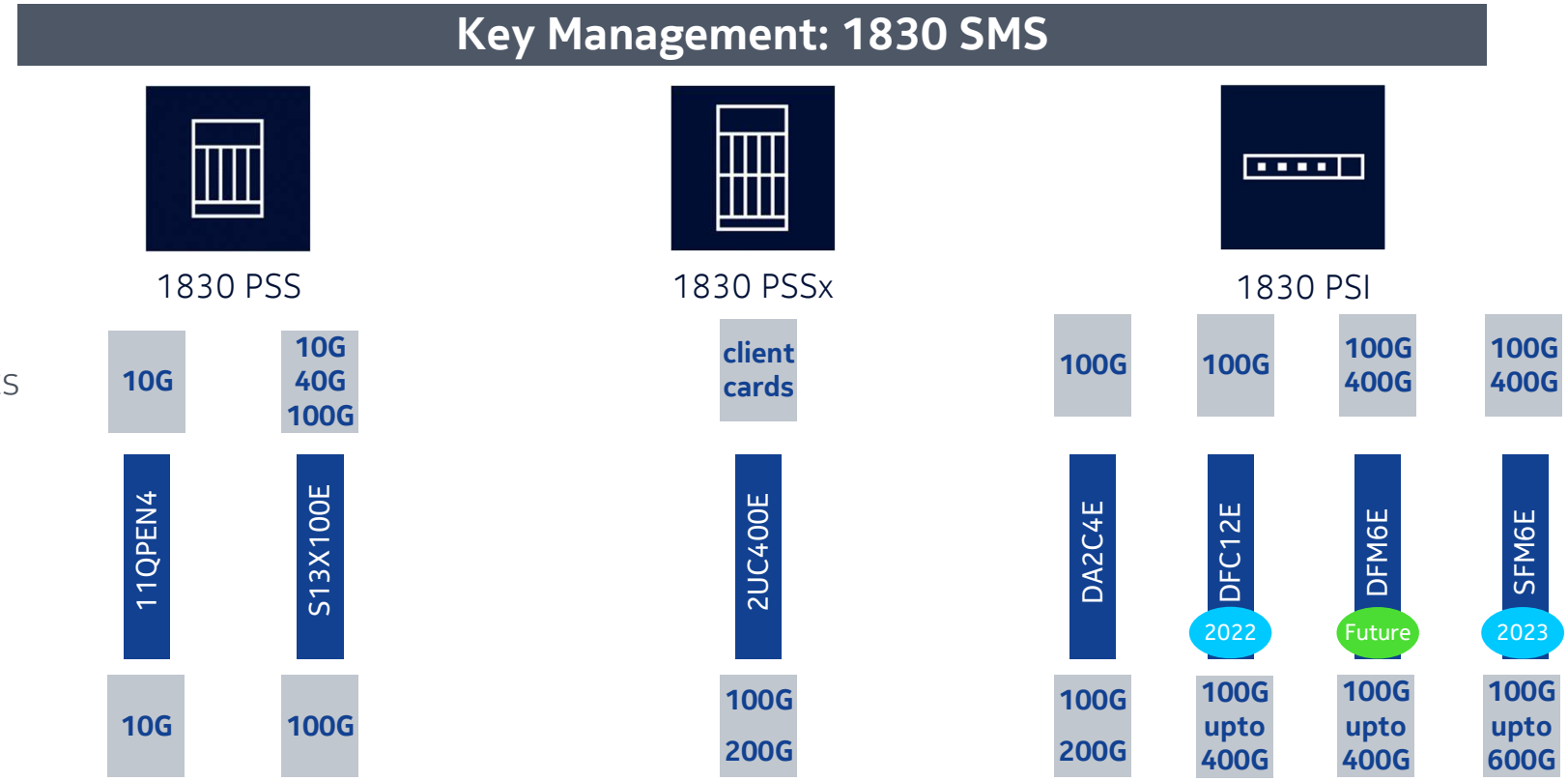
Nokia Optical Encryption – NE Portfolio

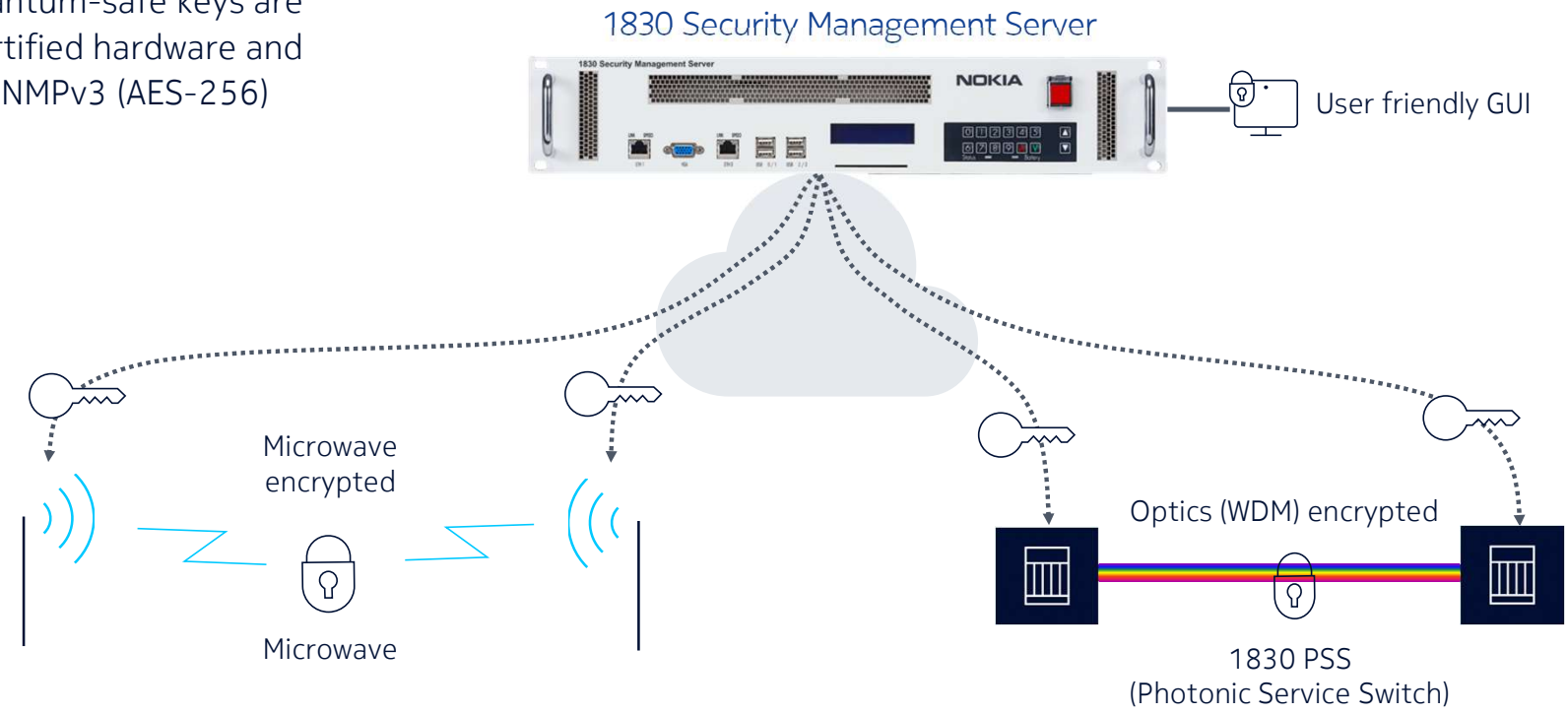
Nokia supports AES encryption at L1 using 256-bit quantum-safe key sizes

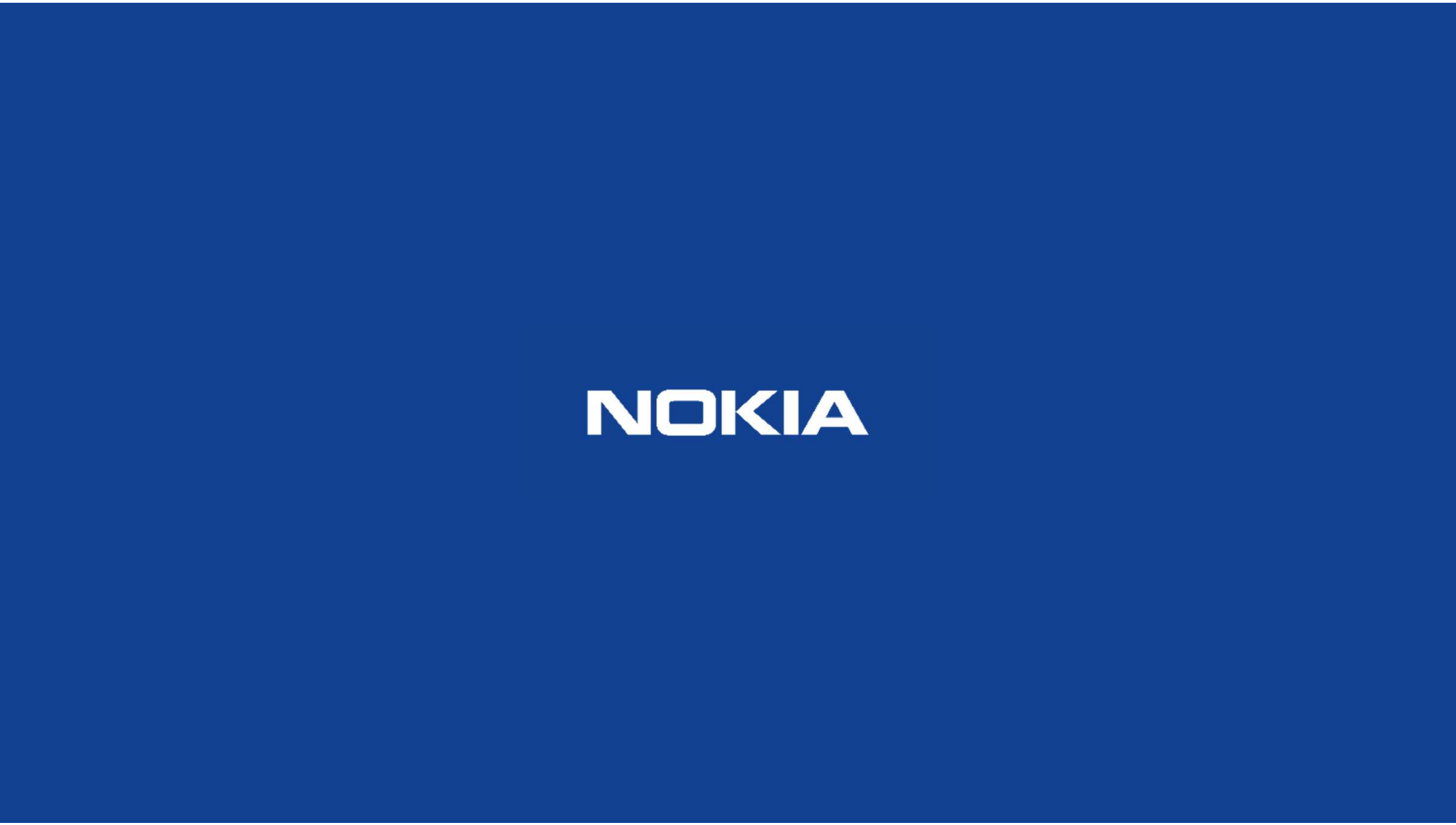


Nokia Layer 1 Quantum-safe Key Management

Uses symmetric algorithms and pre-shared keys to ensure quantum safety

High-quality quantum-safe keys are generated in certified hardware and distributed via SNMPv3 (AES-256)

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