

QKD INTEGRATION INTO COMMERCIAL DWDM NETWORKS

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Agenda



Context



Encryption for data transmission



QKD fundamentals



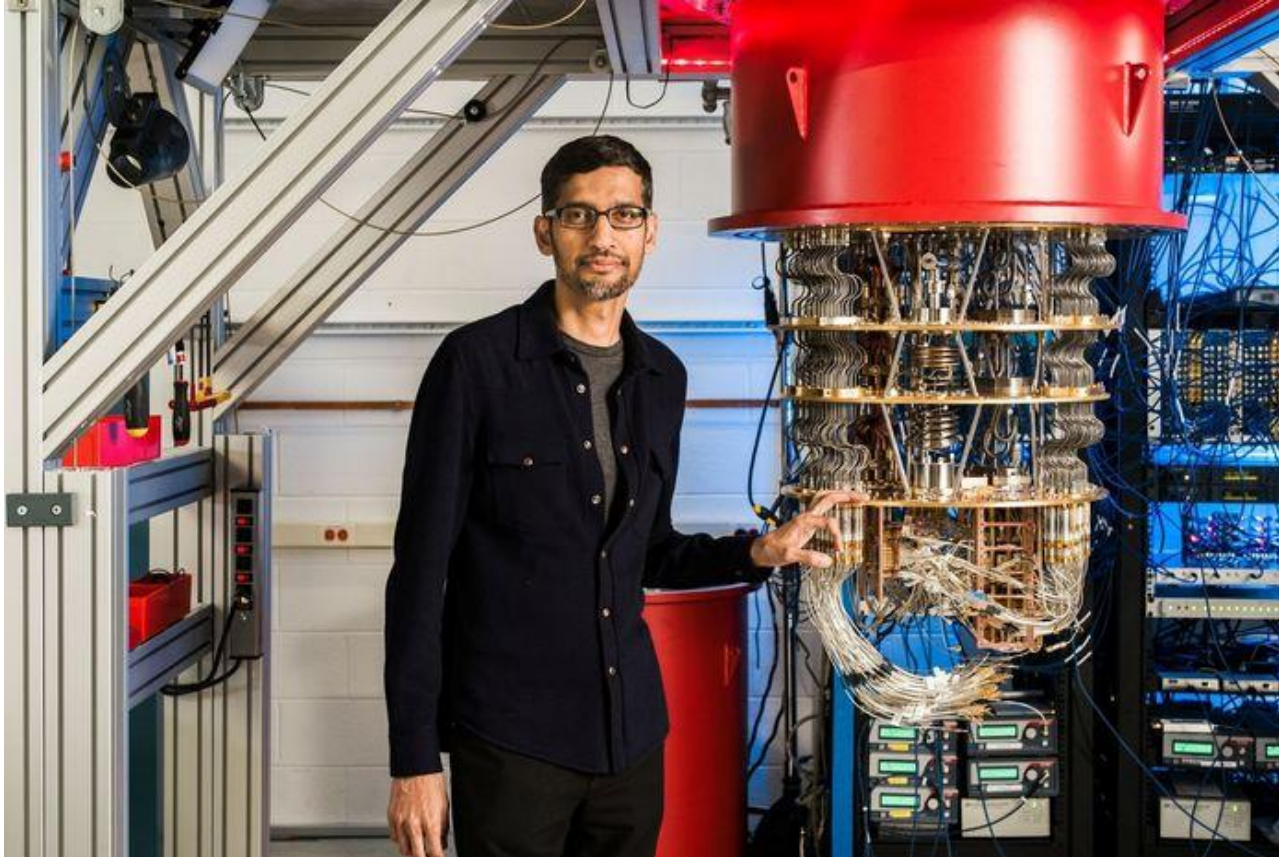
QKD over DWDM

Context

Quantum Technologies



Quantum technologies. Are they...?



THE WALL STREET JOURNAL.

Google Claims Breakthrough in Quantum Computing

Others, including IBM, dispute the science behind Google's experiment

October 23, 2019

DISRUPTIVE

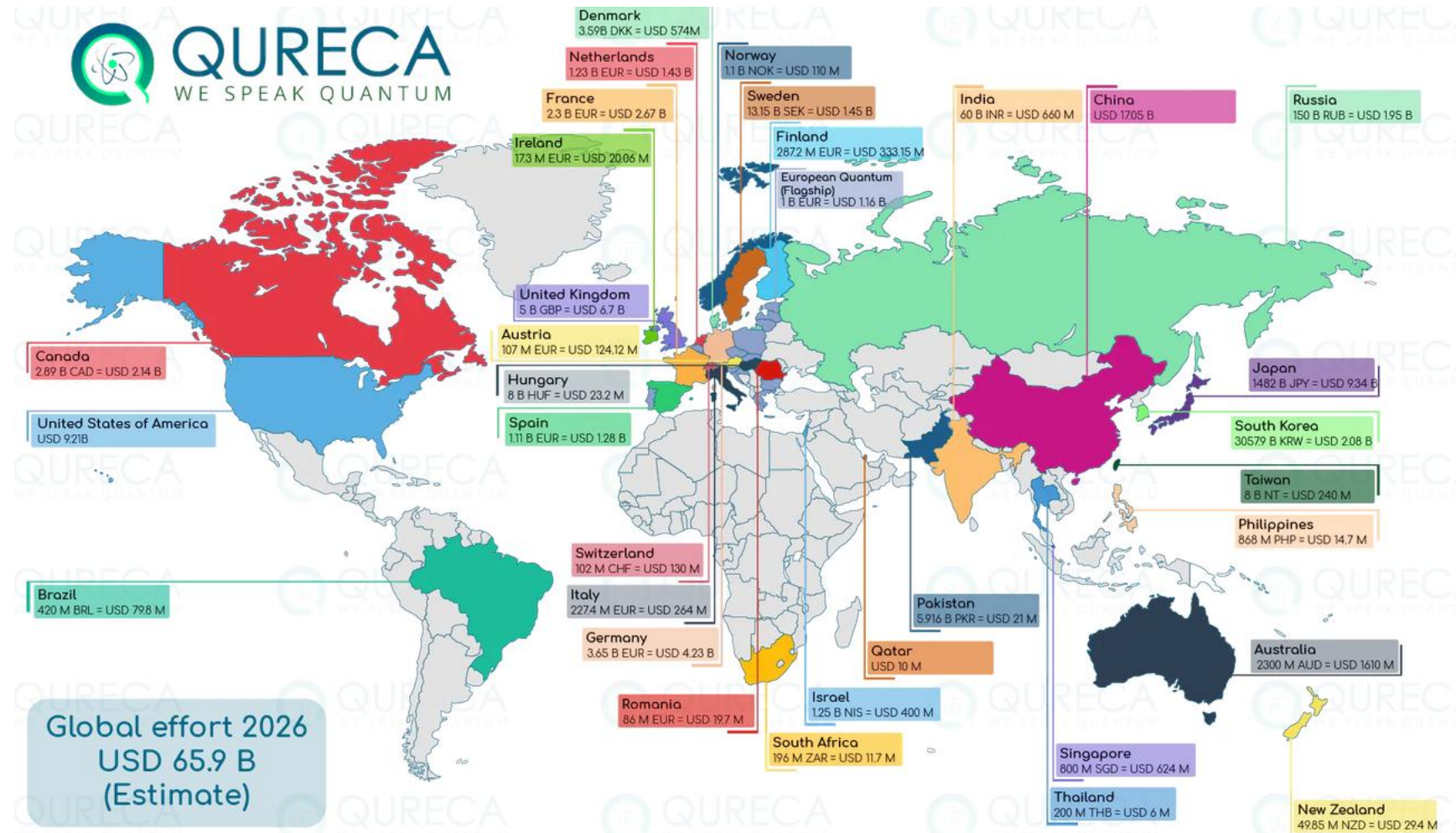
Quantum technologies. Are they...?

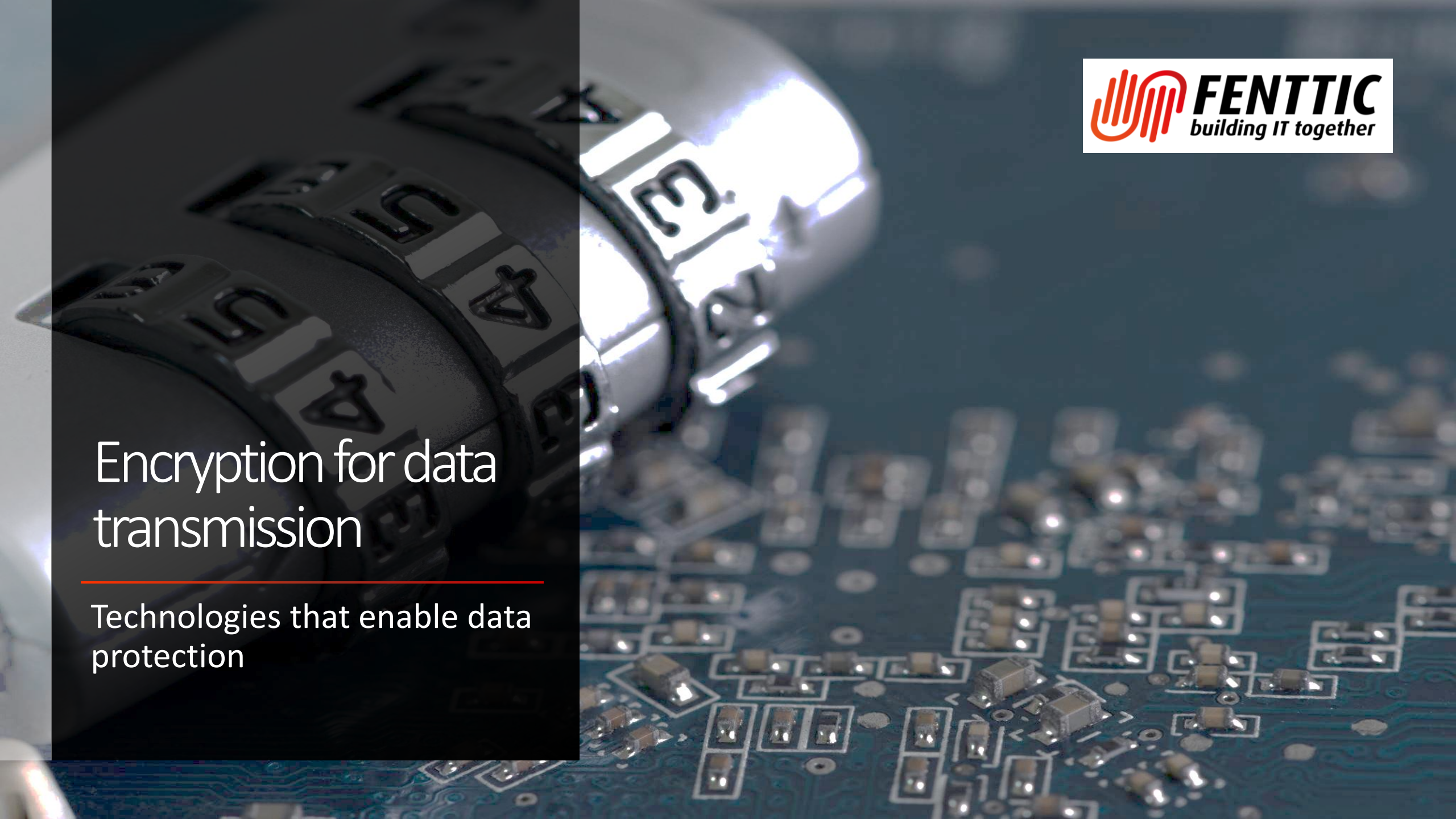
- Based on **QUANTUM PHYSICS**: the properties that matter and energy has at its most fundamental level.
- Take advantage of the **quantum phenomena** to run operations almost imposible or not efficient at all with the classical technology.
- So we can:
 - ✓ **Acquire information**: Metrology, through quantum sensors, benefits from the precision and sensitivity that only quantum physics allows, enabling measurements and detections with a precision not achievable through classical equipment.
 - ✓ **Process information**: Quantum computation manages qubit superposition and entanglement to perform calculations and solve complex problems much faster than traditional computers.
 - ✓ **Transfer information** : Quantum communication is based on sending and receiving information through photons to achieve secure and potentially instantaneous data transfer.

USEFUL

Quantum technologies. Are they...?

TRENDY

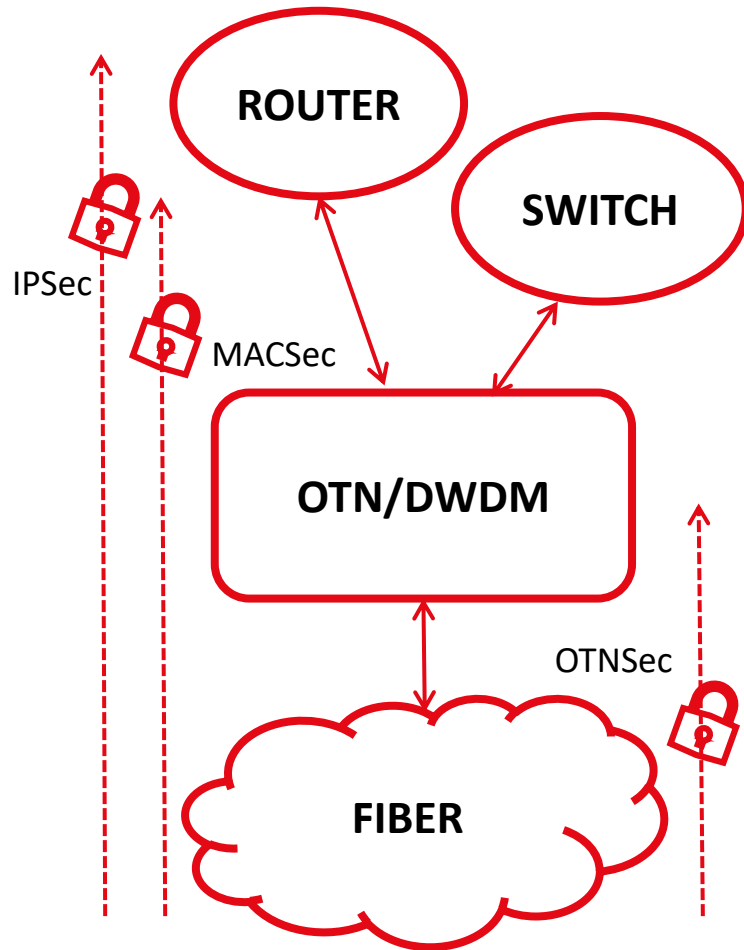




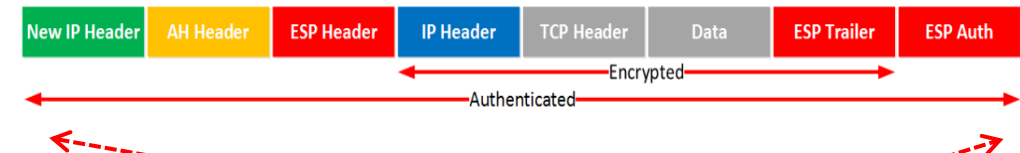
Encryption for data transmission

Technologies that enable data protection

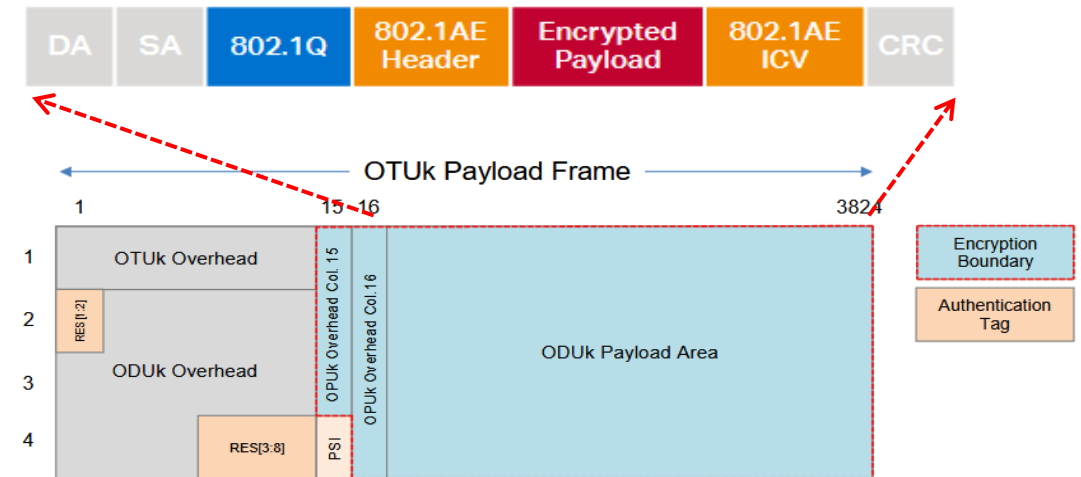
What is secured in L1, L2 and L3



- IPsec Tunnel mode



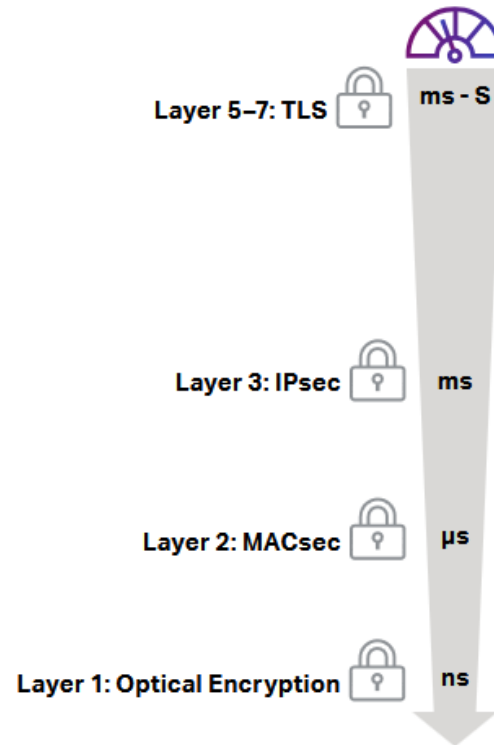
- MACsec



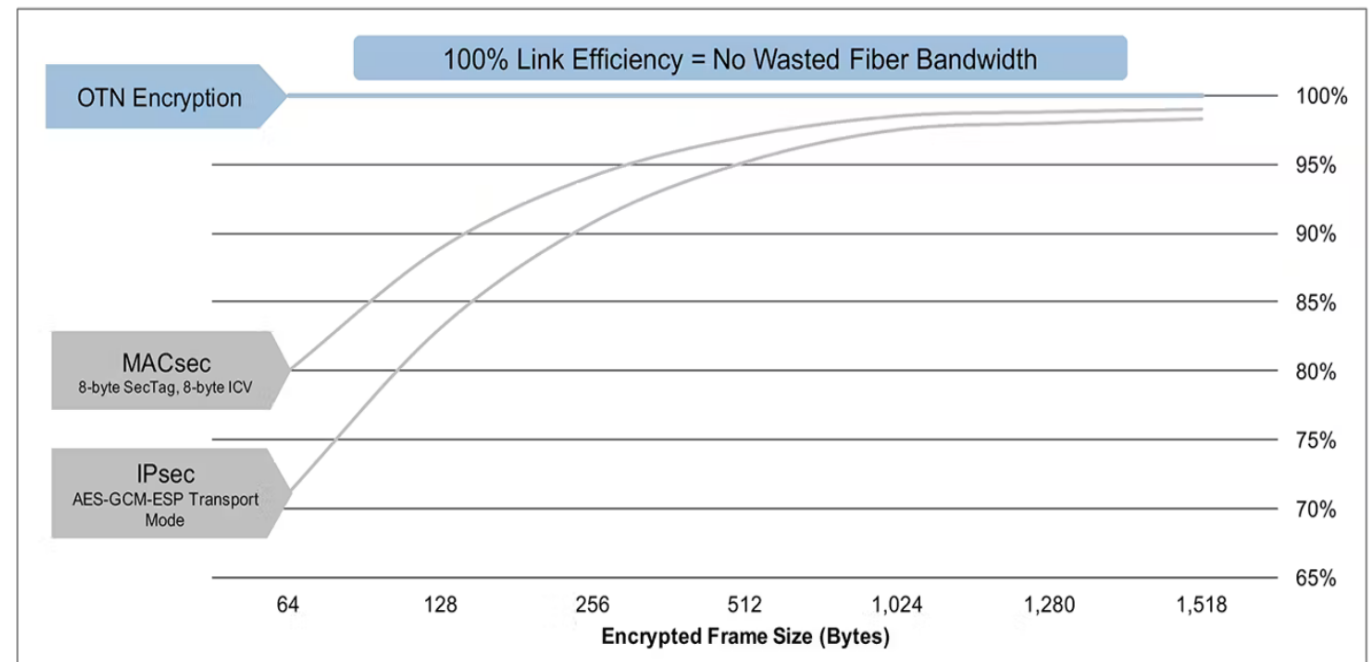
- OTNsec

Encryption solutions performace

- Latency

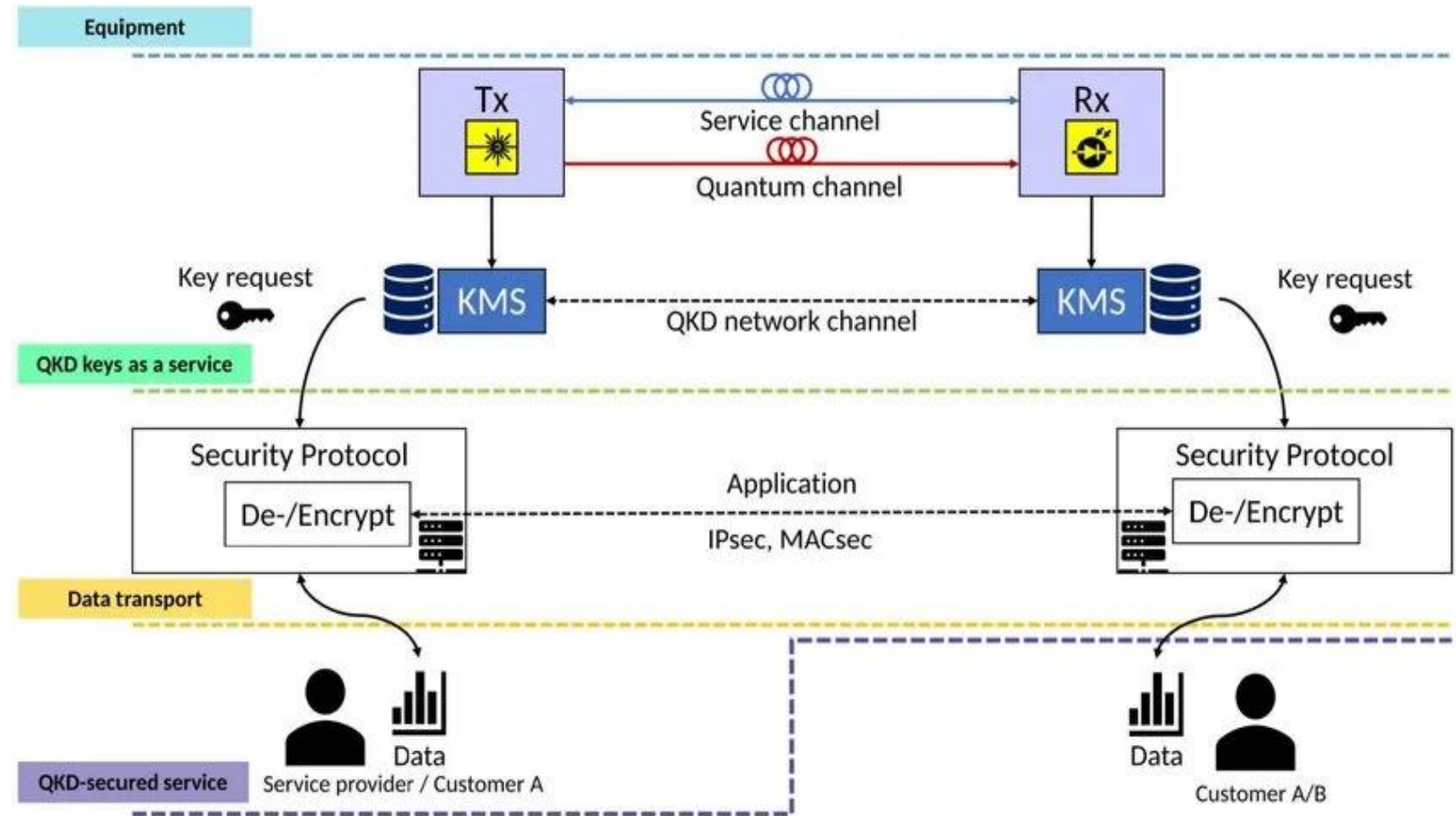


- Throughput



QKD Key life cycle

1. Key is generated
2. Key is stored
3. Key is used



QKD fundamentals

Quantum properties and
communication requirements

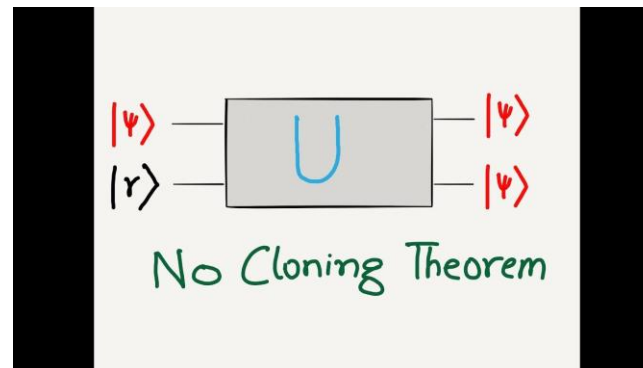


Quantum properties used in communication

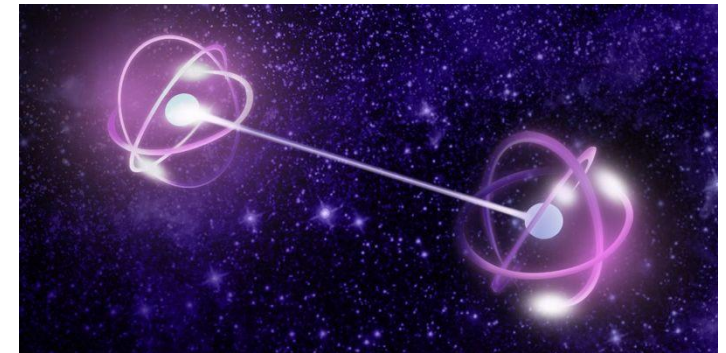
Quantum superposition



No-cloning theroem



Quantum entanglement

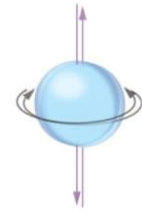


Quantum properties used in communication

Quantum superposition

Qubit can exist in superposition state:
 $|\psi_{qubit}\rangle = \alpha|0\rangle + \beta|1\rangle$ where $|\alpha|^2 + |\beta|^2 = 1$

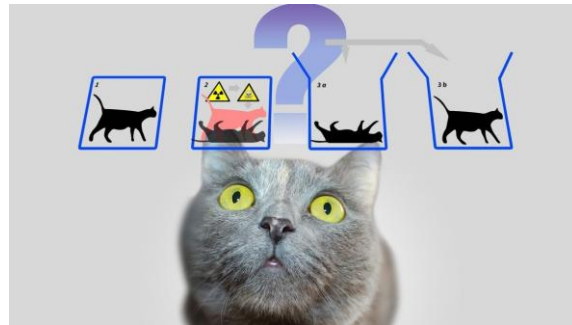
Only when measuring it collapses to $|0\rangle$ or $|1\rangle$



Superposición

$|0\rangle + |1\rangle$

Classical Physics	vs	Quantum Physics
Classical Bits	vs	Qubits



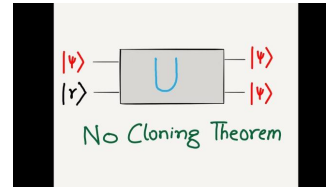
CLASSICAL BIT



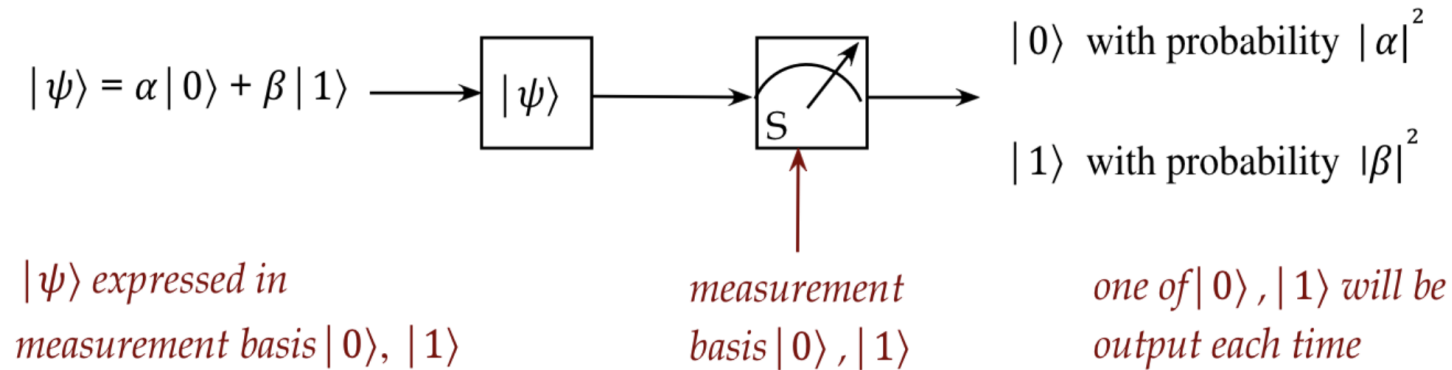
[Video from QuTech Academy](#)

Quantum properties used in communication

No-cloning theroem



It was introduced by Wootters, Zurek y Dieks in 1982 and shows only base states can be copied, but not any 'unknown' state (superposition) could be copied



Problem: a photon could not be amplified.

Benefit: a photon could not be copied.

Quantum properties used in communication

Quantum entanglement



It allows two separated photons, even if by several Km, maintain a certain correlation that classical physics can not explain.

Advantage: Chances to build quantum repeaters



J.S. Bell (imagen del CERN).

What we needed for QKD systems to work

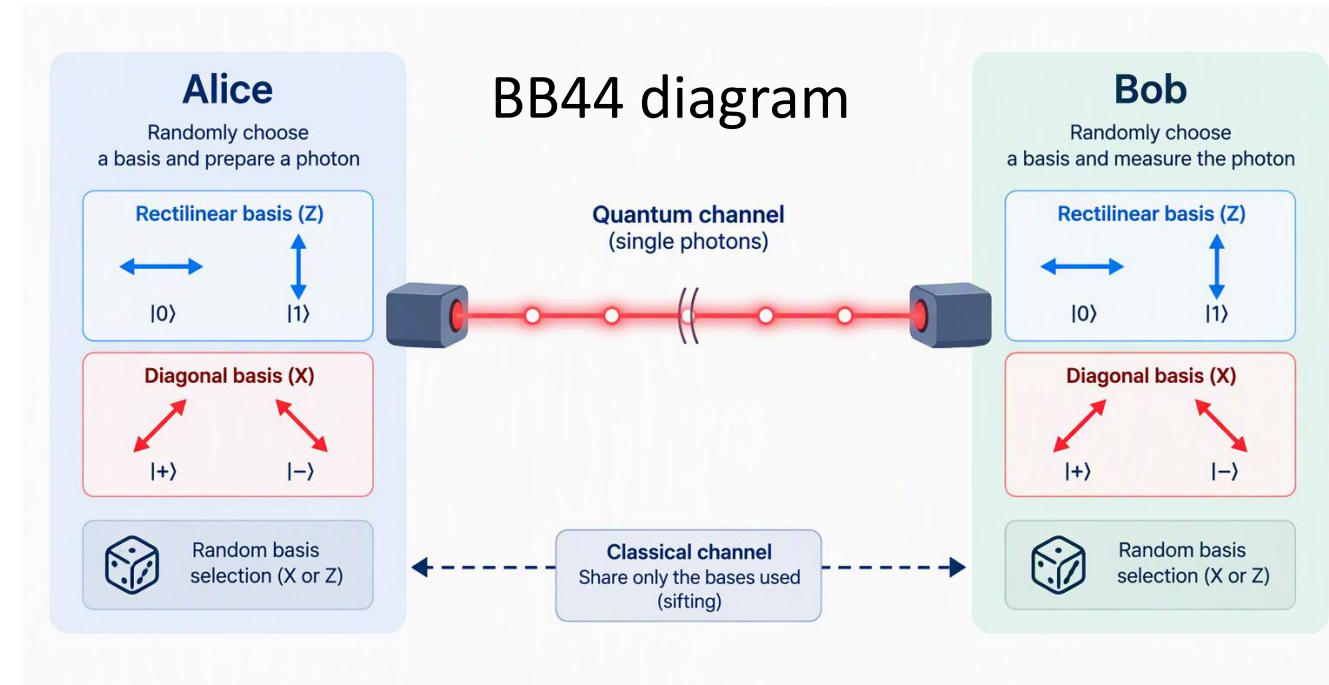
Quantum channel → 1 single photon Qubit transmission

Classical channel → Bases sharing

Qubit preparation and analysis

a) Qubit transmitter

b) Qubit detector



QKD into DWDM

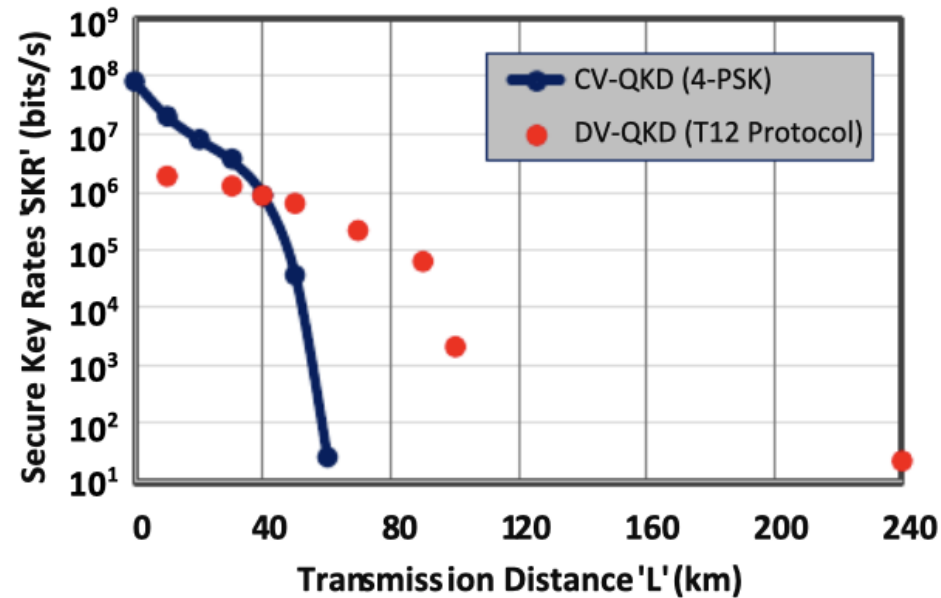
Challenges and options
based on a real design



Can QKD be integrated in a real network?

0 km	10^9 photons/sec.
15 km	$5 \cdot 10^8$
150 km	10^6
300 km	1000
600 km	1 p per 20 min.
900 km	1 p per 36 years

Losses in fibre 0.2 dB/km



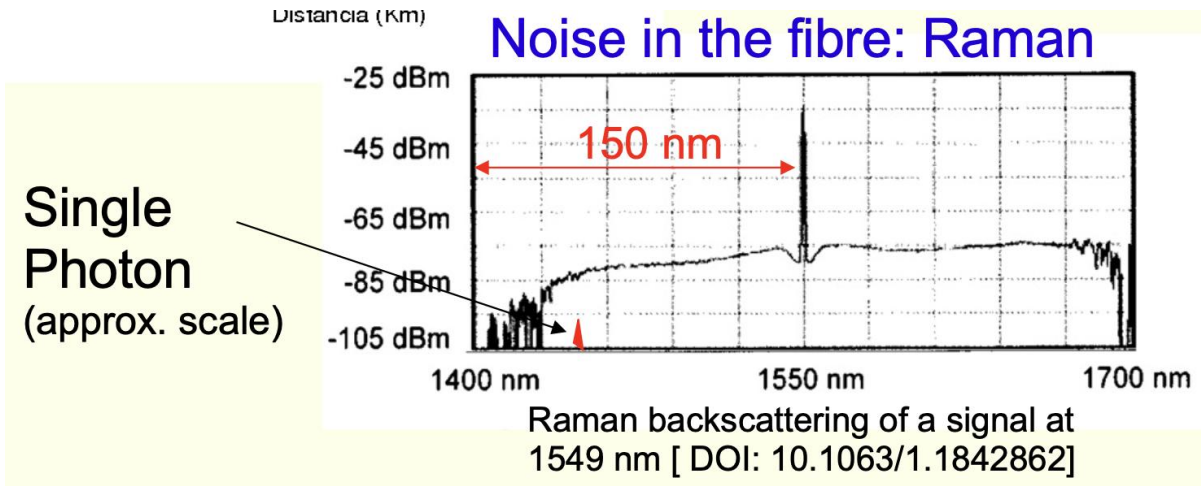
Problem: ~30dB att limit, ~150km to transmit the key

Solution:

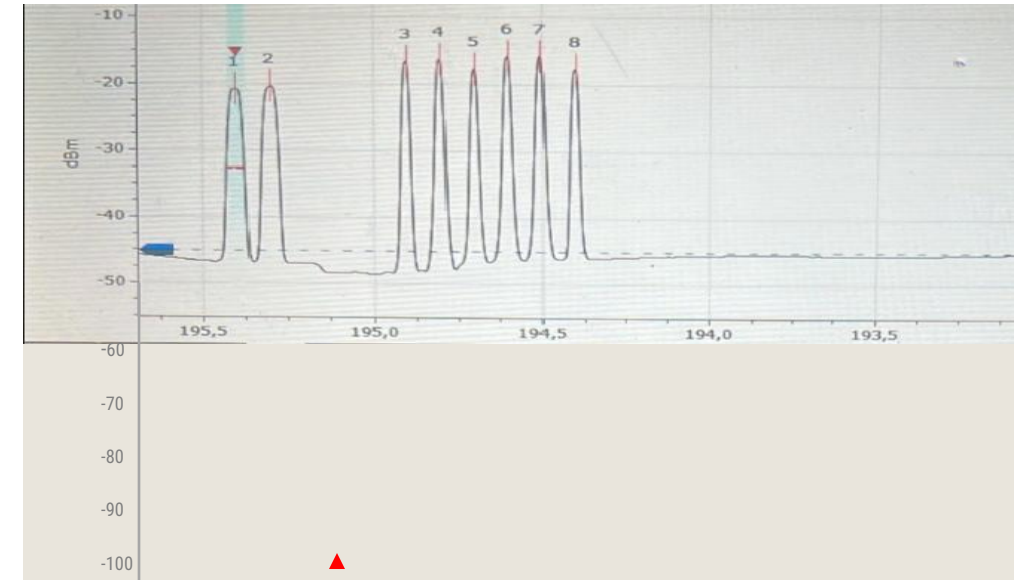
- New protocols extending reach up to ~60dB, ~300km
- Trusted nodes / quantum repeaters
- Satellite

Can QKD be integrated in a real network?

Single Channel: noise at -70 dBm



Amplified DWDM system: noise at -45 dBm



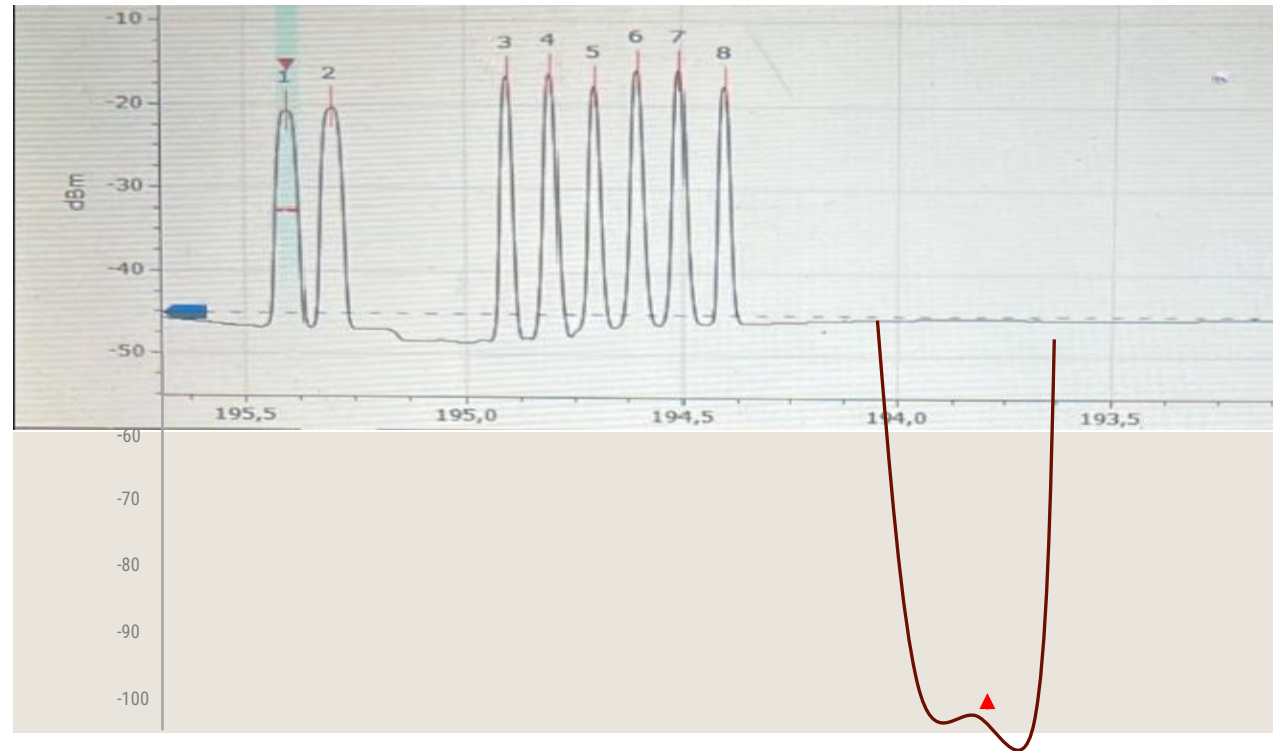
Problem: Noise is masking QKD Photon

Solution:

- Use a separate fibre
- Use a separate band O or L
- Increase isolation on QKD insertion sub-band

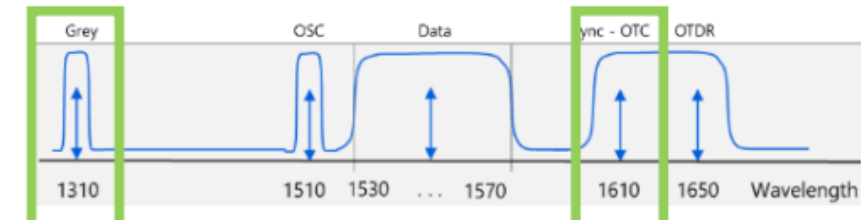
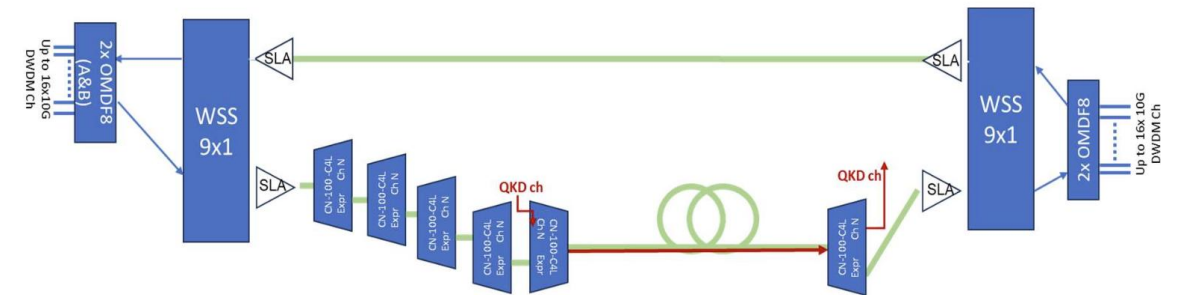
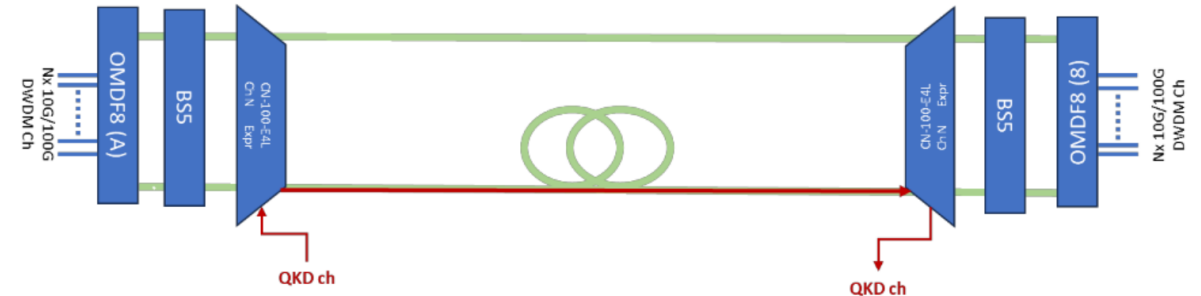
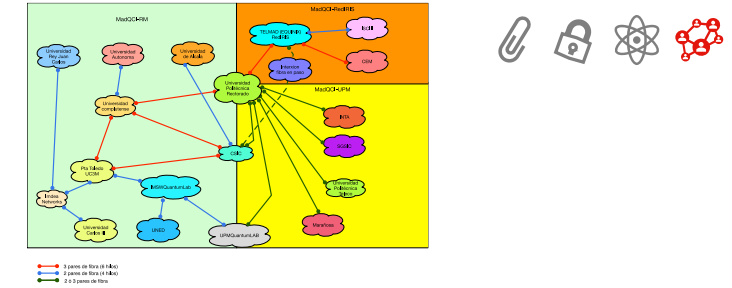
MadQCI design: the challenge

- **CHALLENGE:** Isolate QKD band in a way that a single photon transmission will be allowed.
- **TARGET:** get $\sim 100\text{dB}$ isolation when booster is used in TX to 'clean' the QKD spectrum slice



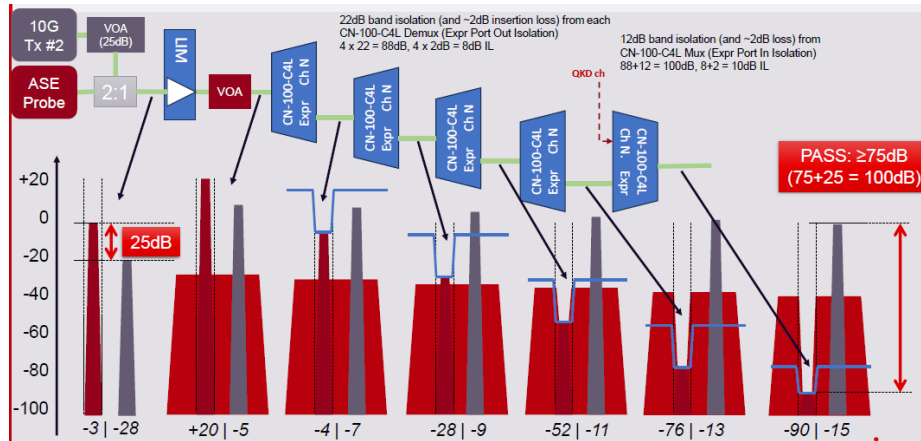
MadQCI design: 5 in 1

- **Dedicated Fibre** out of DWDM
- **FODAM** with quantum channels co-propagation
- **RODAM w/o booster** with quantum channels co-propagation.
 - It allows to have almost a real network avoiding booster noise to interfere in QKD channels.
- **Complete RODAM** with quantum channels co-propagation.
 - It simulates a real operator network with boosters and pre-amplifiers.
 - Notch filters to minimise booster interference
- **O and L couplers** also available

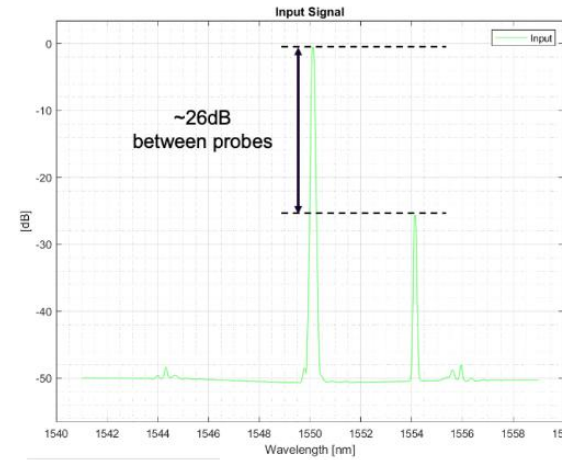


MadQCI: acknowledgement testbed

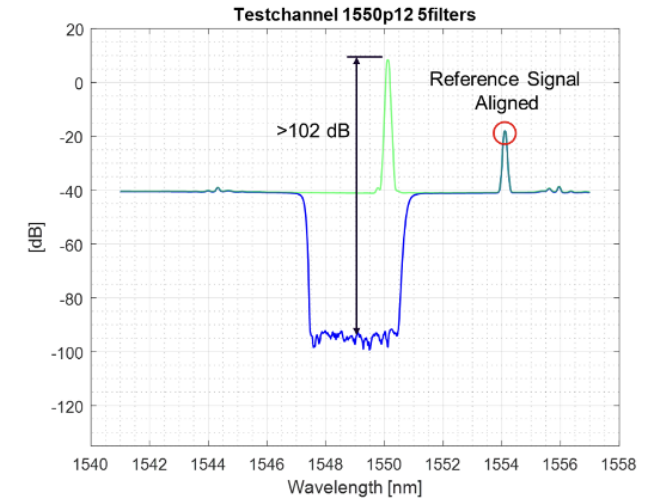
Theoretical Plan:



Outcome:



(a) Probe and reference signals at filter cascade input.



(b) Probe signals measured at the output of the 5-filters cascade.

SFP Channel 34 amplified	Measures after 1st filter	Measures after 2nd filter	Measures after 3rd filter	Theoretical value after 4th filter	Theoretical value after 5th filter
1550.12 nm	Att = -40,98 dB	Att = -90,78dB	Att = -107,6dB	Att $\approx$ -130dB	Att $\approx$ -152dB



MadQCI: lessons learned

- **Technological Missalignment:**

Optical vendors have been sprinting and are now ready to integrate quantum transmission.

Nevertheless notch filters is not something they can provide and are still dependant on QKD providers

- **Resistance to change:**

Out of the box solutions, even if there are being designed with off-the-shelf components, are not easily moved forward to a quote that could be purchased.

- **Inmature Ecosystem:**

Due to not having any previous industrial deployments on QKD, system integrators are in a lack of knowledge and experience on how to deal with this QKD projects.

- **QKD needs to evolve:**

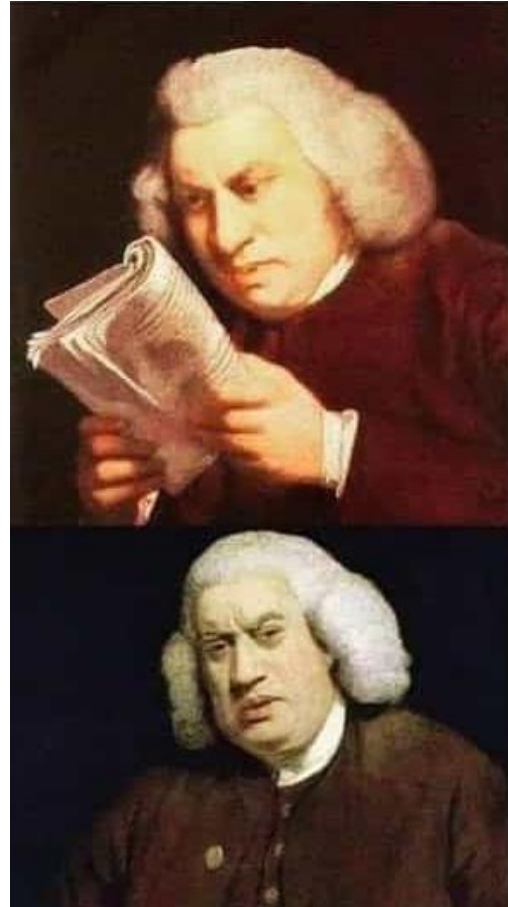
QKD providers need to improve their solutions to avoid non-standard requirements such dedicated fibre, ultra high isolation on QKD spectrum slice or additional need of channels for sync, distillation, etc.

- **Optical Fibre limitations:**

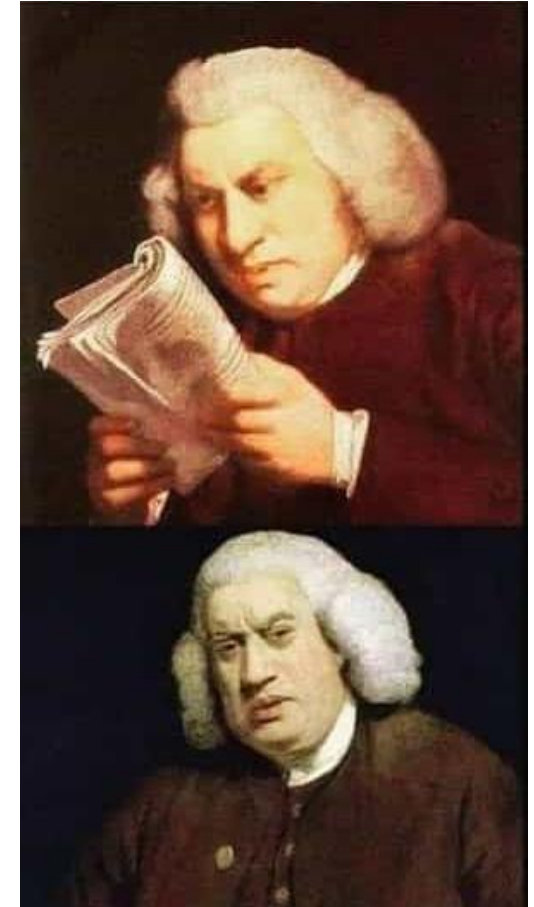
actual fibre attenuation is highly enshortening QKD links distance. So, advances on hollow fibres, Quantum Repeaters and increased attenuation support on QKD systems will be required.

Still a long way to go...

The 1st time you
read about quantum
mechanics:



The 1.000th time you
read about quantum
mechanics:





Thank You



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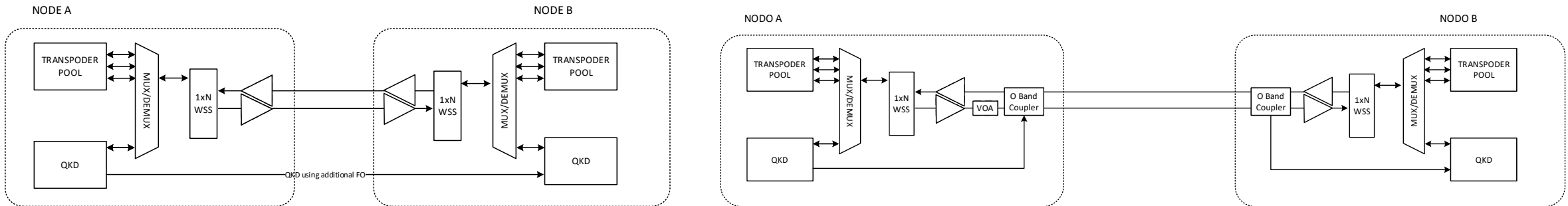


BACKUP



QKD over DWDM: state of art

- Optical **fiber** is a finite and **expensive** resource:
 - DWDM systems provide a technology that optimizes fiber usage in transmission networks.
- QKD does **not** integrate effectively with **optical amplifiers** due to ASE noise affecting the QKD foton
 - To overcome this limitation, actual deployments are using separate fibre or a separated transmission band :



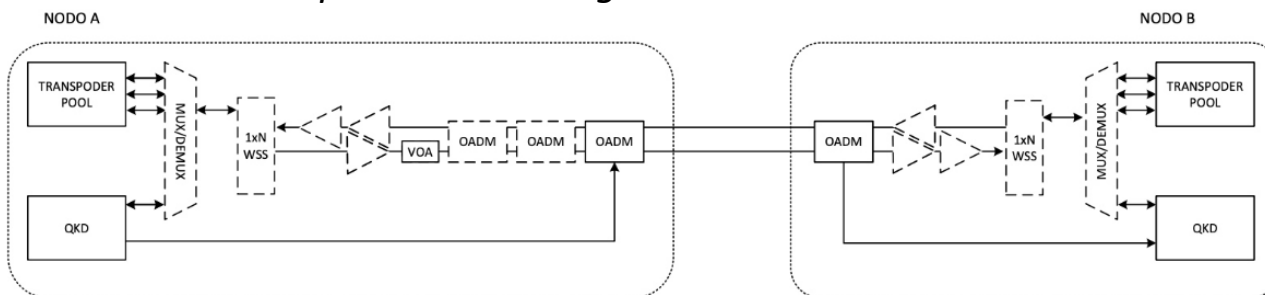
- BUT... the introduction of any system that requires **extra fibers** is a significant **challenge** for Network Operators

QKD over DWDM: Band C copropagation

- QKD **copropagating** in any **C Band** channel is a genuine **need** for Network Operators
- To mitigate interference from **ASE** amplifiers, it is necessary to **isolate** the QKD insertion channel(s) from any type of light (with power levels below **-80dBm**)
- The only effective way so far is to reduce launch power per channel and attenuate power in the QKD insertion band by **filtering**

NOTE: Last MadQCI public tender in Spain launched after and RFI to the industry was requiring this approach to the participants:

Proposed block diagram



Isolation at QKD insertion frequency

