Status and perspectives of satellite quantum communications: toward a fully connected quantum network

Daniele Dequal
Telecommunication and Navigation Unit
Italian Space Agency

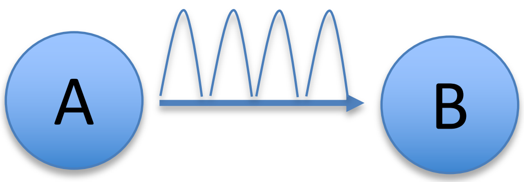
www.asi.it

21 September 2022- European Conference on Optical Communication 2022

Quantum networking: basic schemes

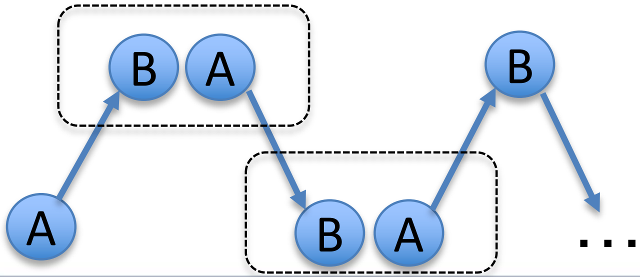
Quantum communication: the distribution of a quantum state among two or more end terminals

Simplest case: Prepare and Measure (P&M)



A single transmitter (Alice) sends a series of independent quantum states to a single receive (Bob)

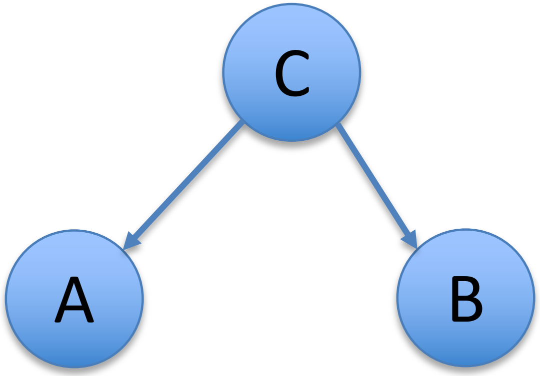
Networking with Prepare and Measure (P&M)

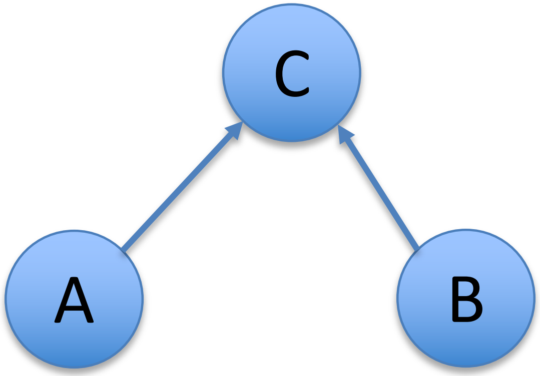


Pros: "easy" to implement, requires only P&M
Cons: limited applications (QKD), limited security (trusted nodes)

Quantum networking: basic schemes

More challenging case: Entanglement Distribution (ED)/Bell State Measurement (BSM)

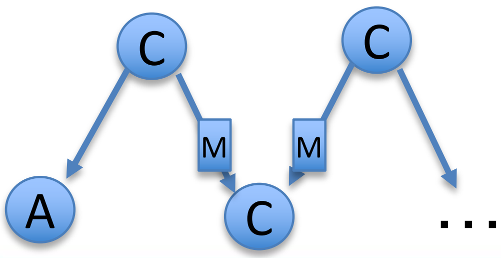




Untrusted node

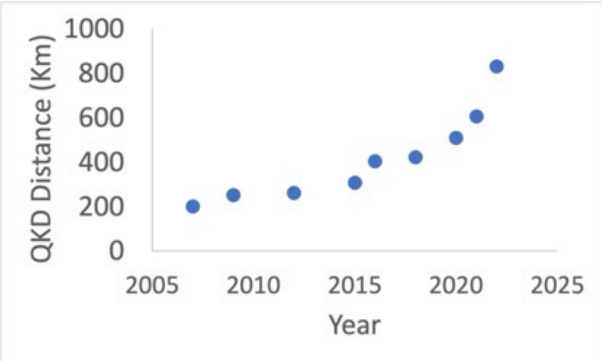
Intermediate node (Charlie) can only know the correlation between Alice's and Bob's states

Networking with untrusted nodes



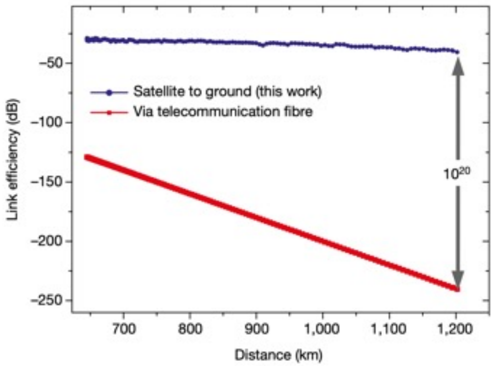
Pros: more flexible configuration
Cons: Needs ED and BSM, bad scaling with distance unless quantum memories are implemented

A global reach for quantum communication



Exponential attenuation in optical fibers makes it impossible to extend point-to-point QKD beyond several hundreds of kilometers.

Recent improvement in QKD bound thanks to “Twin-field” schemes, which seems to have reached the limit.



“…over a distance of 1,200 km, even with a perfect 10-GHz single-photon source and ideal single-photon detectors with no dark count, transmission through optical fibres would result in only a 1-bit sifted key over six million years.“

Liao et al, Nature 549, 43 (2017)

Connecting remote locations

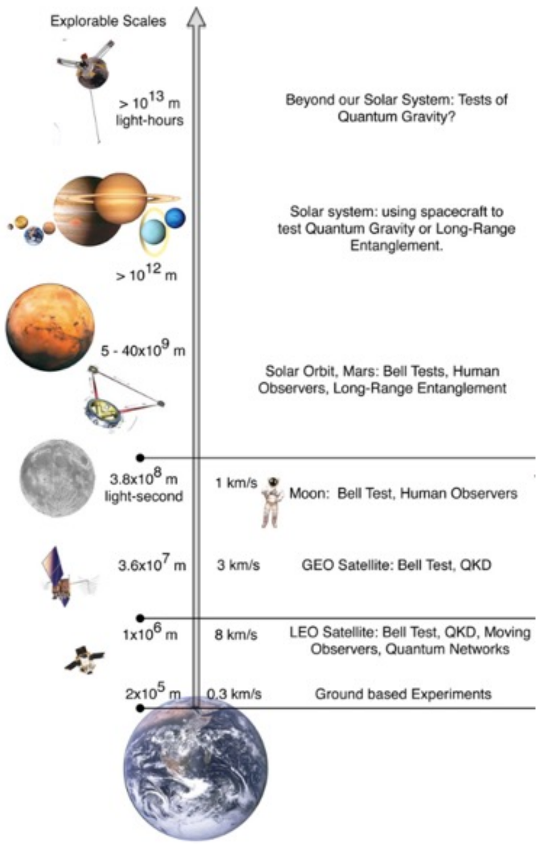
QKD will most likely be used to protect critical infrastructures, to provide governmental/institutional secure communication. However, several impediments prevents the use of optical fibers: physical, political, economical.

Locations inaccessible to fibers

Isolated / hostile territory

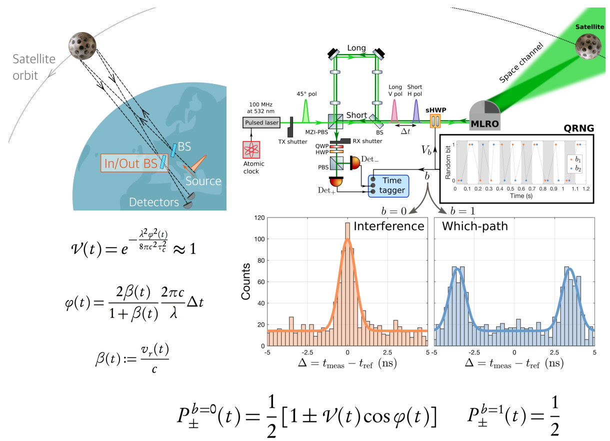
Remote locations

Testing fundamental physics



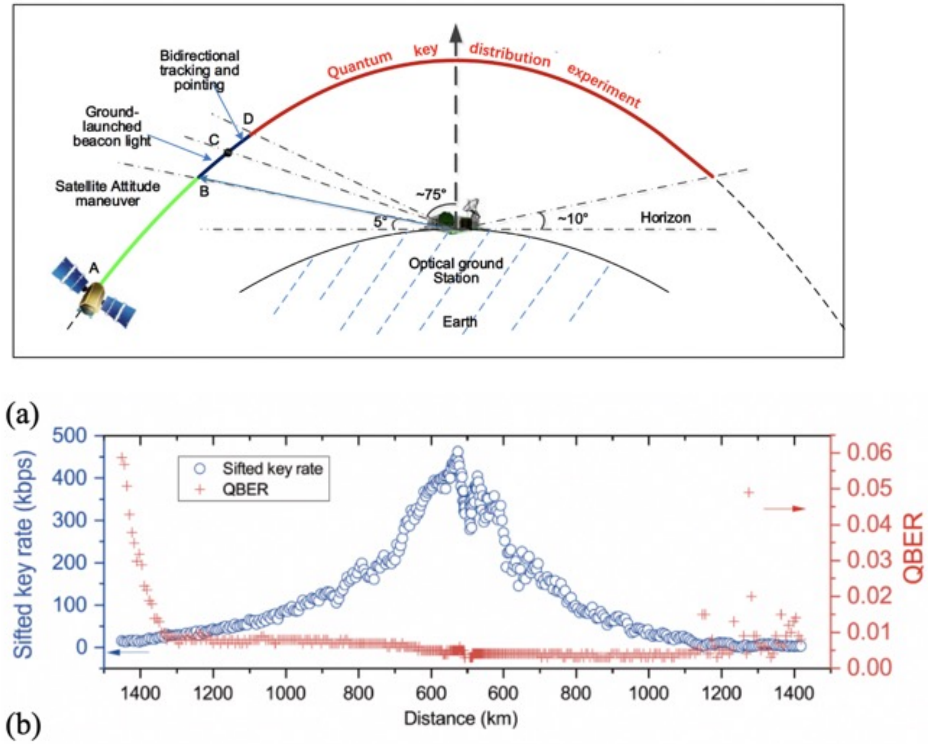
Satellite links can provide a unique environment for fundamental tests:

- Collapse of the wavefunction
- Interplay between relativity and quantum mechanics
- Gravitational decoherence…



D.Rideout et. al, Class. Quant. Grav. **29**, 224011 (2012)
F. Vedovato et al., Sci. Adv. 3, e1701180 (2017)

Satellite: P&M realizations



Satellite QKD demonstrations performed so far:

- Micius/Mozi satellite (2016)
- QKD payload on Tiangong-2 (2017)

Other projects foreseen for the next future:

- Jinan 1: Successor of Micius, more compact (100 kg) launched in Jul 2022
- ESA industry initiated: QKDSat, Eagle-1
- ESA-EC SAGA mission: the space segment of EuroQCI

Liao, S-K et al., Nature Nature 549, 509 (2017)
Liao, S-K et al., *Chinese Phys. Lett.* **34** 090302 (2017)
Y. Chen et al, Nature589(7841):214-219 (2021)

Satellite Networking: P&M realizations

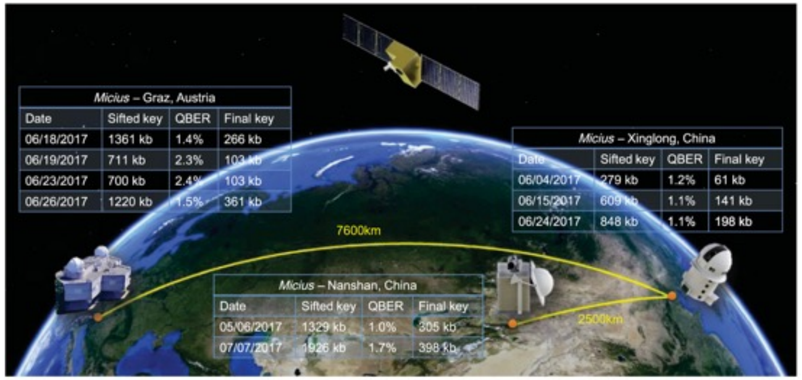


Table 1. Estimated Key Generation Results for the Two Orbit Types in 1 Year

Analysis Results	SSO Satellites	MIO Satellites
Maximum communication times per day (s)	649	2169
Total communication time in 1 year (s)	150,776	525,403
Maximum final keys per orbit (kbits)	473	532
Total final keys in 1 year (Mbits)	140	463

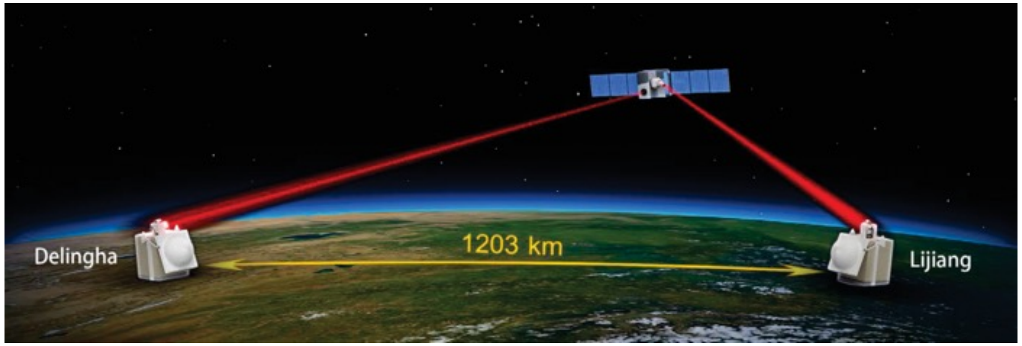
With P&M payload several network have been established.

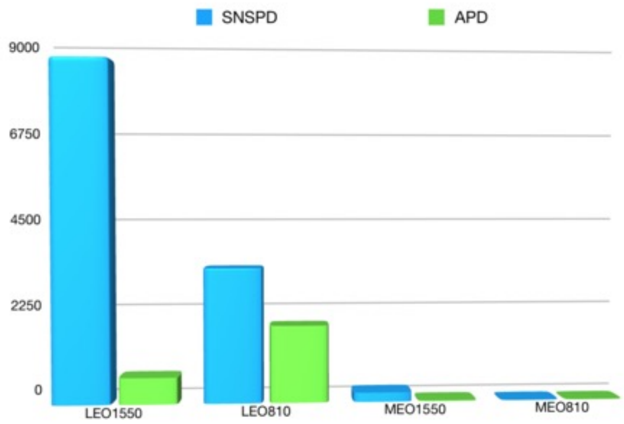
LEO satellite used as single trusted node to establish intercontinental QKD, as well as multicity network.

S-K Liao et al., Phys. Rev. Lett. 120,030501 (2018)
Y. Li et al., Optica 9, 8 (2022)

Entanglement distribution

Micius satellite demonstrated entanglement distribution over 1200 km and quantum teleportation (in uplink).





Extensive comparison of LEO vs MEO performances: LEO show a higher performances, even if lower communication period are allowed

J. Yin et al., Science 356 1140 (2017)
L de Forges de Parny et al., arXiv:2202.01817 (2022)

Summary

Demonstrated:

- LEO P&M
- Trusted network LEO + ground
- LEO ED and teleportation (in uplink)

Still missing:

Technological development

- bell state measurement
- quantum memories
- Higher orbits
- Intersatellite links
- Certification/standardization

Thank you for your attention

ASI
Agenzia Spaziale Italiana
Via del Politecnico snc
00133 Roma, Italia