Quantum communication architectures and protocols Design and implementation for space solutions

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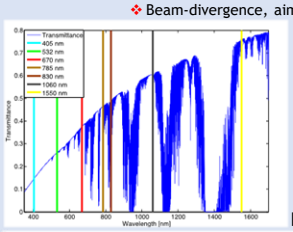
Increasing need of crypted and long-reach communication

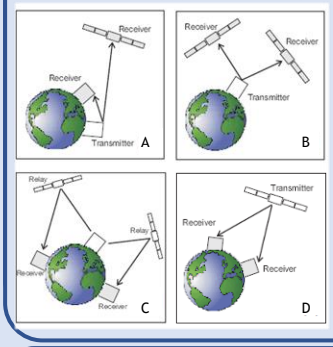
As seen in the context of COVID-19, there is an increased need of secured communication in between countries, armies, companies or banks, and QKD answer to that. The longest fibered quantum communication repeaterless links are of the order of 100 km and can't be applied for distant or moving locations as islands or ships. Thus, space quantum communication is a solution to these problems as it manage to create a link in between points distanced by an order of 1000 km.

QKD (Quantum Key Distribution) in space

- BBM92 protocol
- Problems to overcome while communicating through atmosphere:
  - Clouds, turbulences
  - Beam-divergence, aiming to ground station



810 nm and 1550 nm are chosen as we got the technology to detect these wavelengths, generate them at high power, and 1550 nm is used in our telecom fibered networks. [1]



Configuration of entangled communication:

A/Hybrid uplink and fibered

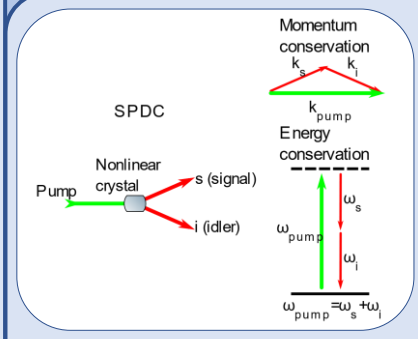
B/Uplink to 2 satellites

C/Uplink and downlink with satellites relay

D/Downlink to 2 ground stations

[2]

Type-I Spontaneous Parametric Down-Conversion (SPDC)



SPDC needs:
- Momentum conservation
- Energy conservation

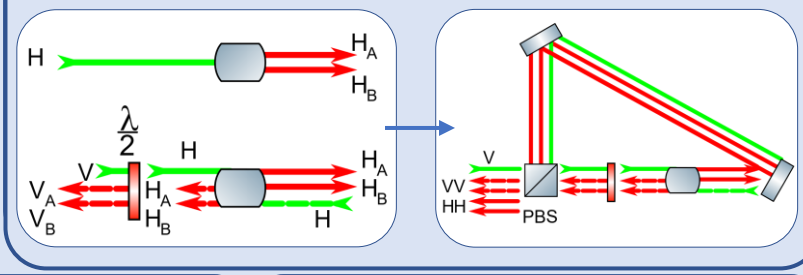
Type-I SPDC generate entangled photons at the same polarization:

$$|\Psi\rangle = |H\rangle_A |H\rangle_B$$

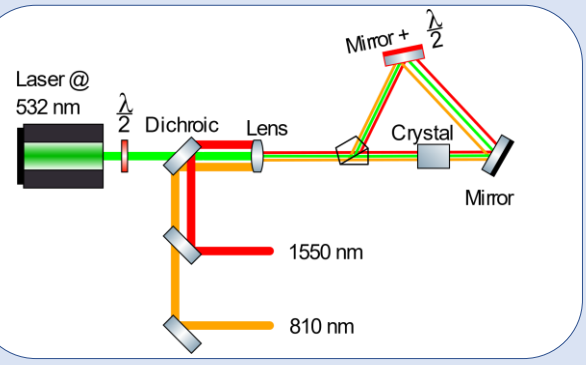
To get a superposition of state as:

$$|\Psi\rangle = |H\rangle_A |H\rangle_B + |V\rangle_A |V\rangle_B$$

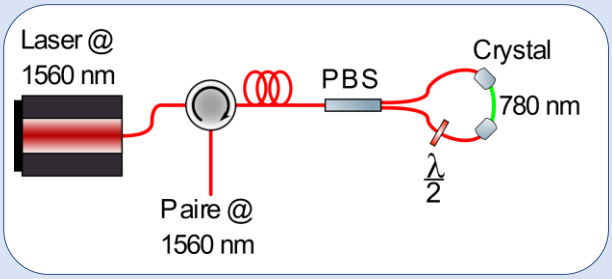
2 paths are needed, as we overlap both ways in the Sagnac loop.



Developed Sagnac sources in our lab

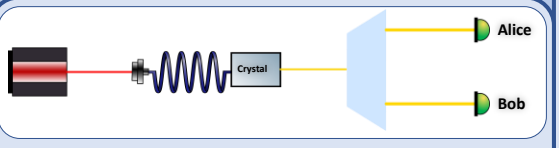


Bulk
- High power
- Multiple wavelengths
- Mirrors motorizable



Fibered
- Plug and play
- Compact
- Spacializable laser
- Large spectrum

BBM92



Entangled state $\|HV\rangle + \|VH\rangle = \|DA\rangle + \|AD\rangle$	A / B	A / B	A / B	A / B	A / B
Measurement base	HV / HV	HV / HV	HV / DA	DA / HV	DA / DA
Measure and bit conversion	H / V 0 / 1	V / H 1 / 0	H / D 0 / 0	D / V 0 / 1	D / A 0 / 1
Sifting	Yes	Yes	No	No	Yes
Inversion	0 / 0	1 / 1	X	X	0 / 0
Final key	0	1	X	X	0

- 1 source of entangled pairs encoding on 2 orthogonal bases (here in polarization, i.e., H / V and D / A)
- Alice and Bob perform a measurement of the observable according to one of the 2 orthogonal bases
- Alice and Bob convert their measurement to bit ([H, D] = 0 and [V, A] = 1)
- Alice and Bob reconcile their measurement basis (Sifting)
- Bob reverse are bit if the "Sifting" is successful

Protocols based on entanglement allows to develop a network.

Conclusion

Bulk source:
- 2 wavelengths for hybrid communications (free space/fiber)
- Allows to test both wavelengths in real field

Fibered source:
- Easier to implement in a satellite
- Large bandwidth

References

►[1] A comprehensive design and performance analysis of low Earth orbit satellite quantum communication
J-P Bourgoin *et al* 2013 *New J. Phys.* **15** 023006

►[2] Long-Distance Quantum Communication with Entangled Photons using Satellites
Markus Aspelmeyer *et al* 2003
arXiv:quant-ph/0305105v1 19 May 2003