Quantum Communication from a Telecom Point of View

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May 5, 2009

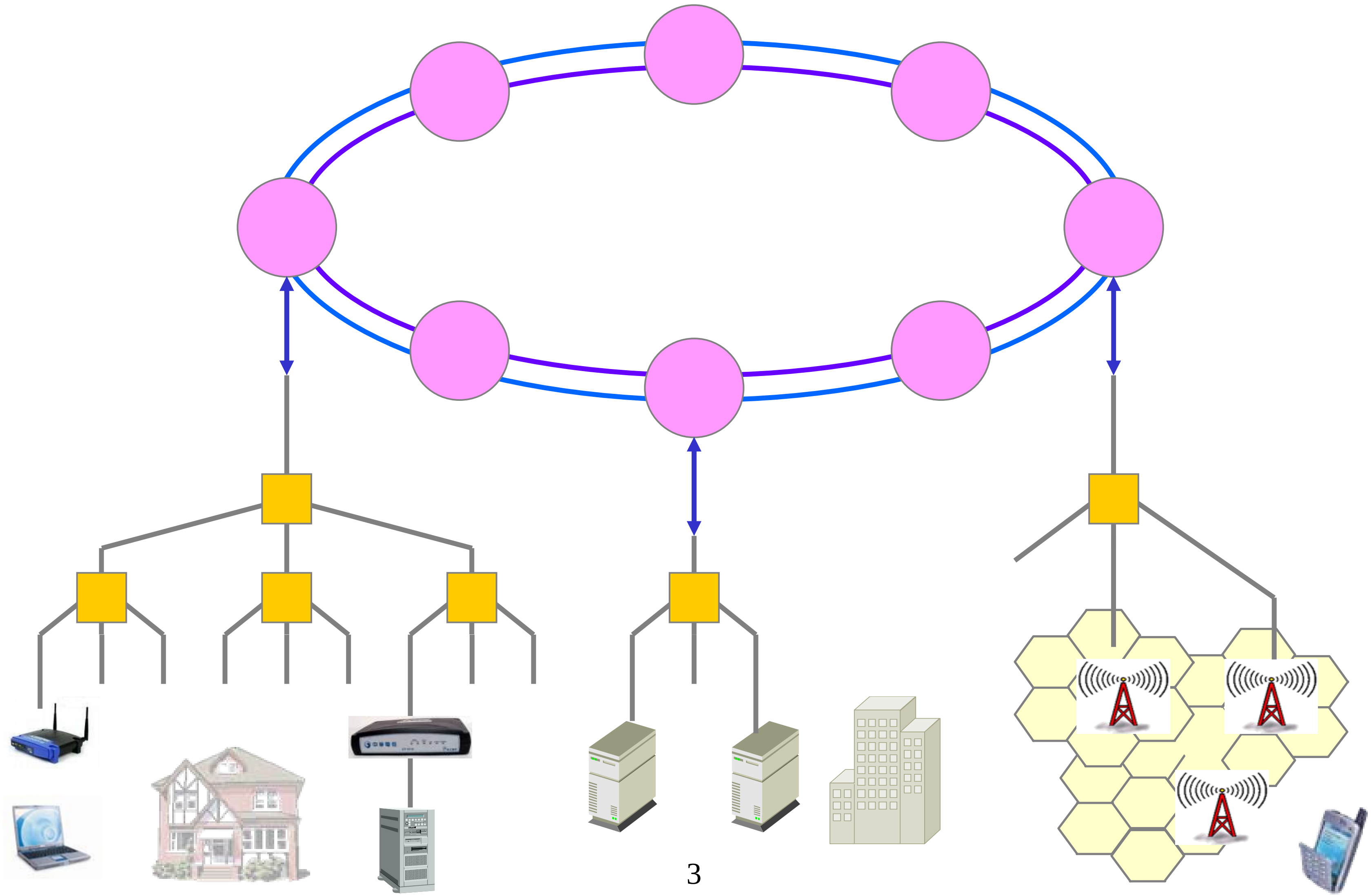
Outline

Classical Communication

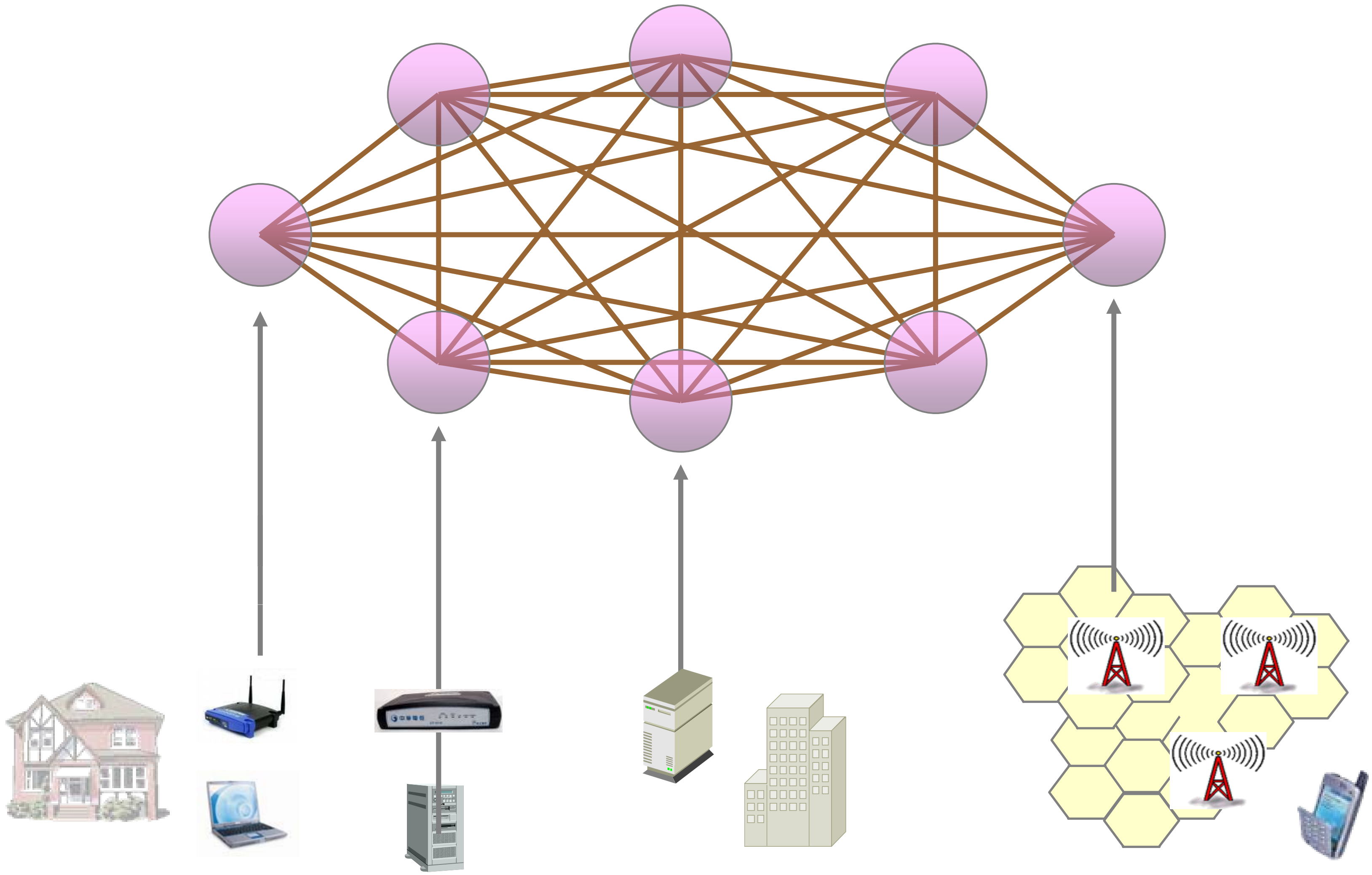
- Cryptography
  - Telecom Viewpoint
- Teleportation
- Dense Coding
  - Telecom Viewpoint
- Space Communication
  - Telecom Viewpoint

Summary

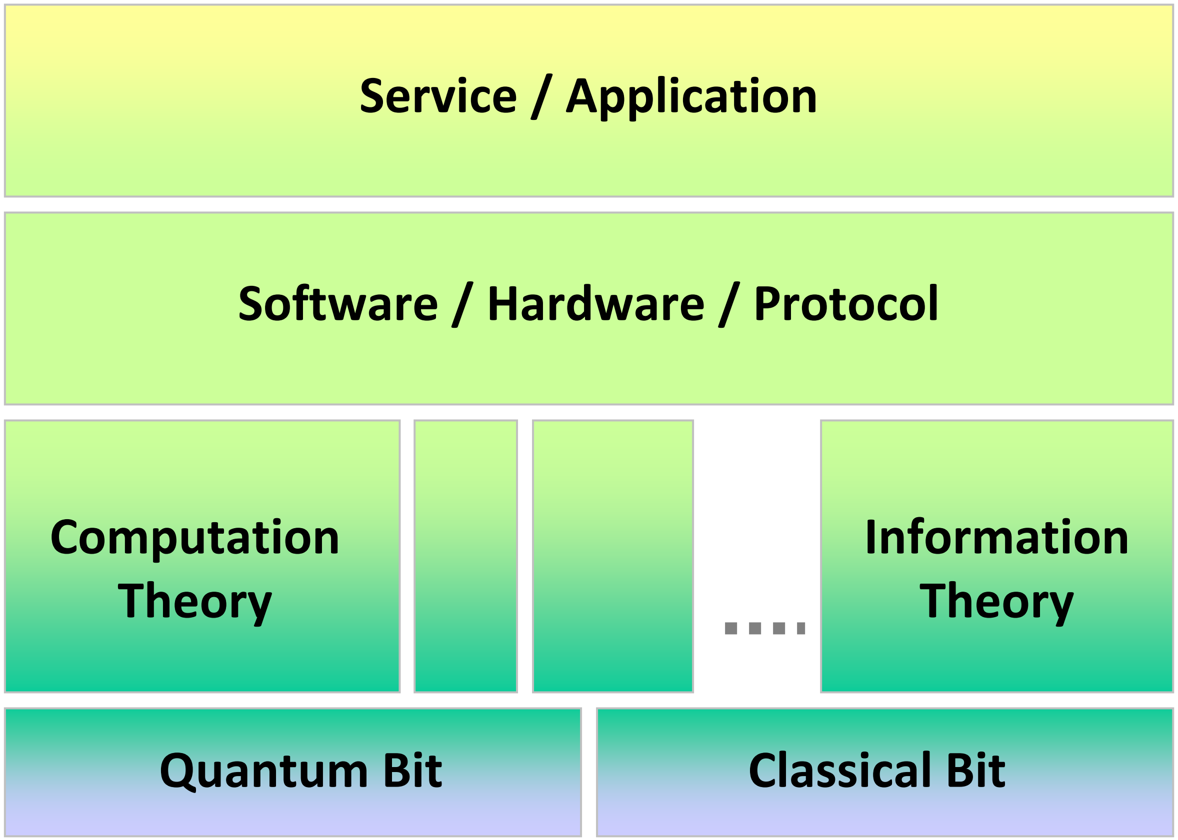
What a Telecom Core Network looks like ….



A Telecom Core Network is NOT something like ….



Quantum Bit as a New Information Carrier



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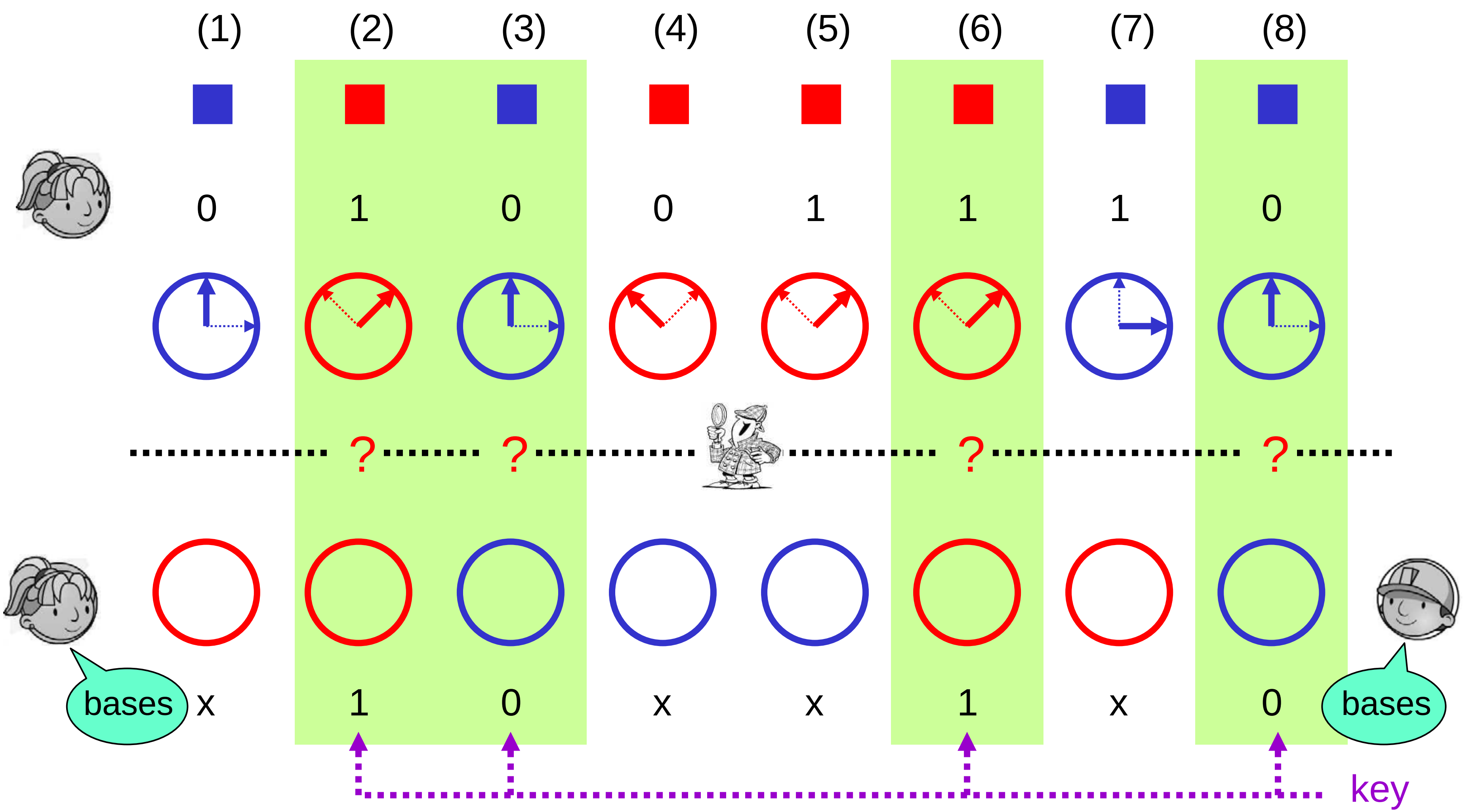
Quantum Cryptography

Security Applications	Bank Transaction, Secure E-mail, etc
Cryptographic Protocols	Diffie-Hellman Key Exchange, RSA Public Key Encryption, etc
Physical Laws / Mathematical Conjectures	Discrete Logarithm is hard, Factorization is hard, etc

(1) Quantum Computers solve these problems in polynomial time.

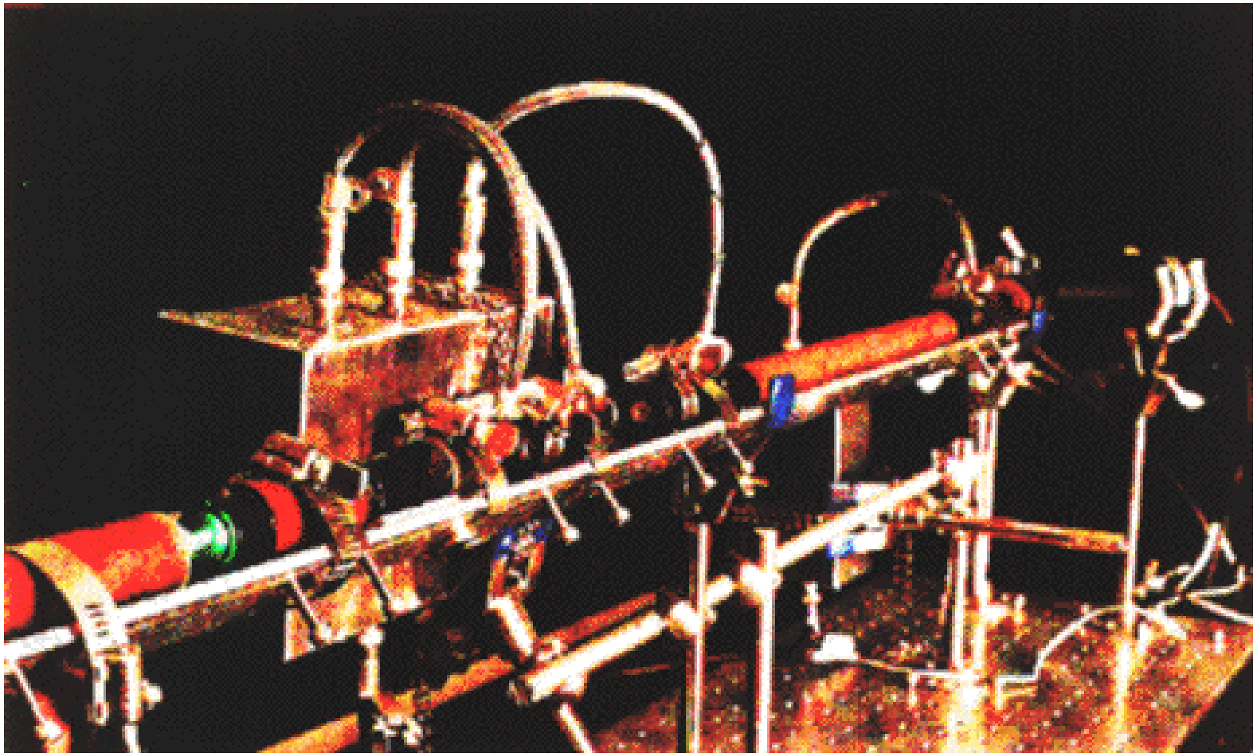
(2) Quantum Cryptography provides a "nature" way as an alternative.

The First Quantum Cryptographic Protocol -- BB84



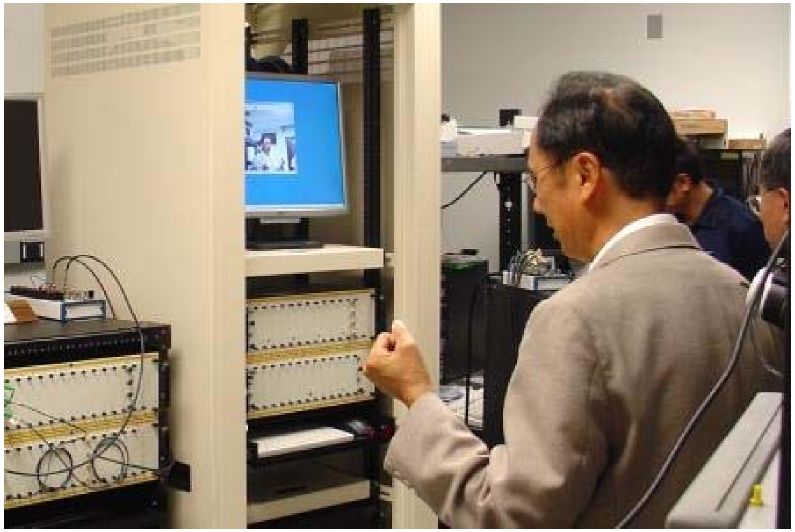
Physical Implementation

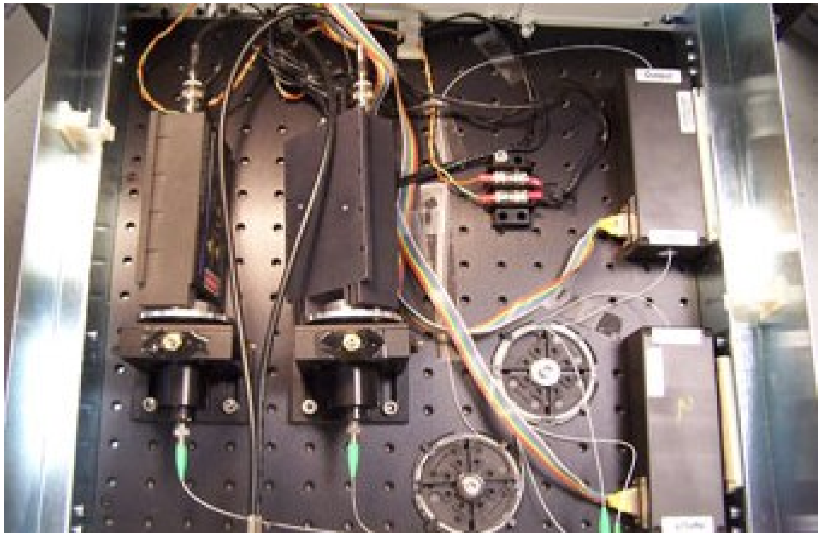
- Physical implementation at IBM



NIST ITL, US.

- Encrypted Video Transmission, using One-time Pad.

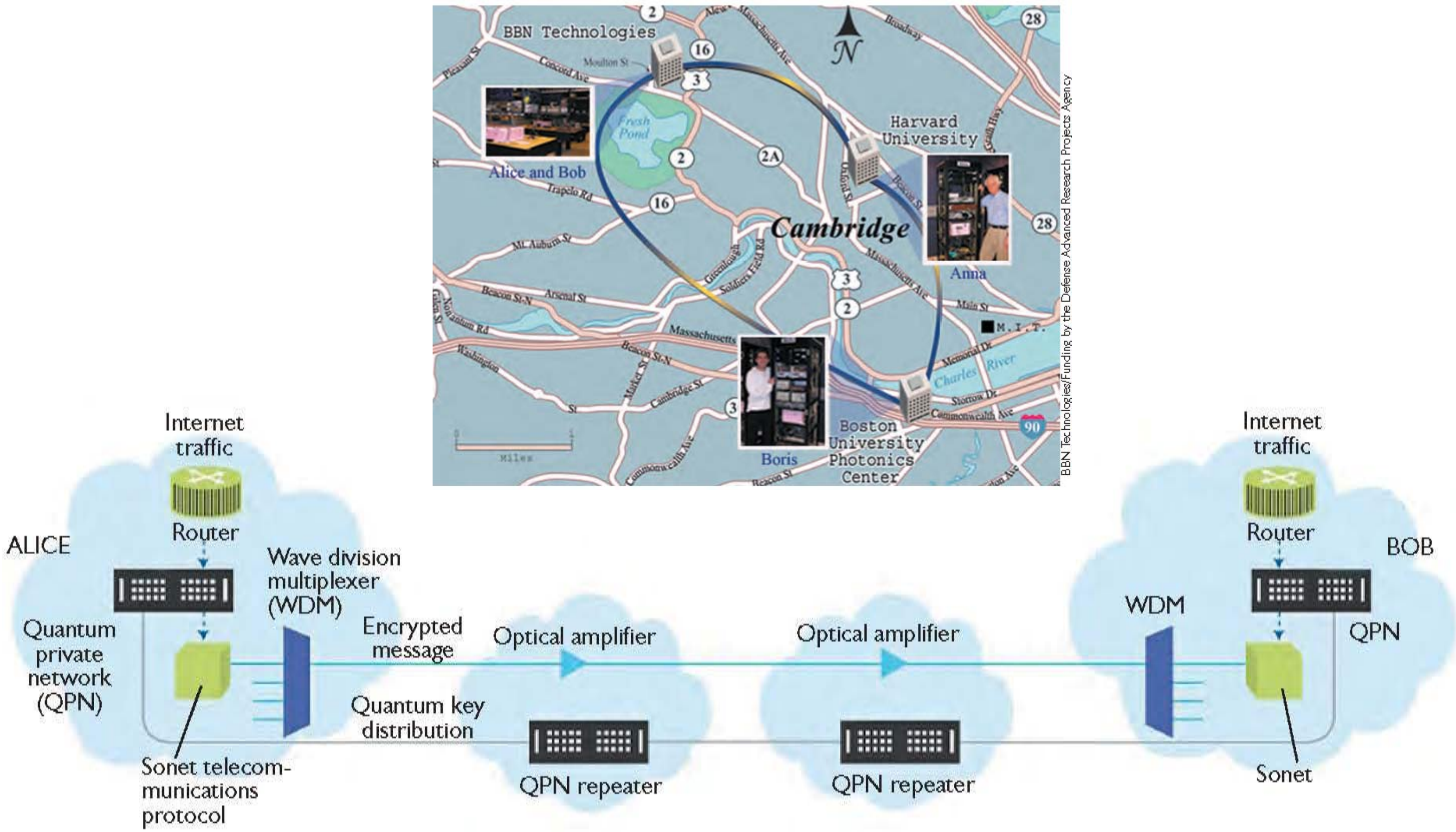




- Detection stage of the NIST prototype quantum key distribution (QKD) system: Photons are "up-converted" from 1310 to 710 nm by one of the two NIST-designed converters at right, then sent to one of two commercial silicon avalanche photo diode units to the left.

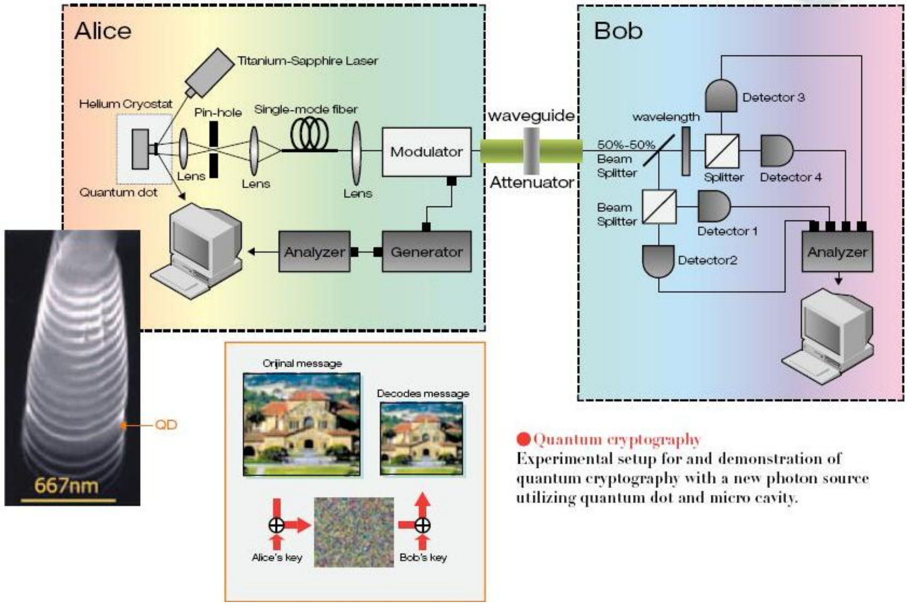
DARPA, US.

- The world’s first quantum cryptographic network.

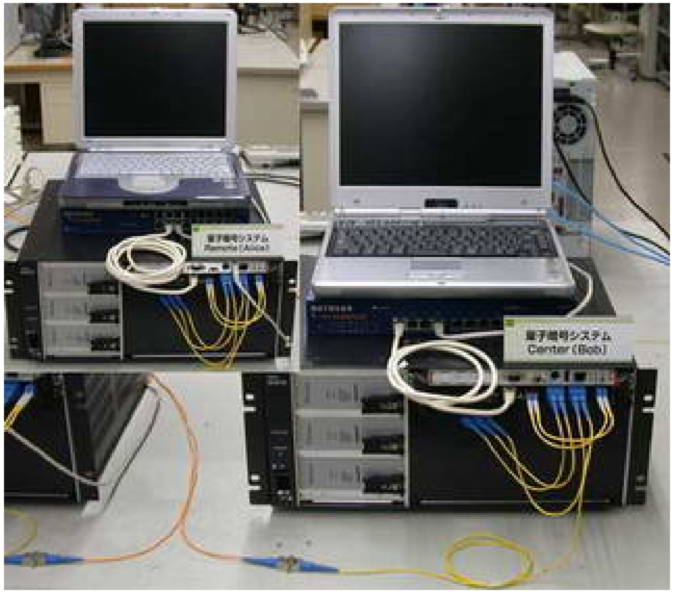


JAPAN

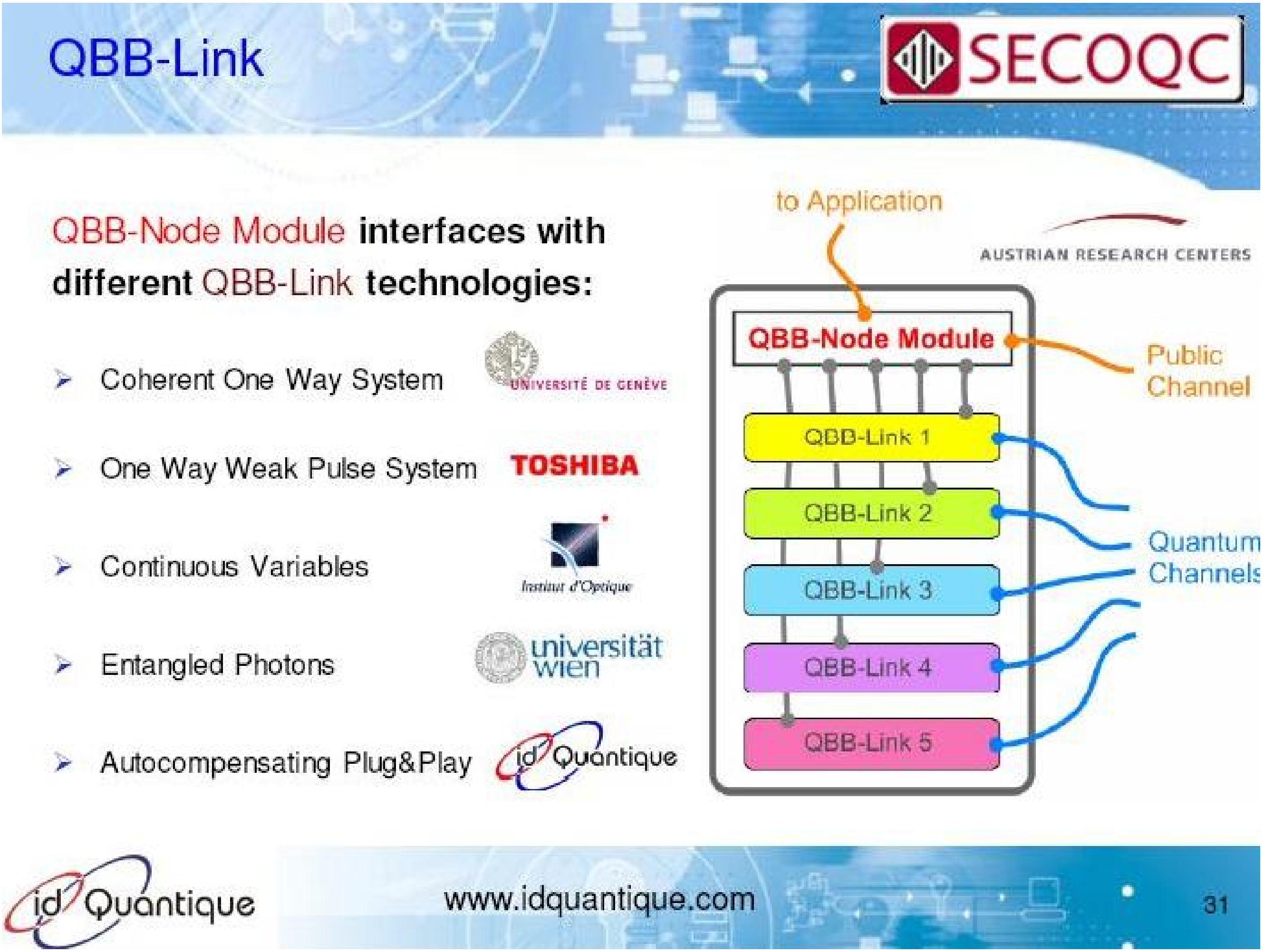
- NTT Basic Research Lab.
- Mitsubishi, NEC, IIS, and U. of Tokyo.



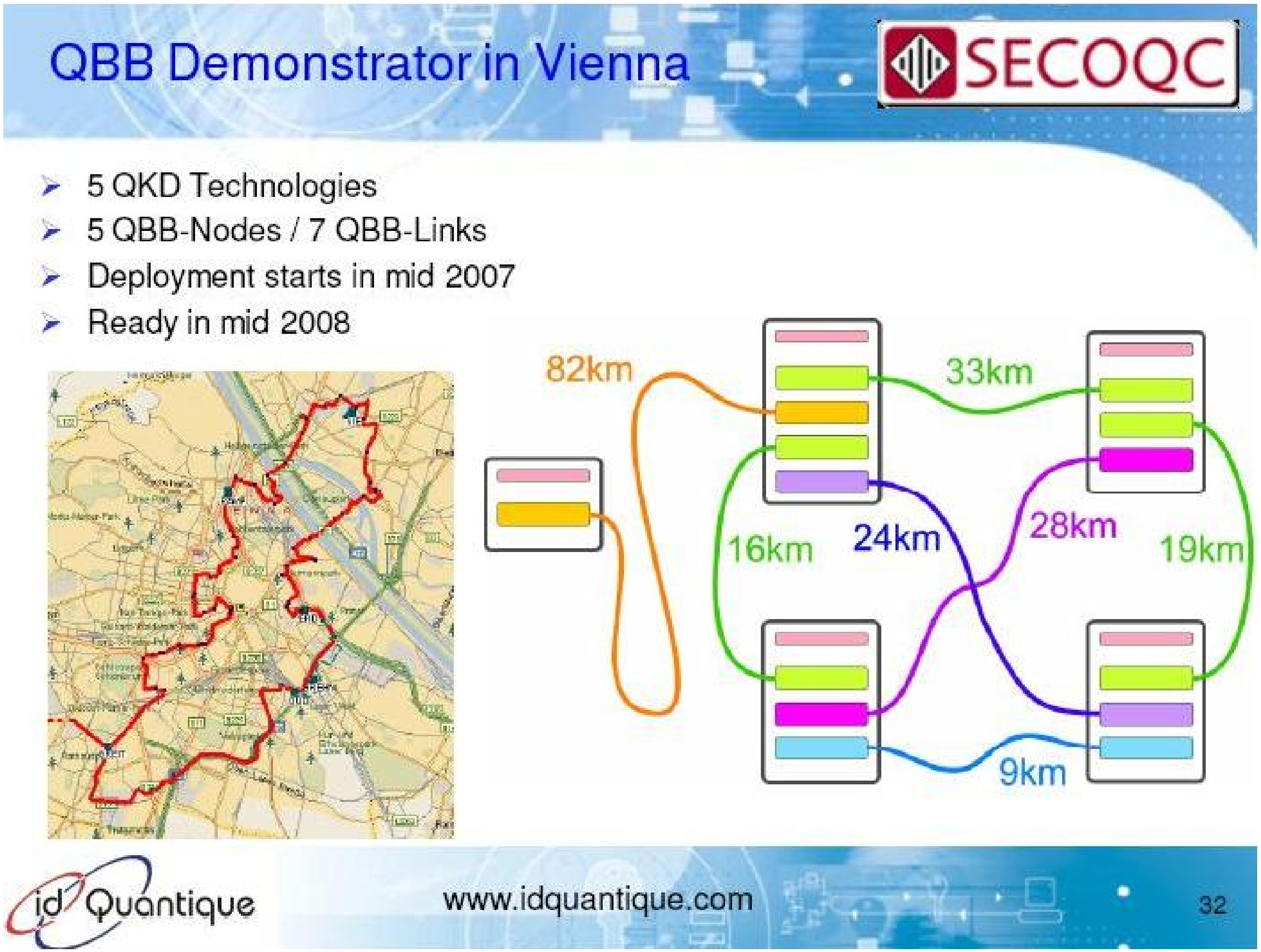
● Quantum cryptography
Experimental setup for and demonstration of quantum cryptography with a new photon source utilizing quantum dot and micro cavity.



SECOQC, Europe

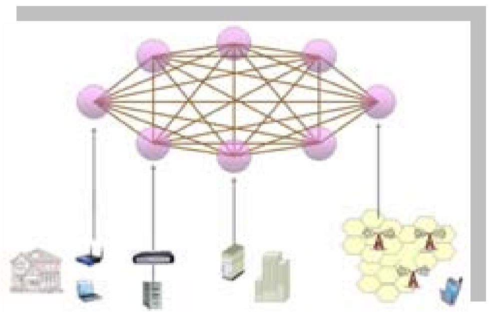
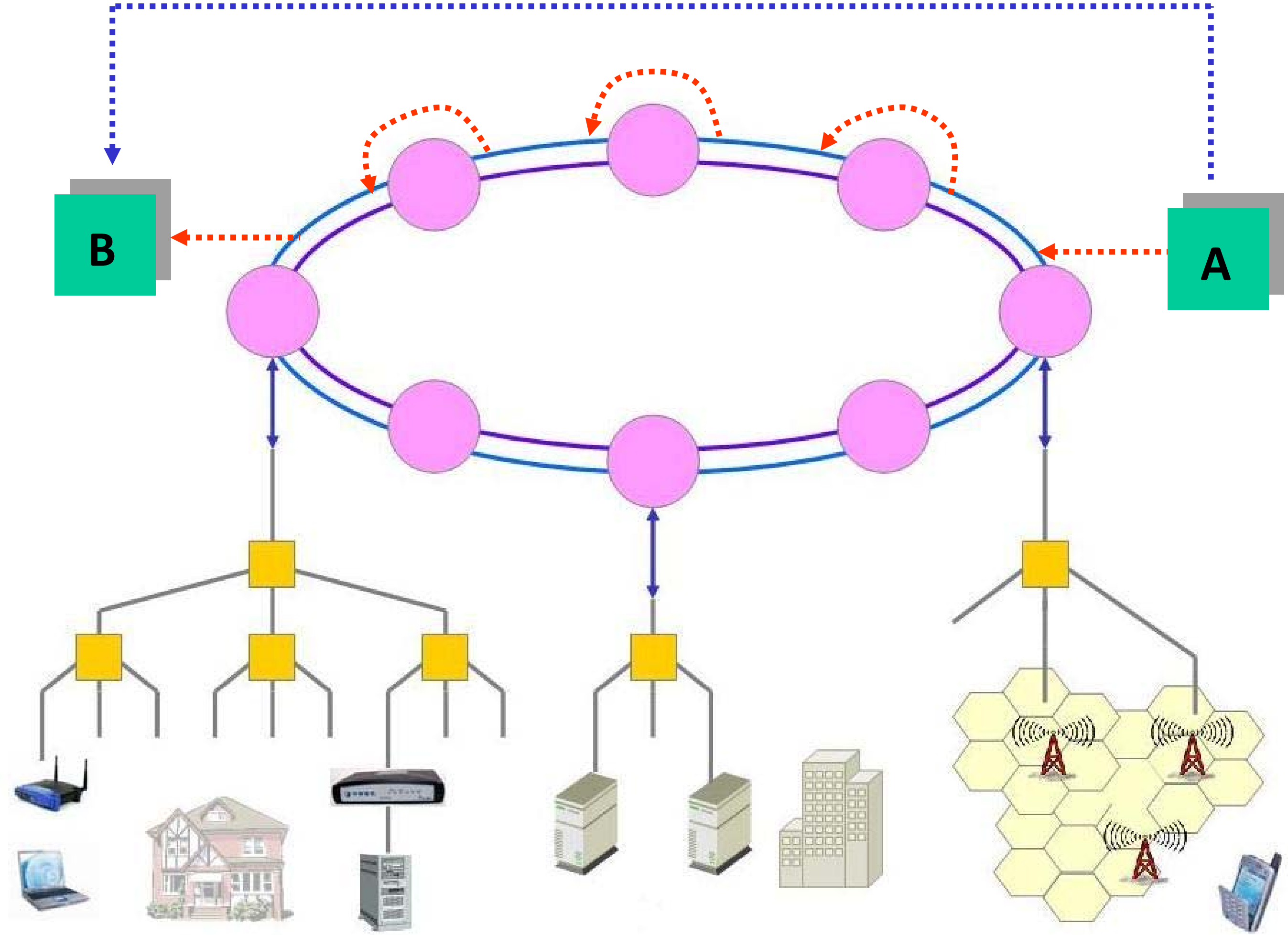


SECOQC, Europe

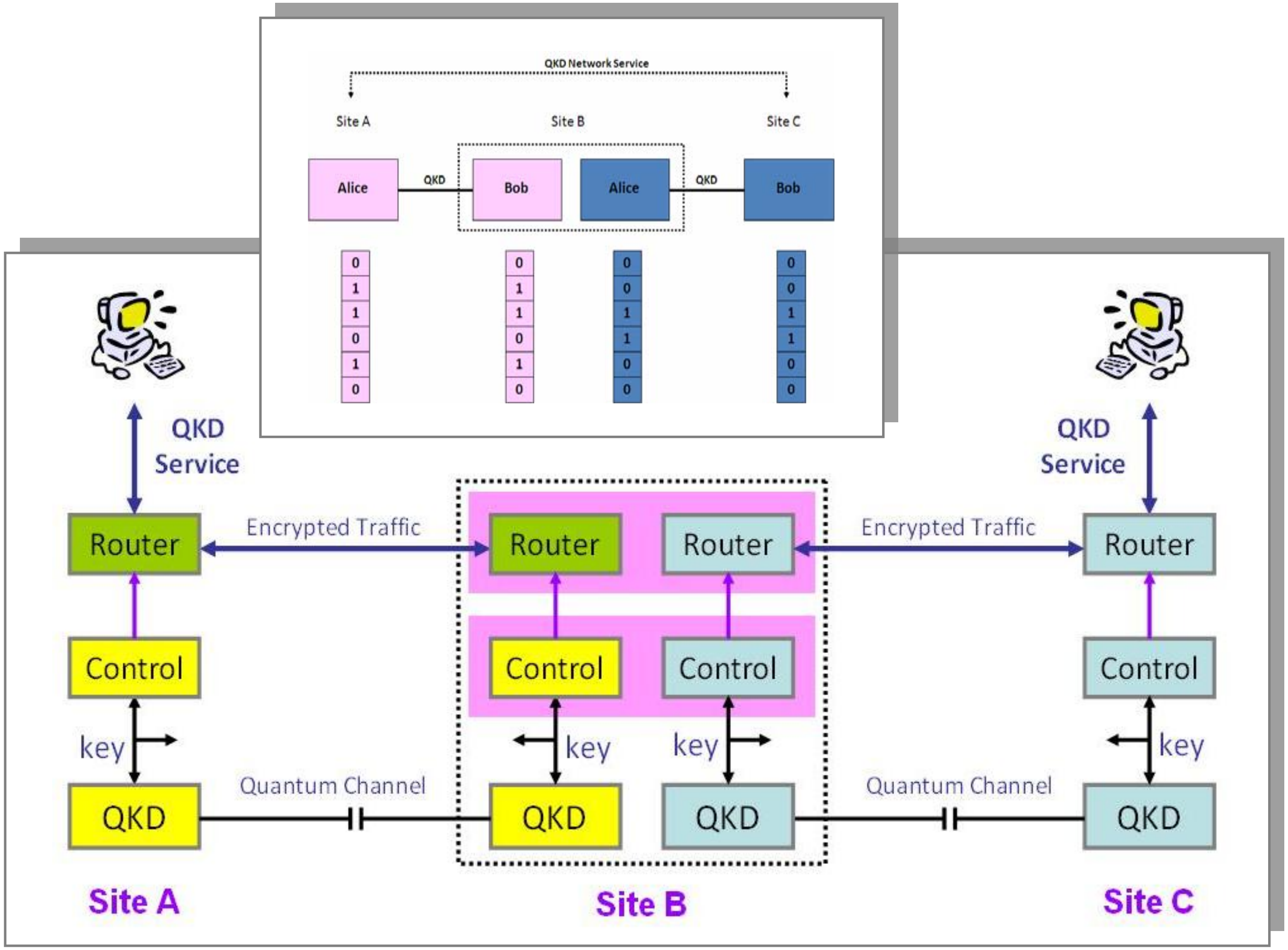


Telecom Point of View

- Resource
- Flexibility
- Traffic cost

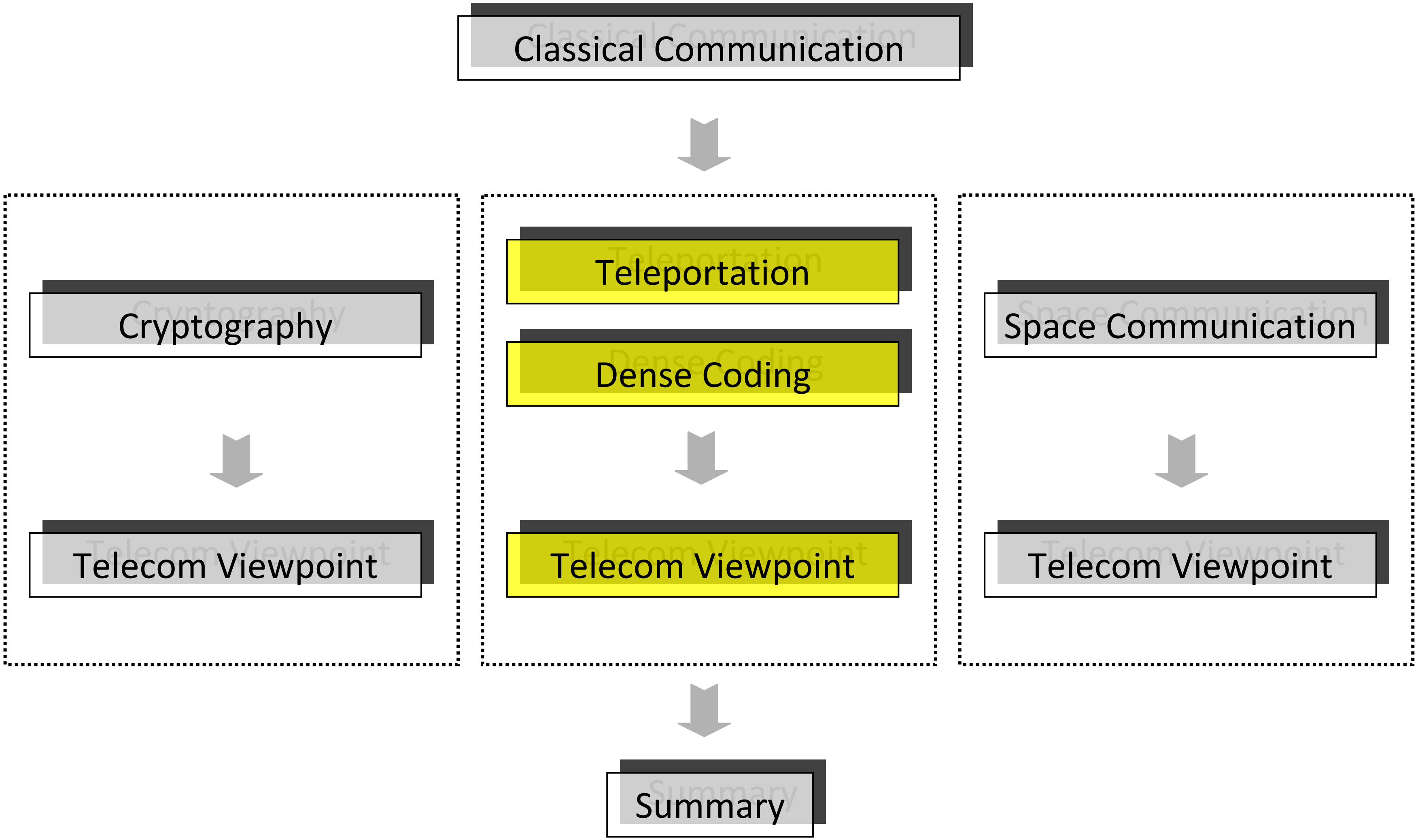
QKD Service Network



Target Customers

- For those who are paranoid … ☺

Outline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Teleportation
Dense Coding
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Space Communication
Telecom Viewpoint
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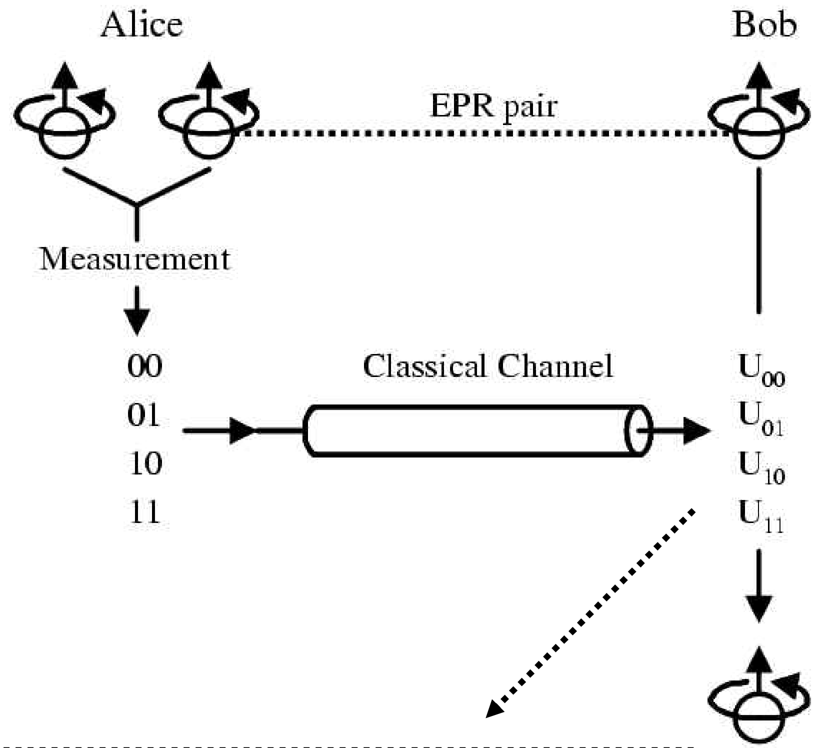
Beam me up, Scotty !

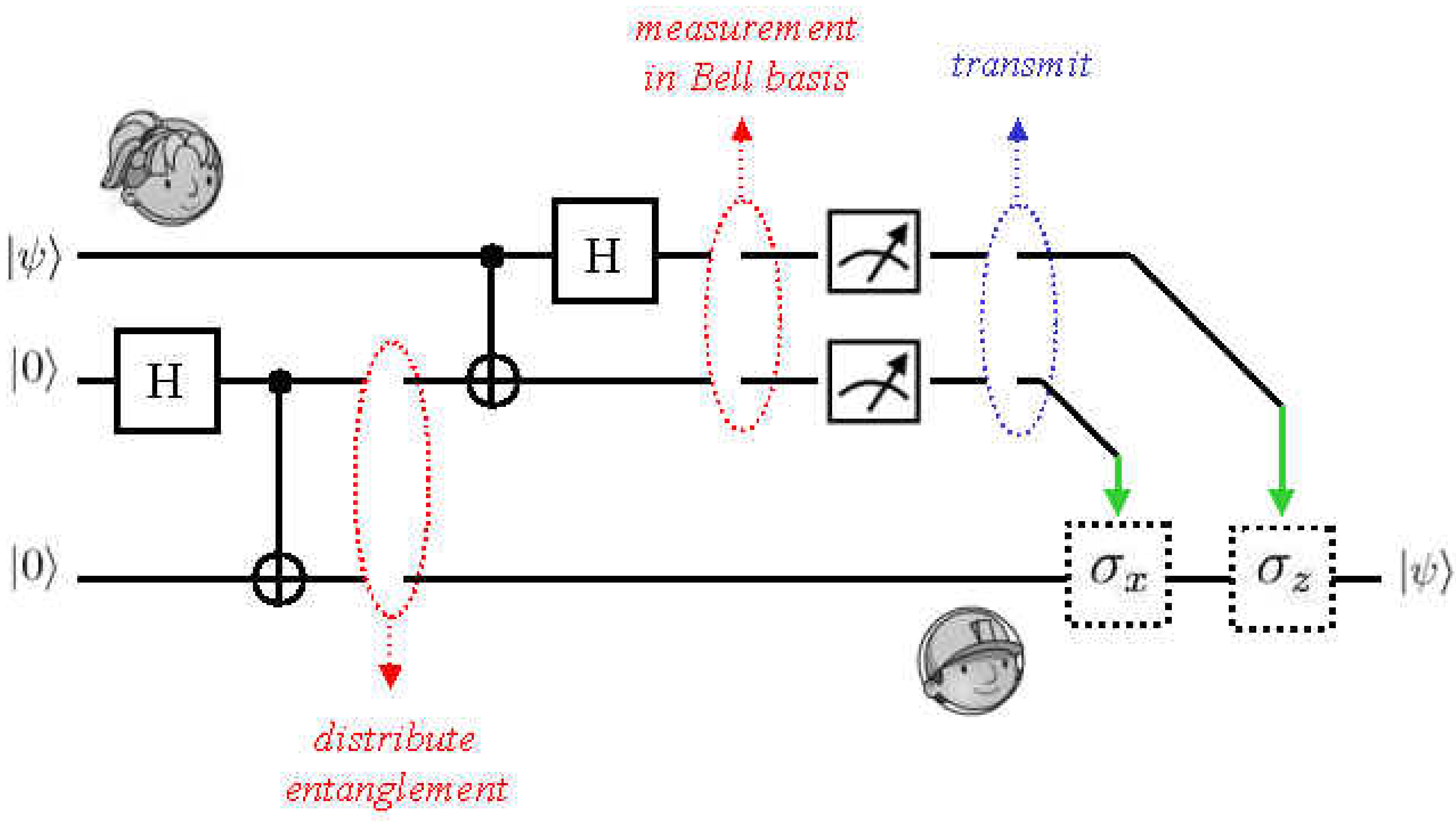
Teleportation

- Alice and Bob share an EPR pair, A and B
- Alice takes a measurement on the unknown qubit C and A, with respect to the Bell basis
- Alice sends Bob the result which is encoded by two classical bits
- Bob applies one of the four operations to recover the quantum state



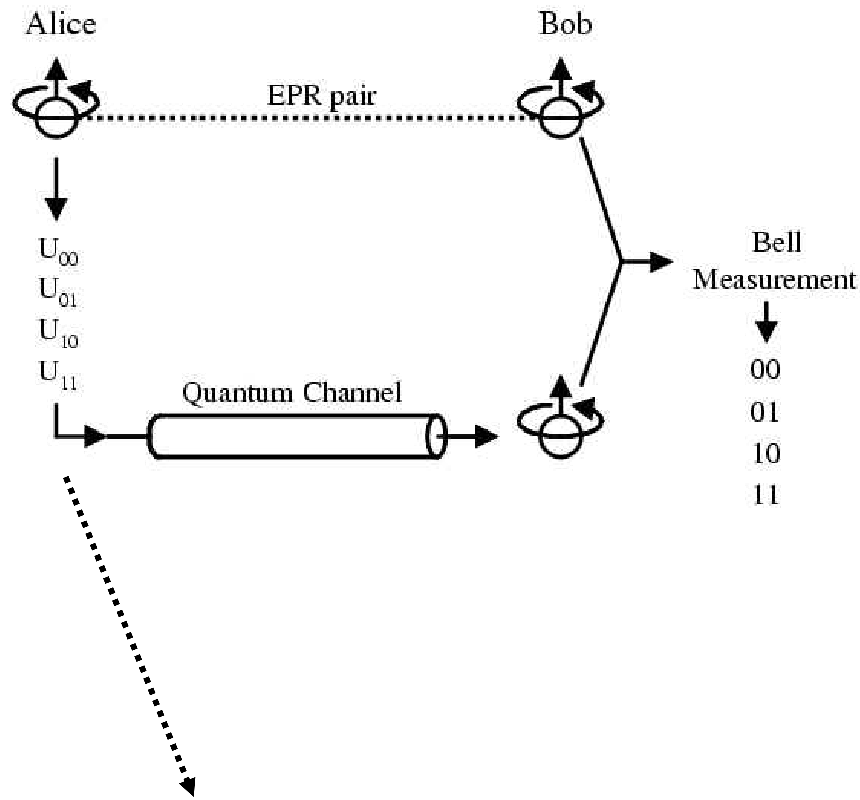
$$U_{00} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad U_{01} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, \quad U_{10} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad U_{11} = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}.$$

Circuits for Teleportation



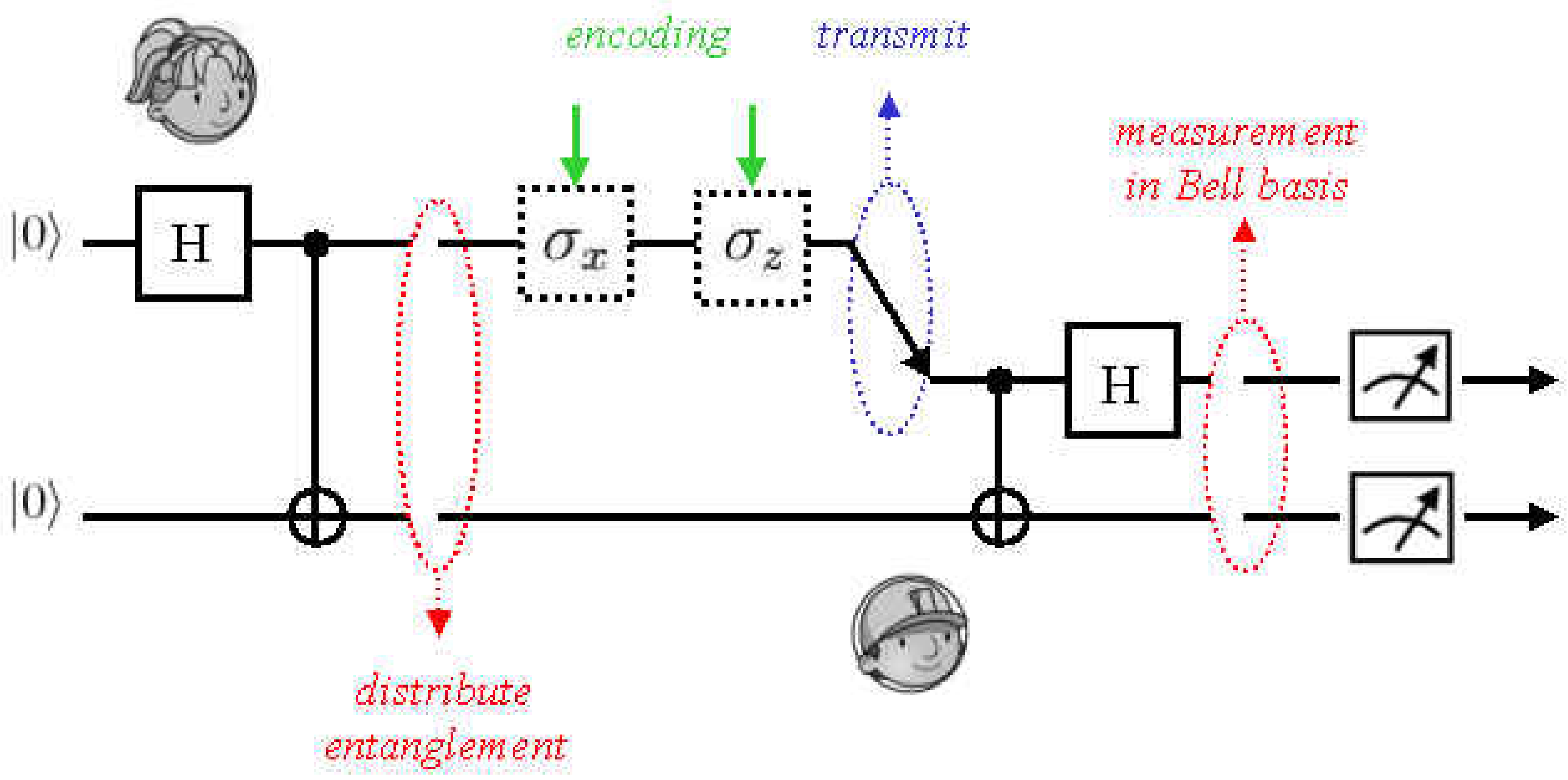
Dense Coding

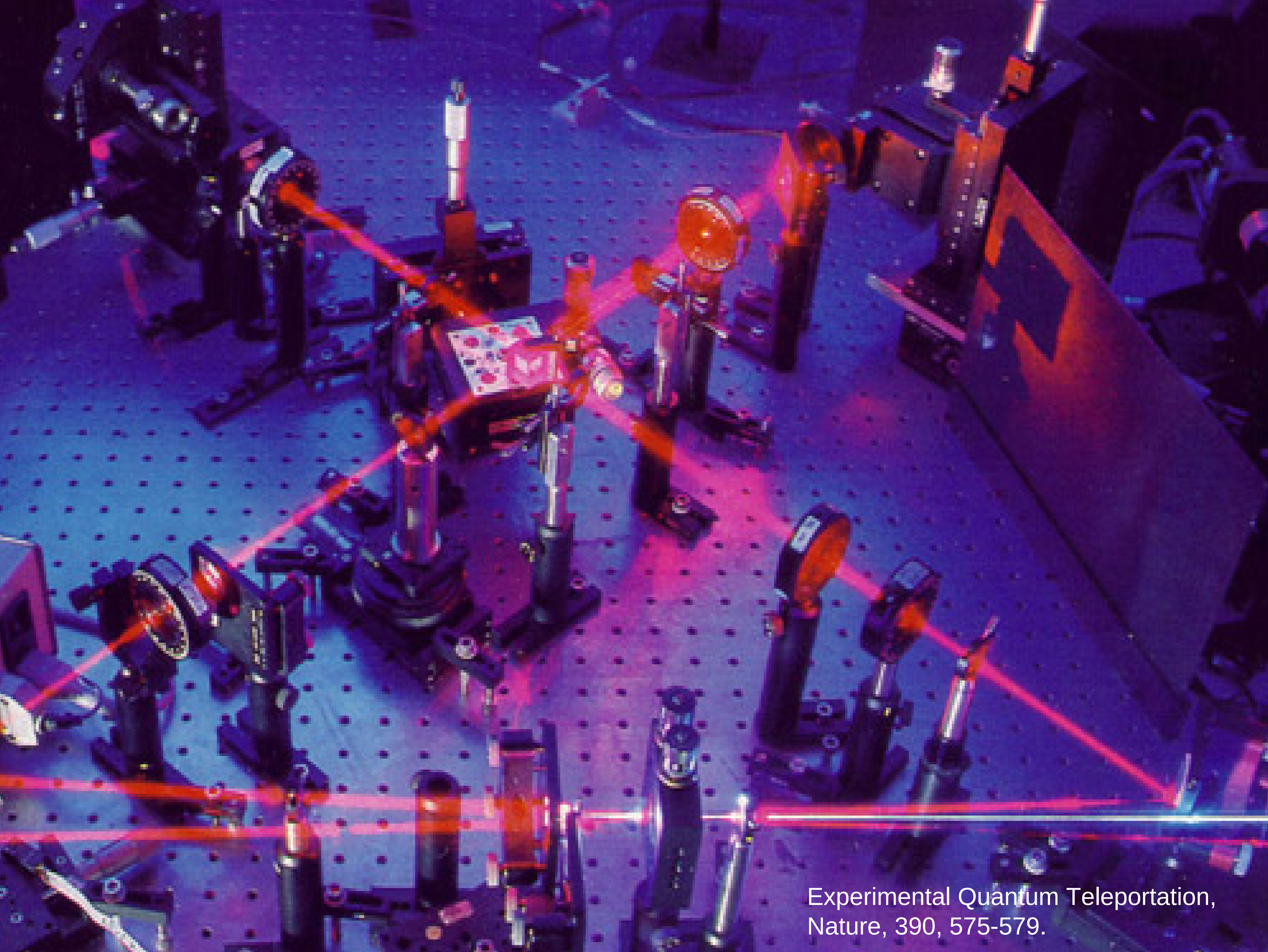
- Alice and Bob share an EPR pair, A and B
- Alice encodes two bits of information by applying one of the four operations to A, and then sends the qubit to Bob
- Bob takes a measurement on A and B with respect to the Bell basis to distinguish the four messages



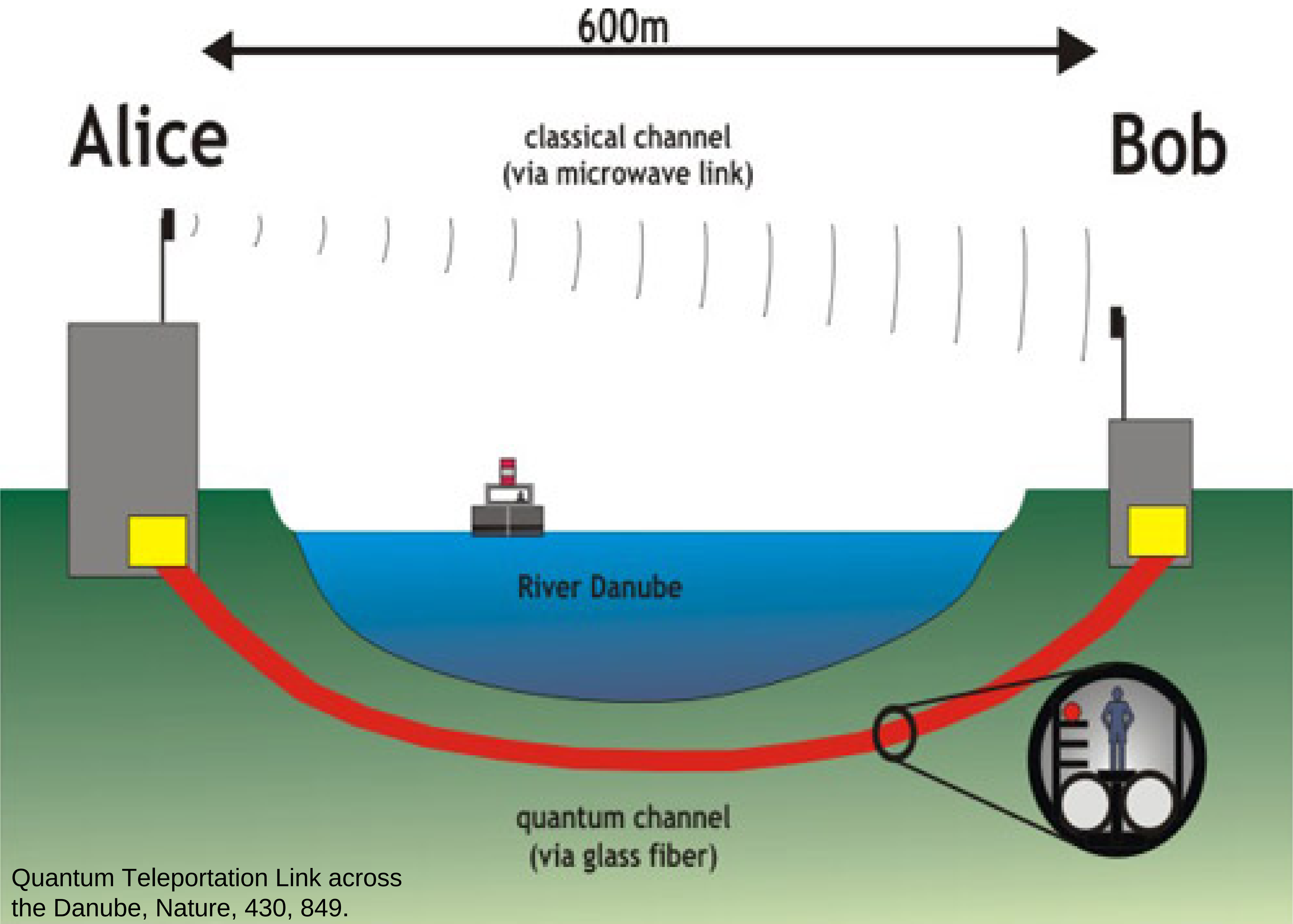
$$U_{00} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad U_{01} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad U_{10} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}, \quad U_{11} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}.$$

Circuits for Dense Coding

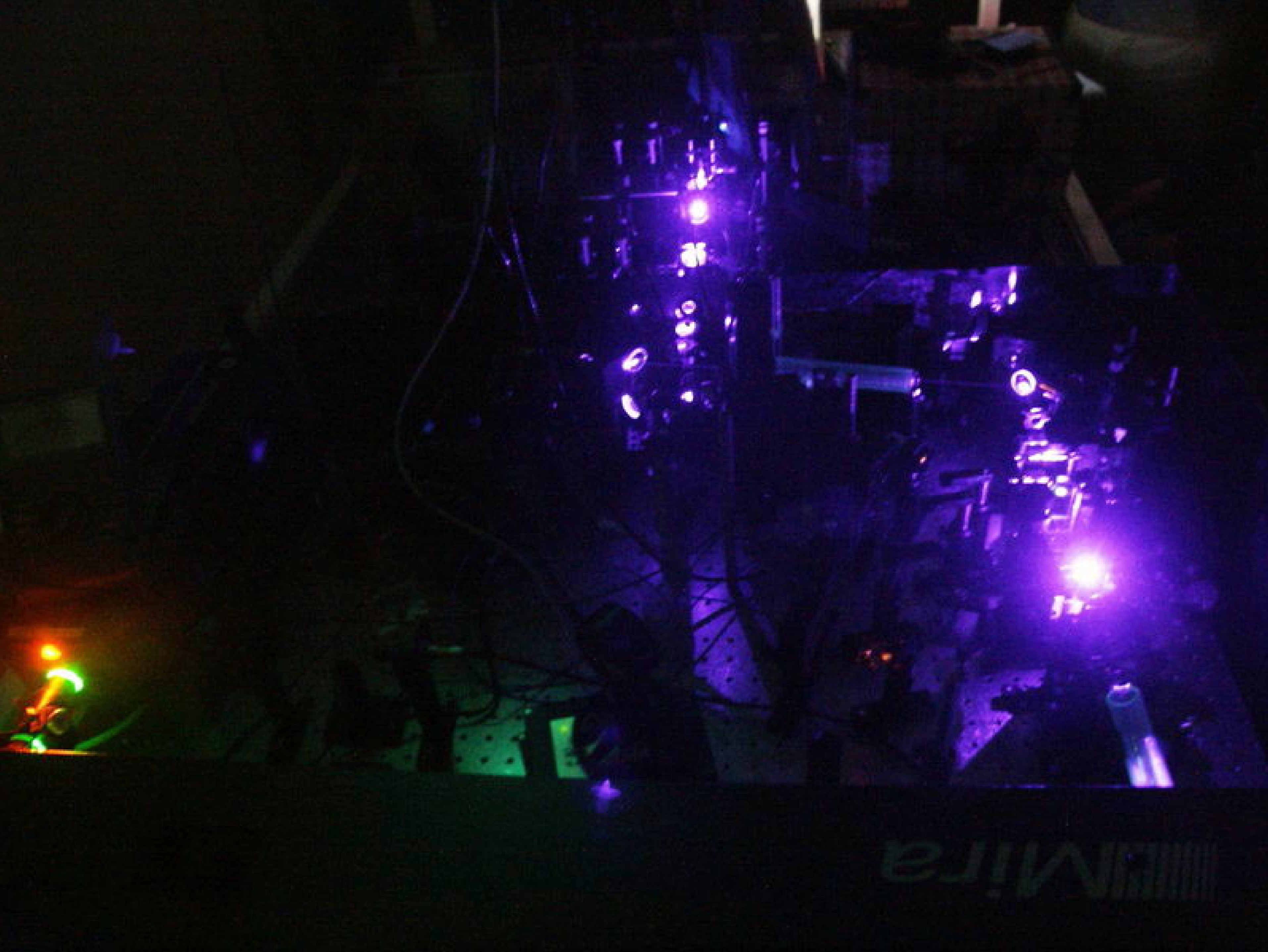




Experimental Quantum Teleportation,
Nature, 390, 575-579.



Quantum Teleportation Link across
the Danube, Nature, 430, 849.


Mira

Iceland
Sverige
Sweden
Norge
Norway
United Kingdom
Polska
Poland
Deutschland
Germany
Україна
Ukraine
France
Italia
Italy
España
Spain
Türkiye
Turkey
North Atlantic Ocean
Iraq
Iran
Algeria
Libya
Egypt
Saudi Arabia
Mauritania
Mali
Niger
Chad
Sudan
Nigeria
Ethiopia
Venezuela
Colombia
DR Congo
Kenya
Tanzania
Brasil
Brazil
Perú
Bolivia
Angola


Nice
Italia
Italy
Toulouse
Marseille
Barcelona
Roma
Porto
Zaragoza
Madrid
Valencia
Portugal
España
Spain
Murcia
Lisboa
Sevilla
El-Jazair
Tunis
Malaga
Cadiz
Oran
Rabat
Tunisia
Dar-el-Beida
Morocco
Algeria
Laayoune
Western
Sahara

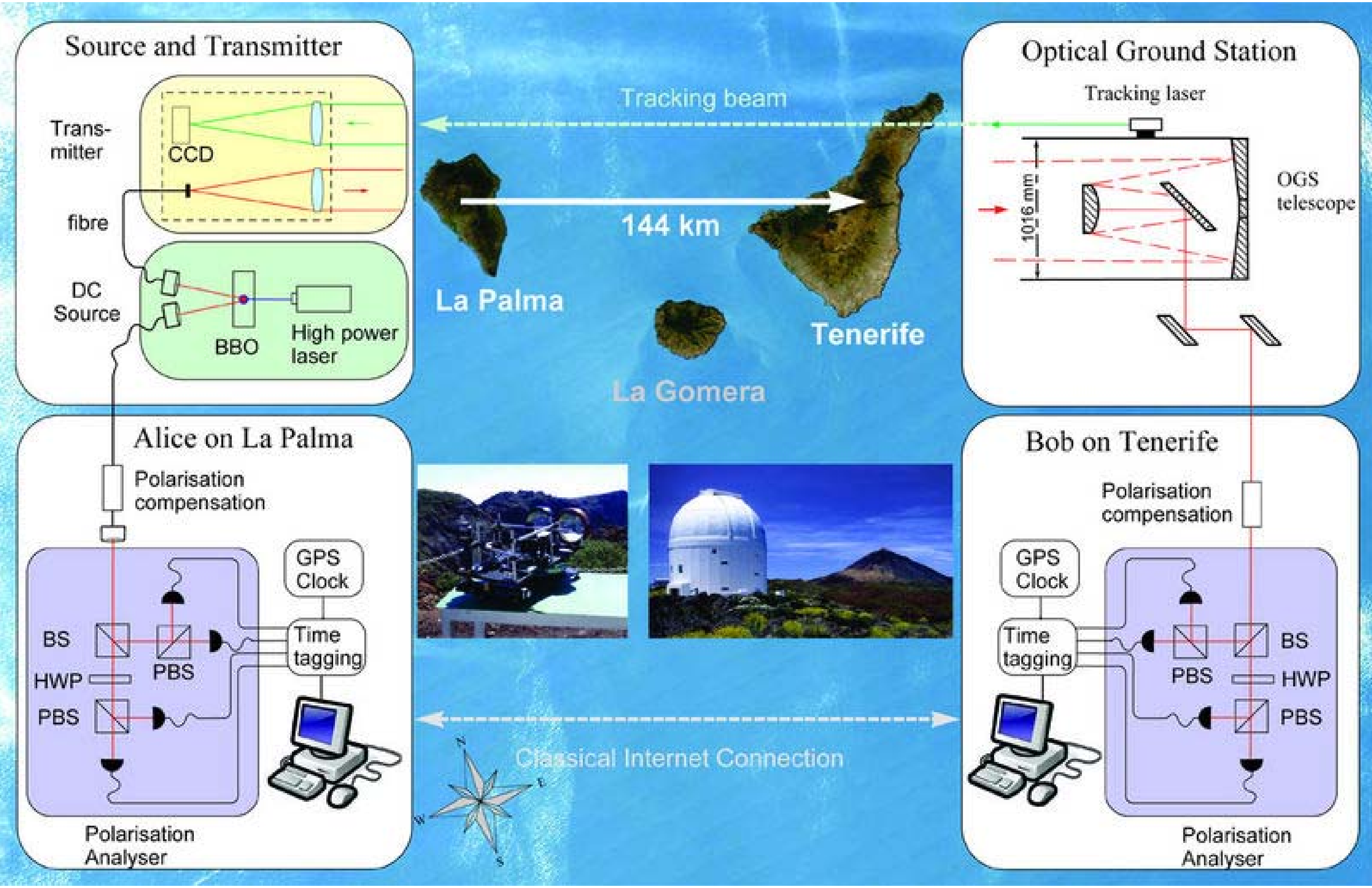

Santa Cruz
de Tenerife
Las Palmas de
Gran Canaria
Laayoune

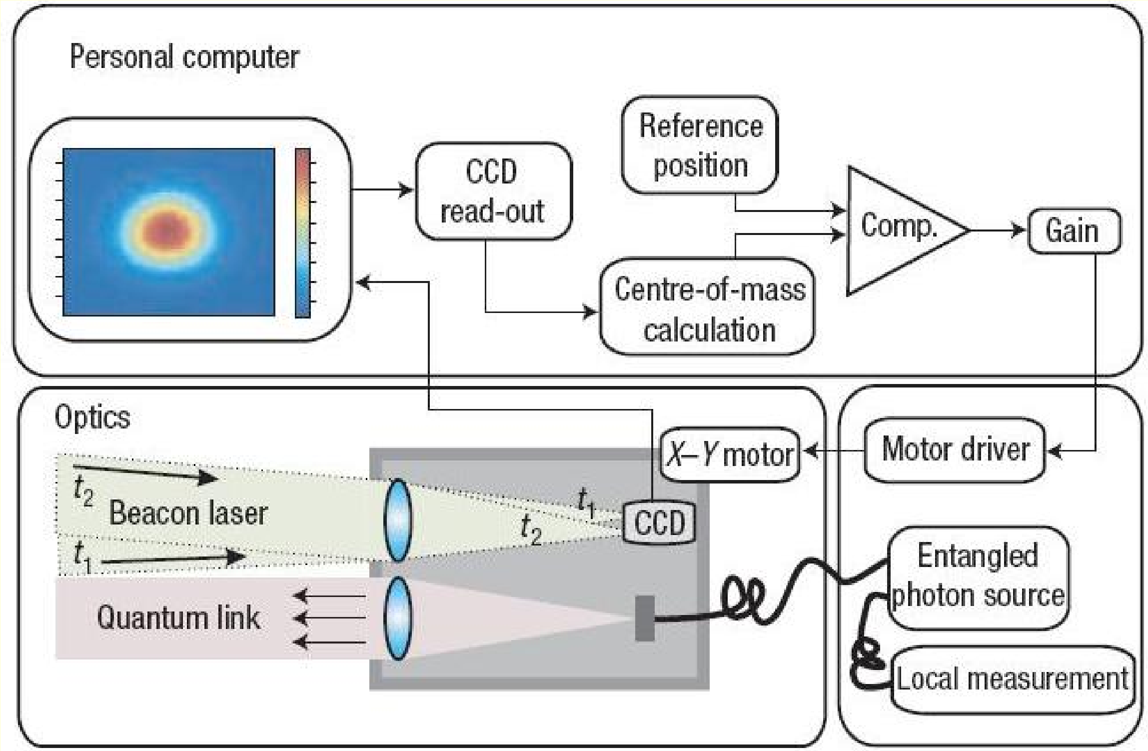
Santa Cruz de la Palma
Los Llanos de Aridane
San Cristóbal de la Laguna
Santa Cruz de Tenerife
La Orotava
Icod de los Vinos
Candelaria
Tenerife
Güimar
Guía de Isora
Granadilla de Abona
Adeje
Arona

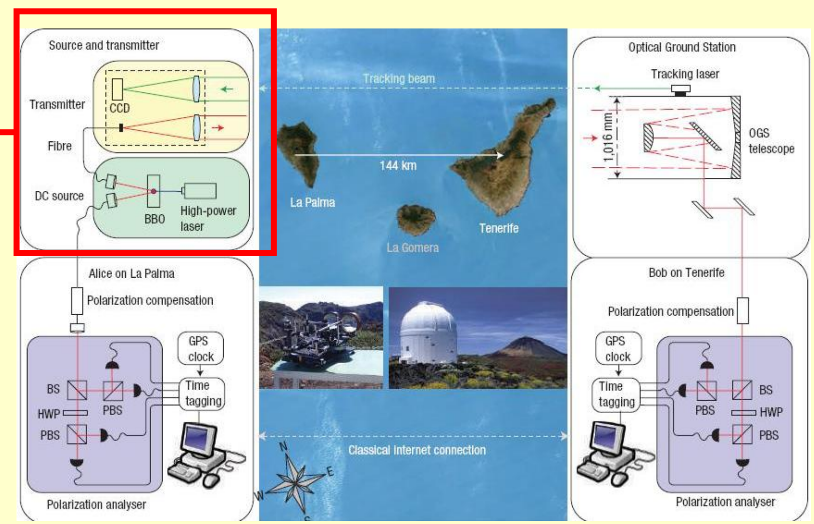
Alice and Bob

Single photon transmitter optics module (Alice) in La Palma aligned towards Tenerife (visible in the upper right corner).

ESA's Optical Ground Station (OGS) is located at the Observatory of Teide on Tenerife, and is situated at an altitude of 2393 meters.

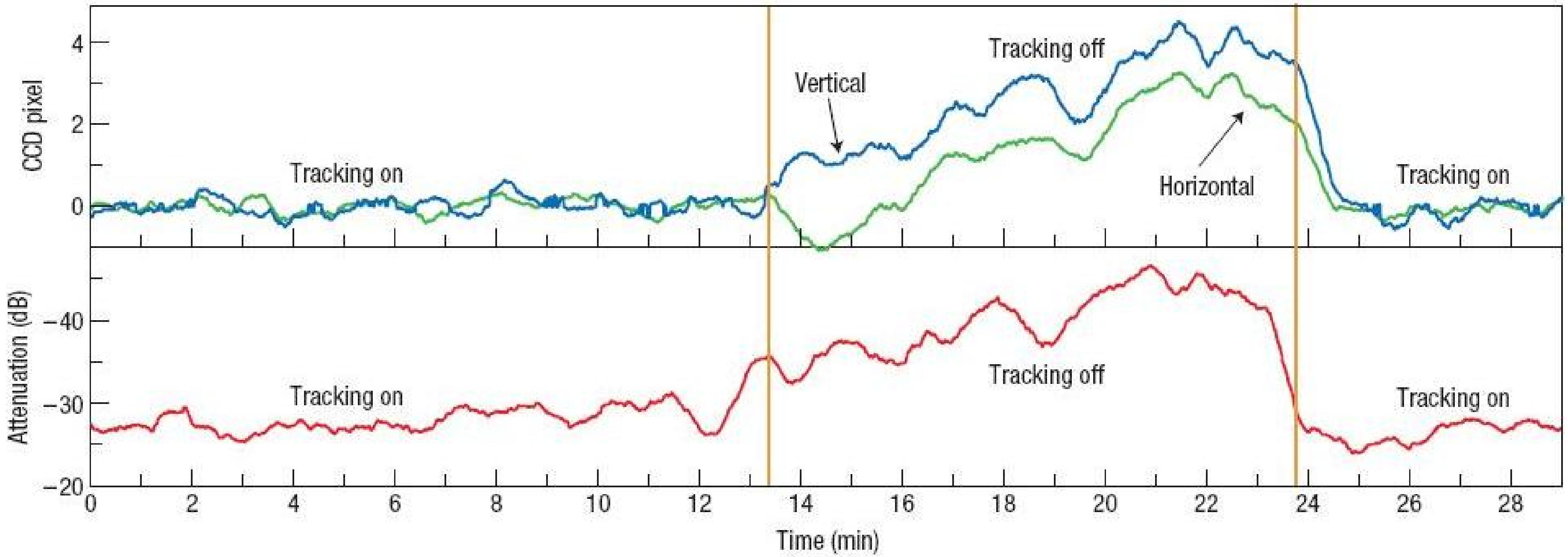

Source and Transmitter
Trans-
mitter
CCD
fibre
DC
Source
BBO
High power
laser
Tracking beam
144 km
La Palma
Tenerife
La Gomera
Optical Ground Station
Tracking laser
1016 mm
OGS
telescope
Alice on La Palma
Polarisation
compensation
GPS
Clock
BS
PBS
HWP
PBS
Time
tagging
Polarisation
Analyser
Classical Internet Connection
N
E
W
S
Bob on Tenerife
Polarisation
compensation
GPS
Clock
Time
tagging
BS
PBS
HWP
PBS
Polarisation
Analyser





The closed-loop tracking system
on La Palma

Tracking between Alice and Bob



Tegueste
San Cristobal
de la Laguna
Tacoronte
Santa Cruz
de Tenerife
TF-5
TF-2
La Victoria
de Acentejo
El Rosario
Puerto de
la Cruz
Santa
Ursula
Santa Maria
del Mar
San Juan de
la Rambla
TF-1
La Guancha
La Orotava
Los
Realejos
Icod de
los Vinos
Candelaria
Arafo
Güimar
Tenerife
Fasnia


La Victoria de Acentejo
La Resbala
TF-5
Los Cercados
TF-24
Lasrosas
Santa Ursula
Camino de los Altos
La Corujera
TF-24
TF-523
Igueste
La Guancha
Caitana
Llanos
Araya
Chajaco
Las Cuevecitas
Malpas

TF-24
TF-24
TF-523


TF-24
TF-24

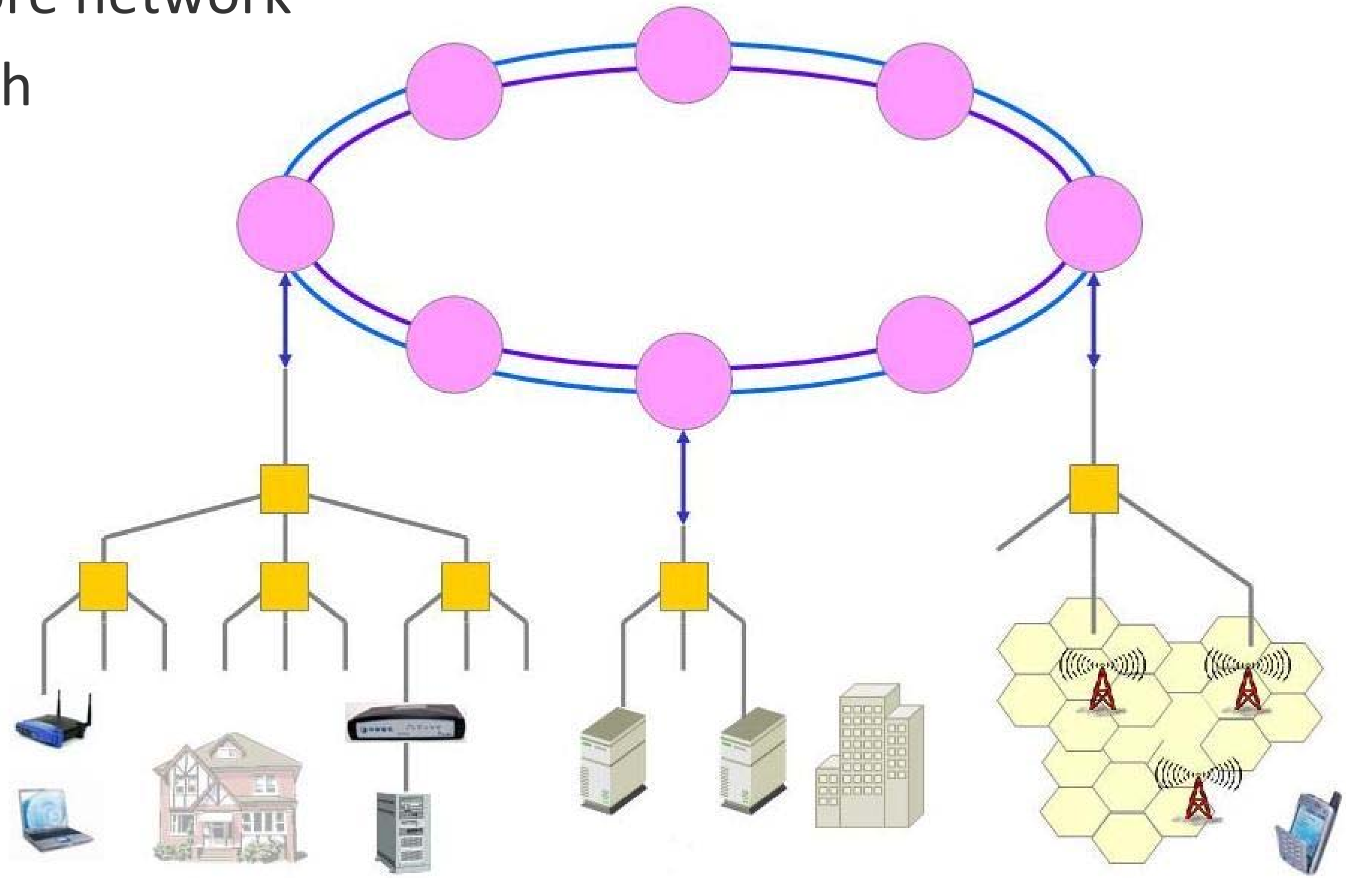

TF-24
TF-24


TF-24
TF-24


TF-24
TF-24

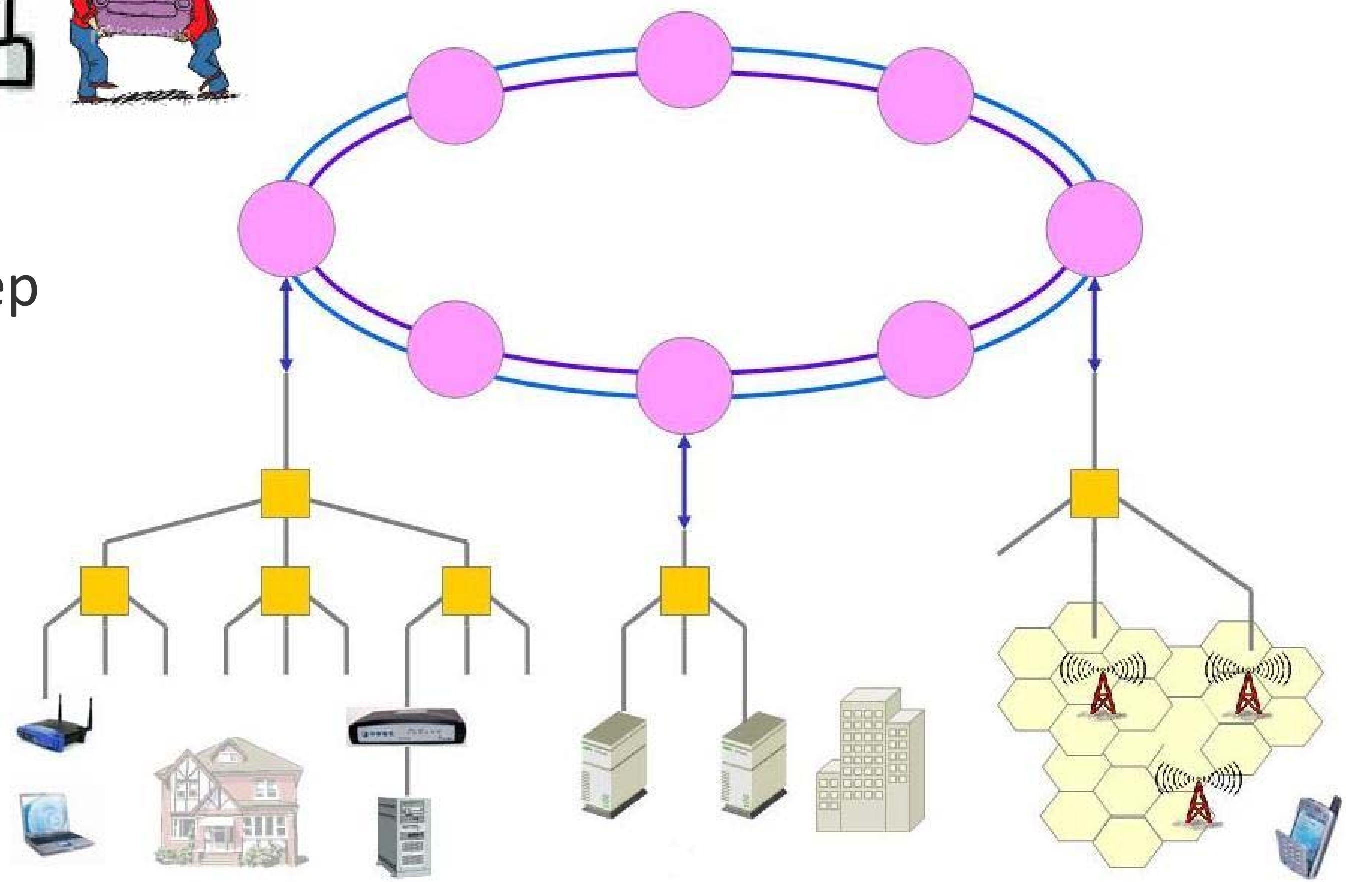
Telecom Point of View – Dense Coding

- 40Gbps Core network
- Not enough



Telecom Point of View – Teleportation

- Next Step



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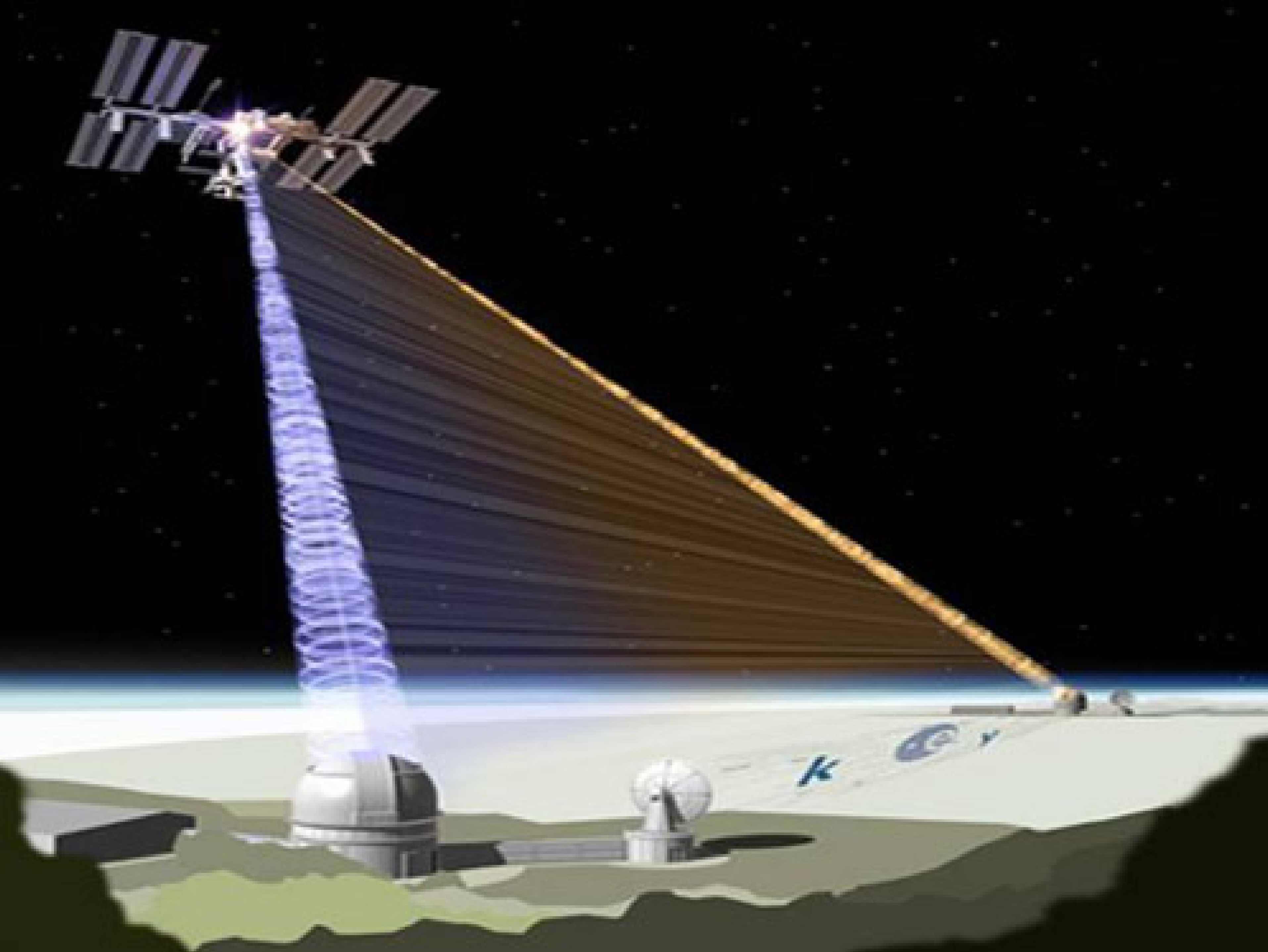
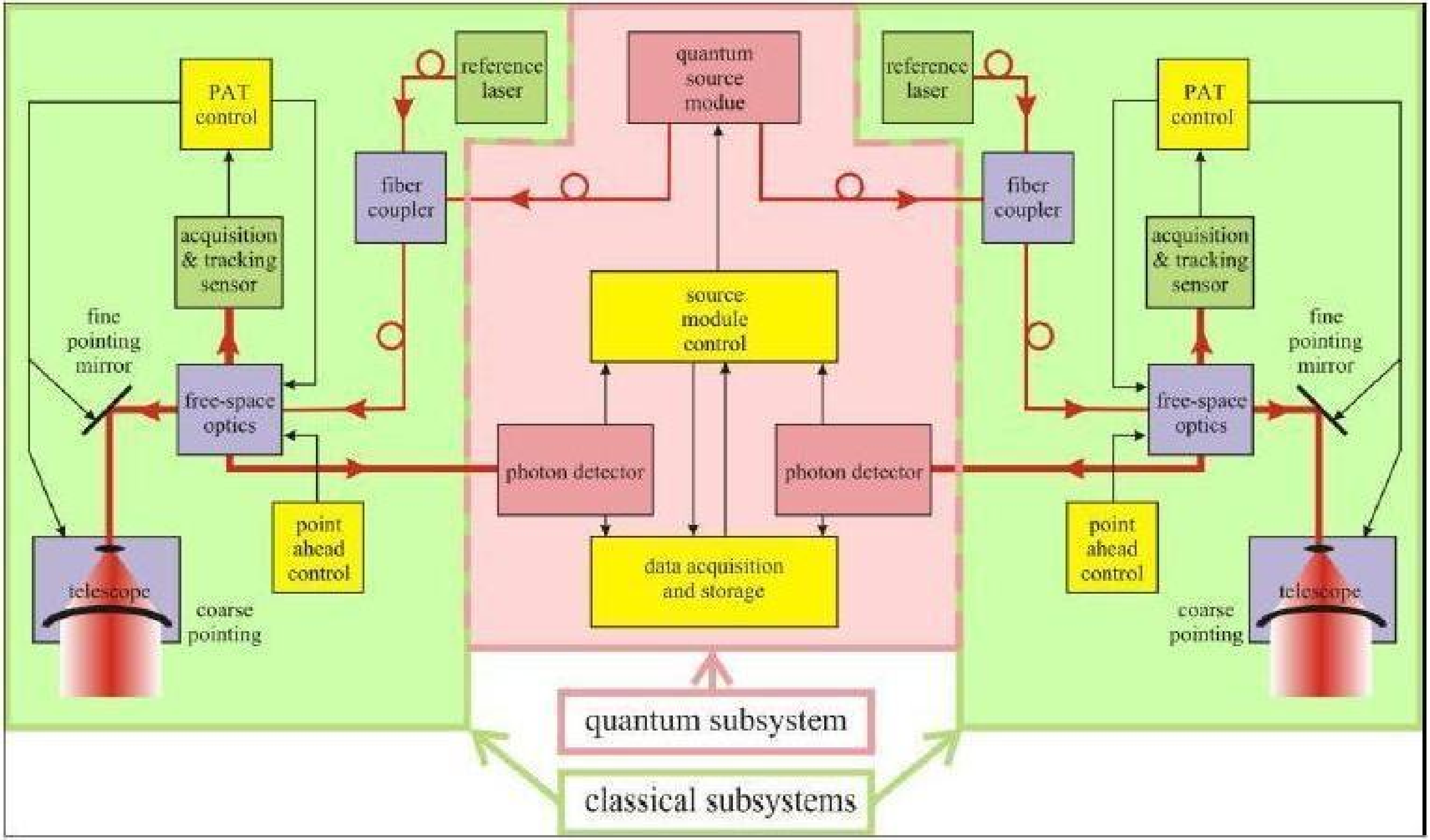


Quantum Protocol and Space Applications

Applications	Benefits	Space application
Quantum key distribution (QKD) using single and entangled photons	Unconditional security = detection of eavesdropper	• Secure access to a satellite • Secure communications between gateways / ground stations • Secure satellite-to-satellite communication
Quantum state teleportation (QT)	Transfer of quantum information without disturbing the quantum information, but speed of light limit for classical information	• Quantum telecomputation for deep space missions • Global distribution of quantum entanglement and global quantum networks
Quantum dense coding (QDC)	Higher channel capacity	• Satellite telecommunications • Deep space missions
Quantum communication complexity (QCC)	Higher efficiency	• Deep space missions

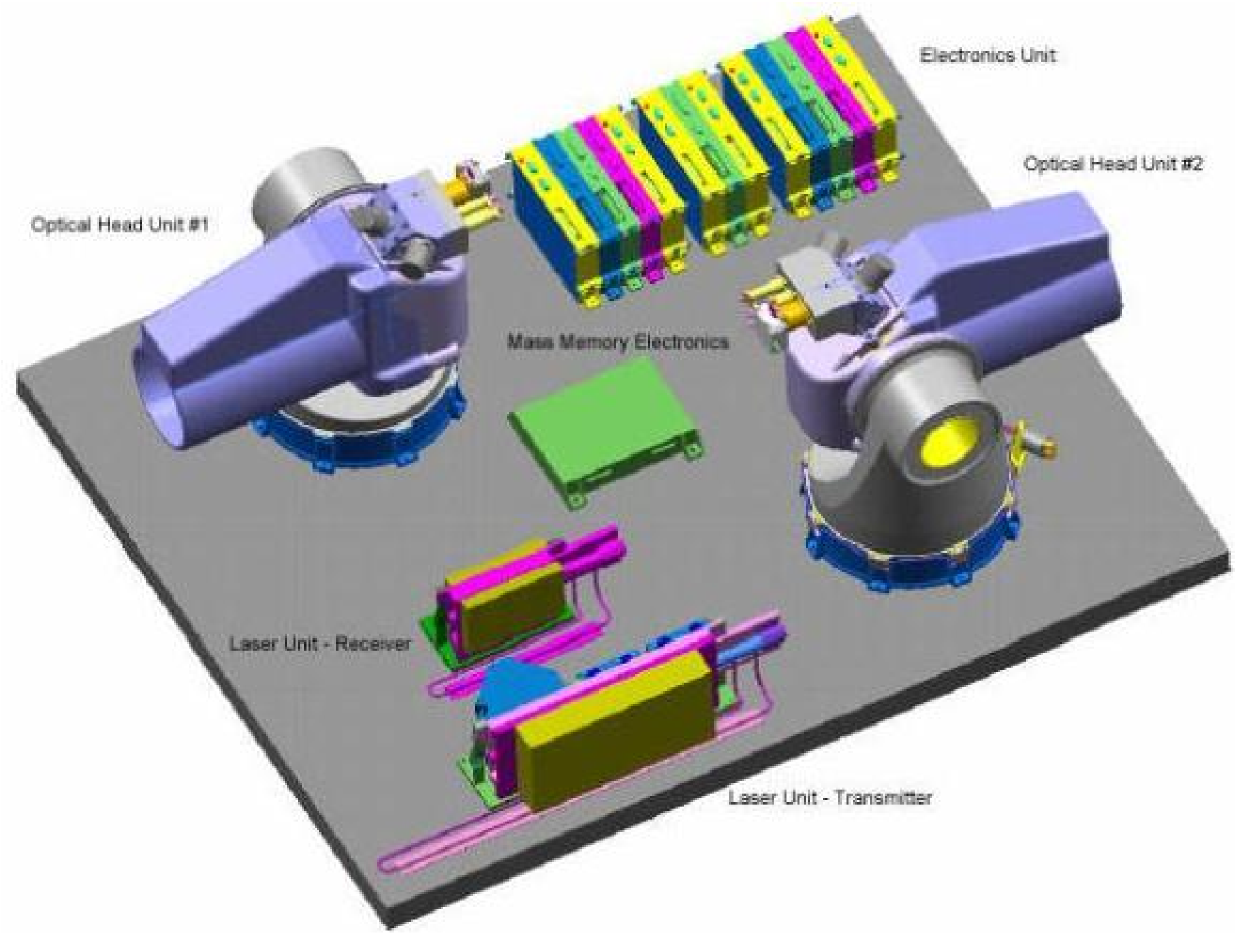
Source: Armengol et. al., 58^{th} International Astronautical Congress

Terminal for Space-Ground Experiments



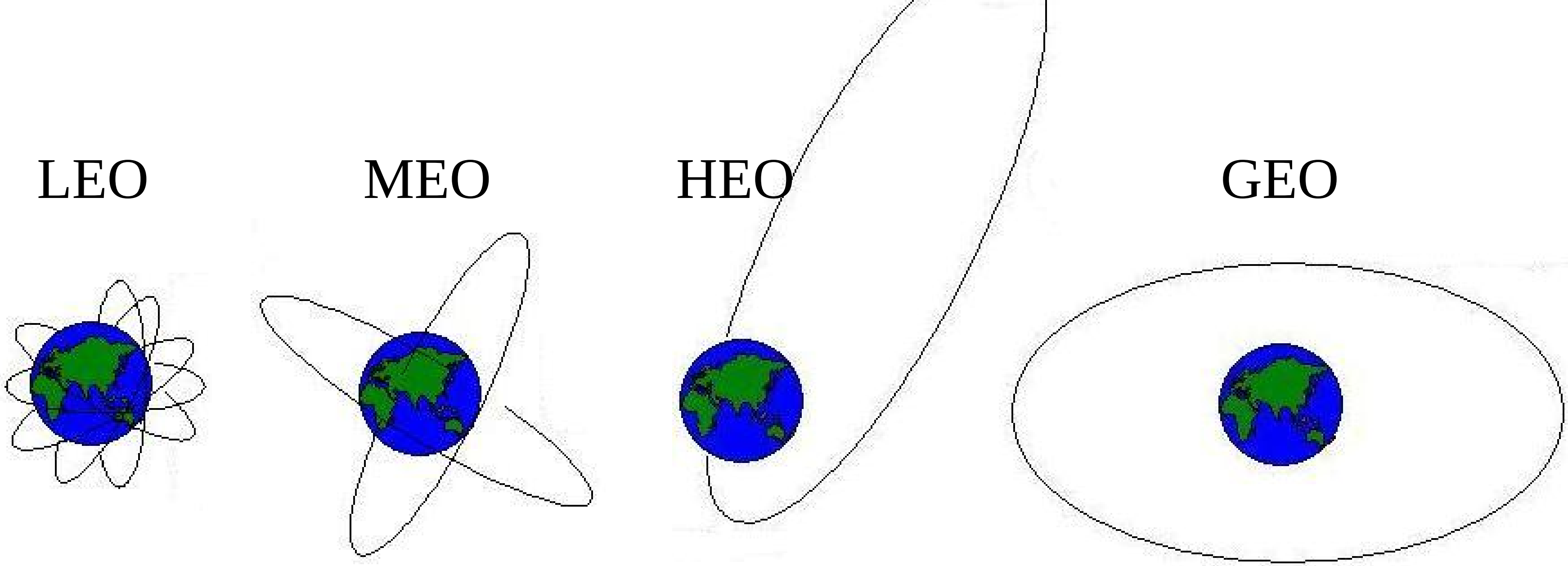
Source: Armengol et. al., 58th International Astronautical Congress

Space-based Payload for Two Ground Stations



A Telescope of ESA's Optical Ground Station

Satellite Orbit



Low Earth Orbit : **700-1500 km**

Medium Earth Orbit : **10000-20000 km**

Geostationary Earth Orbit : **35768 km, 24 Hr**

Highly Elliptical Earth Orbit

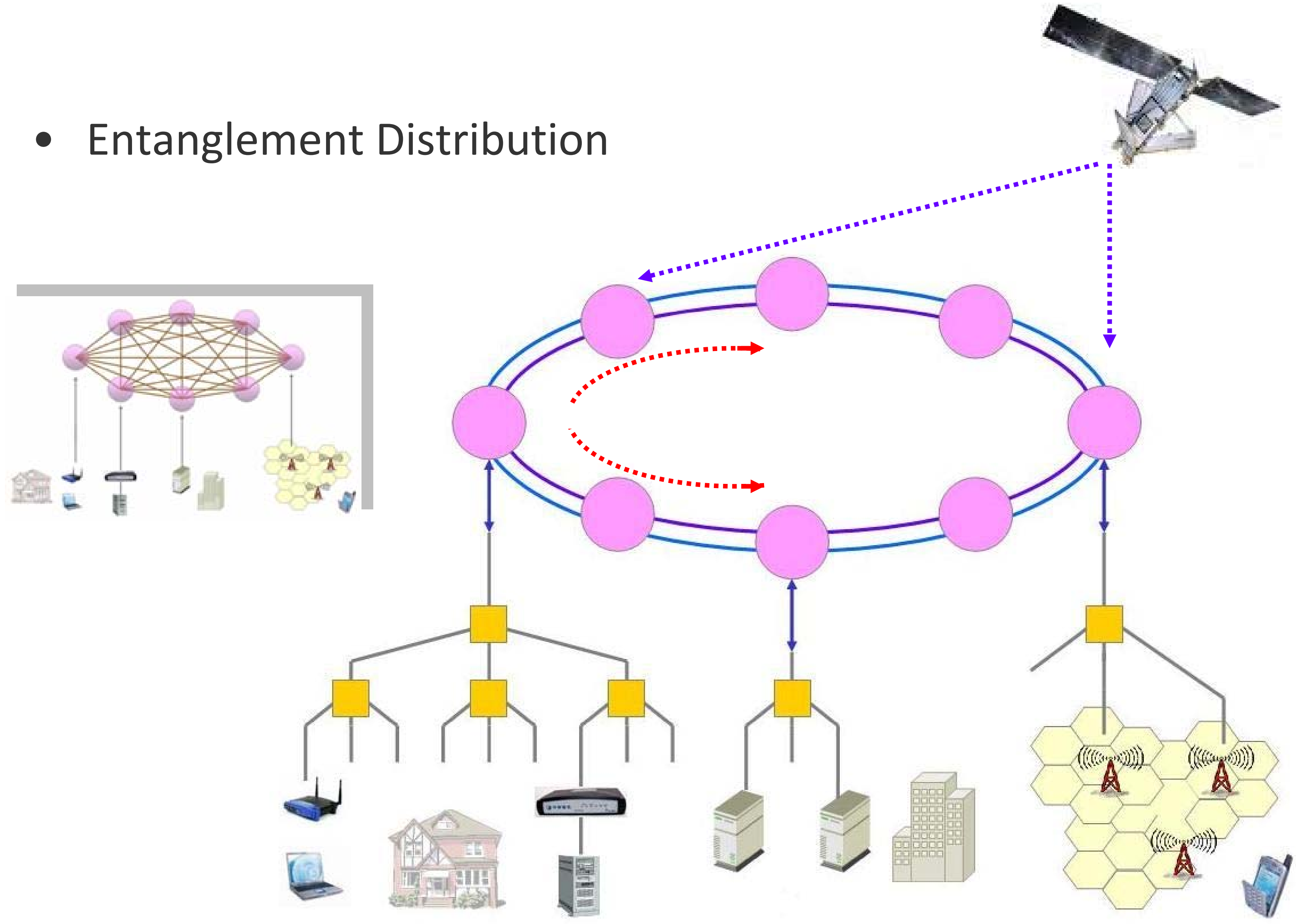
Orbit Trade-off for QKD via Satellite

	LEO	MEO	GEO
Average key length per day (normalized to LEO)	100%	~15%	~30%
Link distance variation	~300%	~5%	~0%
Average gap duration between consecutive links (night operation only)	~1 day	~1 day	~0.5 day
Maximum gap duration between consecutive links (night operation only)	<15 days	< 22 days	~0.5 day
Pointing complexity of space-based quantum communications terminal	High	Medium	Low
Pointing complexity of optical ground station	High	Medium	Low
Sensitivity to link acquisition time	Critical	Uncritical	Independent
Instantaneous ground coverage	<1%	~30%	~33%
Total ground coverage	~100%	~100%	~33%

Source: Armengol et. al., 58th International Astronautical Congress

Telecom Point of View

- Entanglement Distribution



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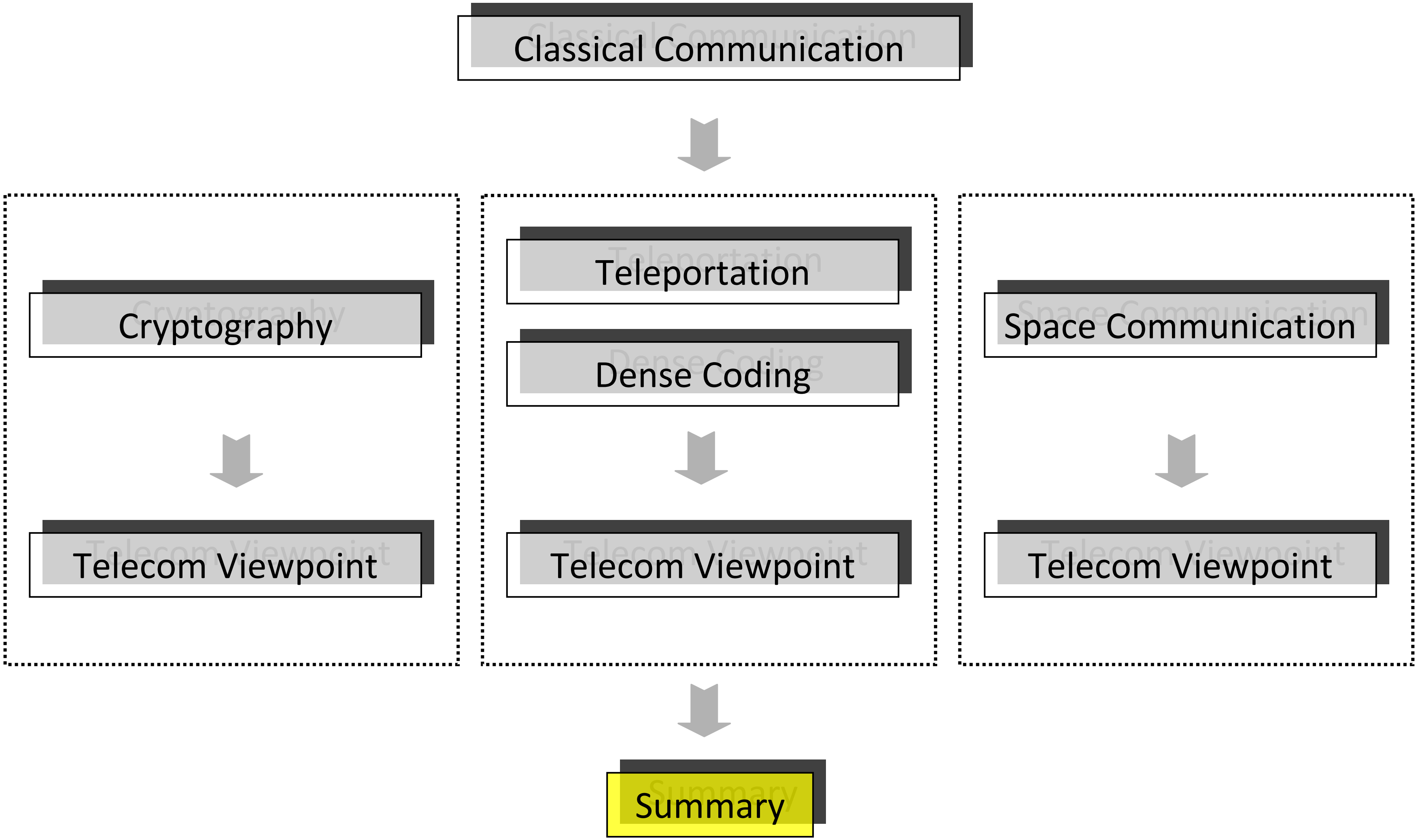
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- Quantum Communication is a promising field of study.
- Science, Technology, Engineering should be closely integrated.
- Interdisciplinary support is of great significance to each of these communities.