Analyzing entanglement-based quantum key distribution on satellite-ground channel

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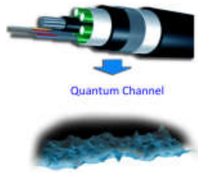
Quantum Communications

- From the engineering point of view, the quantum circuits built from different quantum gates give many possibilities to perform computational calculations in a more efficient way than the nowadays used traditional computers [1].
- Although quantum computers are still the tools of the future, there are promising quantum-based applications, mainly in the field of communication.



quantum-based satellite communications

The free-space quantum communication can be extended to ground-to-satellite or satellite-satellite quantum communication, which could be an ideal application for global quantum cryptography [2].

Research problem

- According to the laws of quantum mechanics, any attempt of eavesdropping the key will disturb the quantum states during the quantum key distribution (QKD) process, thus revealing the presence of an eavesdropper [1].
- Although commercial applications of QKD technology are already available, currently direct fiber-based QKD links cannot reach distances beyond a few hundred kilometers due to the optical losses on the fiber. With the help of quantum repeaters, long-distance QKD networks may be feasible, but such devices are not ready for operational integration [2]. Instead of wired-links, satellite links can be used as free-space quantum channels [3] to provide a global free-space QKD network [4].

Entanglement-based QKD

- We started to analyze the properties of the Earth-satellite quantum communication by simulating a global, satellite-based quantum key distribution network.

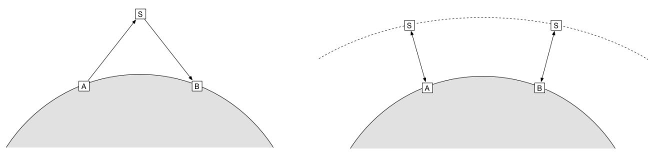


Fig.1. Left: satellite S acts as an untrusted relay and forwards the photons received from ground station A to ground station B without disturbing the quantum state.

Right: satellite S acts as a trusted node and first it establishes a key with station A, then later with station B. This solution does not require simultaneous line of sight between the stations and the satellite, so a larger area can be covered, however station B has to wait for the satellite to arrive.

Results

- We have proposed an entanglement-based QKD satellite network which consists of three satellites.
- One satellite serves as the source of entanglement, the two others work as mirrors to increase the coverage.
- For this constellation, we have calculated the maximum distance allowed between the satellites to minimize the atmospheric distortion of the transferred quantum states. Different simulations were made to determine the rotation of the basis states which has to be taken into account at the ground stations in case of using an entanglement-based QKD protocol.

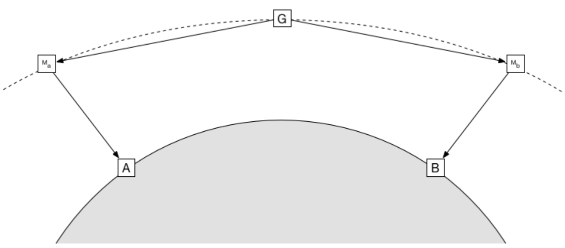


Fig.2. Satellite G generates the entangled pairs and sends one photon of each pair to ground stations A and B. The range is extended with M_a and M_b mirrors. If the links between the generator and the mirrors are above the atmosphere, a significant amount of distortion can be avoided.

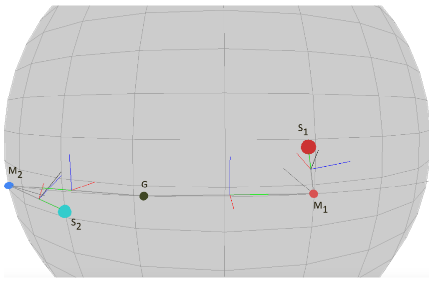


Fig 3. The satellites are visible from the ground stations under 60° zenith angle, so an active quantum communication is possible. The lines connecting the satellites and the stations indicate a quantum communication. The three vectors in the middle of these lines indicate the basis states, the blue vector represents the "up" vector. On the mirror-ground station connections, the black line indicates the true "up" vector which is visible from the ground station's perspective. The difference between this black "up" vector and the received "up" vector is the angle of rotation.

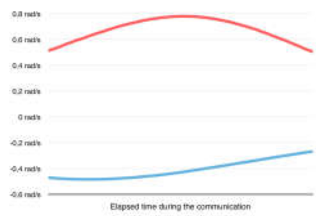


Fig.4. It shows the required rotation during the simulated quantum communication. The S_2 base station (red line) had to rotate the bases at a rate of 0.5 rad/s but the speed of the rotation was the fastest when the M_2 satellite was the closest. The same is visible on the blue line which shows the speed of the basis rotation at S_1 base station.

Fig.5. Cover of the Quantum Satellite Communication Simulator 2.0

Quantum Satellite Communication Simulator

- The aim of the simulation software is to calculate performance characteristics of quantum communication channels.
- Development started in 2010
- Handling different orbits and QKD protocols
- Available: mcl.hu/quantum/simulator

Our research group at BME

- theory of quantum computation and communications
- quantum channel coding
- quantum error correction
- quantum cryptography
- quantum repeaters
- quantum networks
- quantum space communications
- developing the first Hungarian CV-QKD device
- visualizing multi-qubit systems using fractal representation
- undergraduate and graduate courses about quantum computing and communications

MCL Mobile Communications & Quantum Technologies Lab.

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