Optical Ground Station for Satellite-Based QKD: toward industrial-grade implementation

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We present an Optical Ground Station (OGS) dedicated to quantum communications and our recent results we obtained with it. The OGS was built in 2024 and since then was equipped to be ready for performing satellite communications including Quantum Key Distribution (QKD). So far, we performed terrestrial line-of-sight QKD experiments as well as demonstrated tracking of passive satellites to validate our pointing capabilities.

The presentation consists of three components. First, we introduce technical details about the OGS including its main instrument, which is an 80-cm Ritchey-Chretien telescope, the backend optics, and a concept of its operation. Second, we give examples of accomplished missions and tests that have been already performed at the site. Finally, we discuss features of the OGS design that make it an industrial-grade solution. These include flexible multi-mission capabilities, rich infrastructure for both quantum and classical optical communications and auxiliary tools at the site. Below we briefly sketch each of the components.

The main telescope of the OGS is used to collect photons transmitted from space. It performs tracking of the moving satellite by following its predicted trajectory in the sky. Nevertheless, the precision of such trajectories is never perfect and the system has to rely upon the received bright optical beacon signal transmitted along with the quantum signal from the satellite. Both signals are collected by the telescope and are spectrally separated in the optical receiver. Beacon light is imaged with a fast visible or NIR CMOS camera, delivering a high frame rate for real-time pointing correction with a fast steering mirror. Once the image is stabilized at a certain coordinate in the camera frame, the quantum signal starts to pass through the field-limiting pinhole to enter the quantum receiver, where its polarization is measured in two mutually-unbiased bases required for polarization-encoded QKD. Before the measurement, its polarization is corrected by a set of waveplates that can compensate the relative rotation between the satellite and the OGS reference frames during the pass. The OGS as well sends a bright beacon beam co-aligned with the telescope direction to enable closed-loop pointing at the satellite side.

The milestone experiment we performed so far is the entangled-based QKD from a distance of around 2 km. The source of entangled pairs, a local receiver for a single component of generated pairs, and transmitting optics were located at a nearby hill, from where the quantum signal with the wavelength of 780 nm was transmitted to the OGS. Given a relatively small distance and a large 135 mm aperture of the transmitting optics, there is almost no diffraction of the beam, so it is fully captured by the telescope at the OGS. We also used a beacon at the transmitter side to enable closed-loop pointing. During 20 min long active operation, the link demonstrated stable performance delivering around 24 thousand sifted events per second at the QBER below 5%, which translates to around 4.5 kbit/s secret key rate using a finite-size-based estimation for 30 second long processing blocks. These figures make it one of the best results for free-space entangled-based QKD published in the literature.

The OGS was designed having in mind full automation, compatibility with multiple satellite missions, availability of supplemental systems such as a high-precision GPS-synced clock, weather stations, a time-tagger, and modems for classical free-space optical communications. We also maintain an up-to-date interface control document that defines all systems and interfaces the end user may need to interact with at our facility. The site can also be used as a testbed for guest equipment, for which we have a secondary plinth with all necessary connections. All these components contribute to our readiness in providing industrial-grade solutions for satellite-based QKD. We're also working at enabling fiber-based QKD connections with other nodes in the country, so the OGS can become a gateway for long-haul QKD between local users and international partners.