Swiss Space Quantum Communications

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1. Project description and experiment description

"Swiss Space Quantum Communication" is a voluntary big name for a small project, launched with the Swiss NCCR QSIT project, including UNIGE, UNIBE, FHNW, HSLU and UAB Barcelona. The final goal would be to implement quantum communications between satellite and a ground station. This is inaccessible for our small consortium with very limited means, so we decided to start tests of free-space communication on terrestrial links, between ground and a drone, and eventually between ground and high-altitude balloons. We also developed a protocol for secure communication, which is more robust and easier to implement, and allows for higher bit rates than quantum key distribution [1], which we want to test on different links and configuration.

In summer 2022 we learnt about the free-space optical communication trials of a consortium around Thales Alenia Space between the Jungfraujoch and the observatory at Zimmerwald (see [2]). We decided to grasp this opportunity and test our equipment over this link. We performed two experiments.

1) Quantum Key Distribution (QKD)

During the last couple of years, UNIGE has been developing a state of the art QKD system [3,4]. It features very high clock rate and, depending on the used single-photon detectors, it can operate over links with up to 70 dB loss. Since the installed free-space optical link is working in the telecom c-band, like our QKD system, we were very optimistic to be able to perform secret key exchange between the Jungfraujoch and Zimmerwald, which by the way would have been the longest distance for terrestrial free-space QKD. If we are operating our QKD system with telecom fibres, we use a separate fibre, or another DWDM channel on the same fibre, as a service channel, which allows also to synchronize the transmitter and the receiver. This is done, with standard commercial SFP modules. In our trial, we multiplexed the quantum channel and the service channel (at wavelengths of 1550.92nm and 1548.52nm, respectively, see Fig. 2), We also used additional EFDAs at the sender and the receiver of the service channel to cover the loss. Indeed, it turned out that loss was no longer an issue, however, the channel fading perturbed the synchronisation significantly. The discriminators in the SFP modules are not designed to handle strong power fluctuations. Unfortunately, we didn't manage to find a stable alternative solution with the couple of days we had at our disposition for this trial. As a consequence, the periods over which the systems were able to lock, were too short to be able to extract a secret key.

2) Quantum Keyless Privacy (QKP)

QKD is very challenging for satellite links, the channel loss is high, stray light induces errors and as a consequence key rates are very small even for LEO satellites. On the other side, an eavesdropper has no simple access to the channel, like in the case of a fibre optical link. Therefore, it is reasonable to assume that the eavesdropper can only collect a fraction of the optical signal, if you exclude him from a small perimeter around the sender and receiver. Under this assumption, we come up with another protocol, based on a quantum wiretap channel, which allows for direct secure communication between Alice and Bob [1].

This protocol is relatively easy to implement, using e.g. on-off keying, and we built up a demonstrator in our lab, based on a simple laser and a (Si-APD) single-photon detector, working in the visible range (637nm), with a repetition rate of 10MHz. The most relevant characteristics of such system is the bit error rate (BER), which has to be lower than a certain threshold (typically a few percent) to successfully transmit a message with efficient error correction. In optimum conditions, this demonstrator can achieve BERs as low as 0.15%.

The available free-space link from the Jungfraujoch being designed for 1550nm, we had to change our setup to this wavelength. This could be done quickly. However, the available (InGaAs) single-photon detectors capable of detecting in the C-band don't allow to use a high clock rate. Therefore, we reduced this latter to 180kHz. In this configuration, we still managed to obtain very low BER of about 1% for most transmission blocks. Nevertheless, the turbulence induces some fading during which the signal is lost. We managed to exchange messages during a night with medium turbulence conditions, with a few fading per second and with a fading duration up to about 10ms. This results in a small percentage of the blocks having a BER too high for the message to be sent (see Fig. 1). This issue could be circumvented by modulating the block size or the transmission threshold.

Overall, even if the experiments didn't deliver all expected results, they were very useful. We learnt a lot about the free-space communication under difficult conditions, and we know what to do to improve the chance of success in future experiments. In particular, we are currently building up a compact prototype of our state-of-the-art QKD system, which will considerably simplify the logistics, and we work on an alternative way to synchronize the systems on a simple internet link, rather than a dedicated channel.

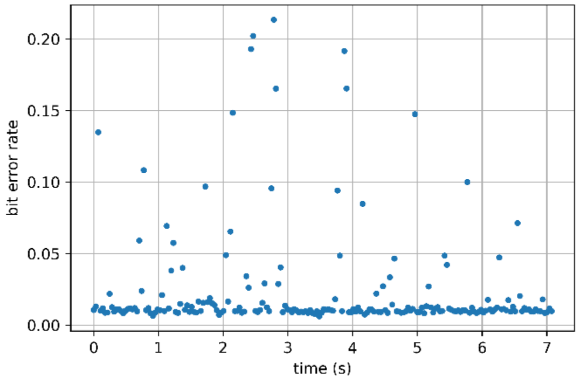

Figure 1. Typical bit error rate over time during a night with medium turbulence conditions. Each point corresponds to a block of 6400 bits.

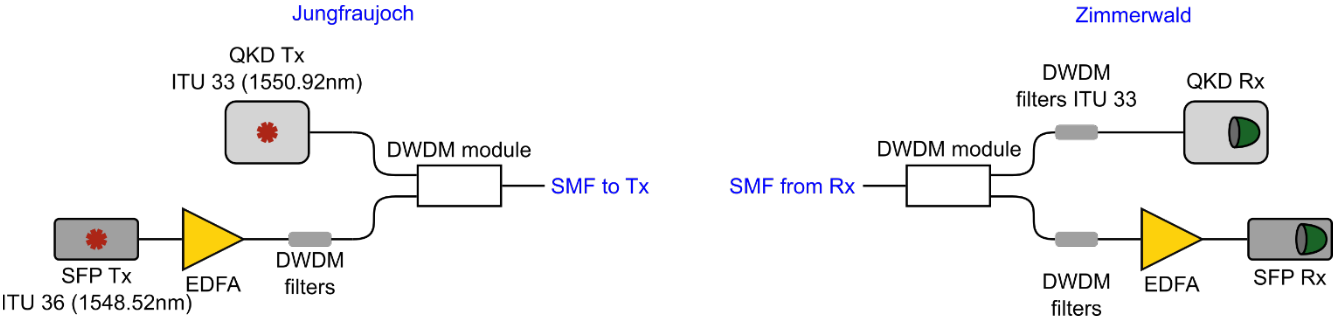

Figure 2. Scheme of the multiplexing of the quantum and classical channels. For the QKP experiment, the SFP Rx was not used. Tx: transmitter; Rx: receiver; SFP: small-form-factor pluggable; EDFA: erbium-doped fibre amplifier; DWDM: dense wavelength division multiplexing; SMF: single-mode fibre.

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