Experimental Demonstration of Upstream Continuous-Variable QKD Access Network

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Introduction

- Quantum key distribution (QKD) is designed to establish symmetric keys among two legitimate parties. Continuous variable (CV) QKD that uses the coherent states and homodyne detection can only apply the cost-effective telecommunication components.
- Experimental demonstration of CV-QKD over 200km has been reported which proves its applicability [1].
- The access network allows multitude end-users to connect to the nodal network.
- Quantum access network was first studied and demonstrated in [2] for discrete-variable QKD. Here, we demonstrate a CV-QKD based upstream access network prototype.

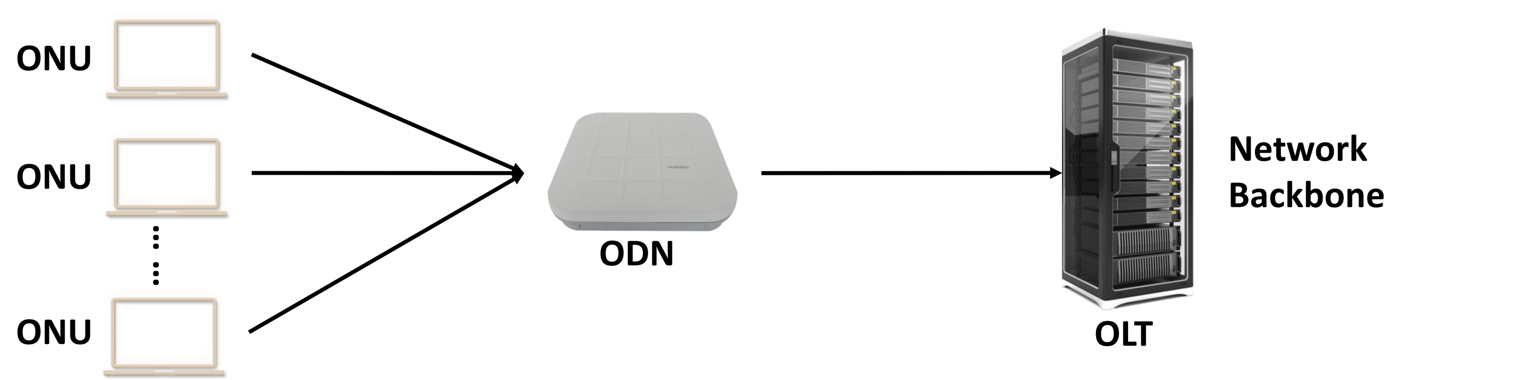

Fig. 1 Example of an upstream access network. Multiple optical network units (ONUs) send signals to the optical distribution network (ODN) simultaneously. The ODN combines the incoming signals and forwards them to the optical line terminal (OLT).

Access network vs. standard CV-QKD

- The standard CV-QKD protocol is essentially a point-to-point protocol, while the access network is designed to realize a multipoint-to-point connection.
- The standard CV-QKD protocol considers the entire channel as being controlled by the eavesdropper Eve. While, in an access network, the ODN is normally trusted and is placed in the middle of the channel.

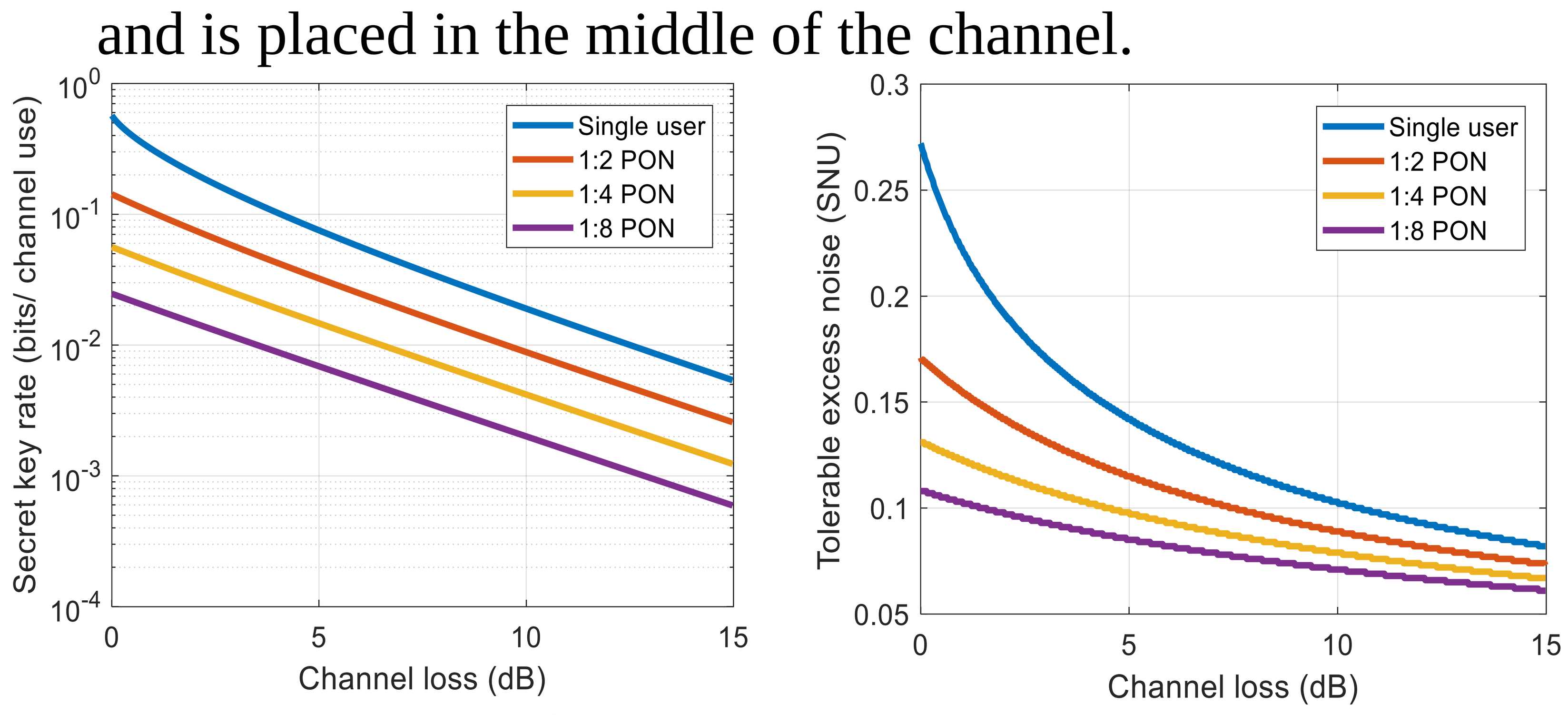

Fig. 2 Simulation results of the secret key rates and the tolerable excess noise of individual ONU as a function of the channel loss, with different split ratios of the passive optical network (PON). Simulation parameters: the modulation variance V_A=3, the excess noise ε_c=0.02 for the secret key rate simulation, the detection efficiency η_d=0.6, the electronic noise η_e=0.95 and the reconciliation efficiency β=0.95.

- We fulfil the gap by modelling the ODN as untrusted loss, so that the security analysis can be performed.
- The secret key rate and the tolerable excess noise are inevitably reduced as the split ratios increases. Yet they are still acceptable when the split ratio is not too high.

Experimental implementations

- Alice is deployed as the ONU, Bob acts as the OLT, the ODN couples the signals from the ONUs to the OLT.
- Alice No.1 and Alice No.2 connect to the ODN through 5.3km and 12.3km fibers respectively.
- Variable delay line (VDL) is applied at each ONU to calibrate the arriving time of the signals.
- Dynamic polarization control (DPC) module is applied at each path of the ODN to pre-compensate the polarization.
- At the OLT, the signals are being compensated again by the DPC, then detected by the standard CV-QKD receiver.

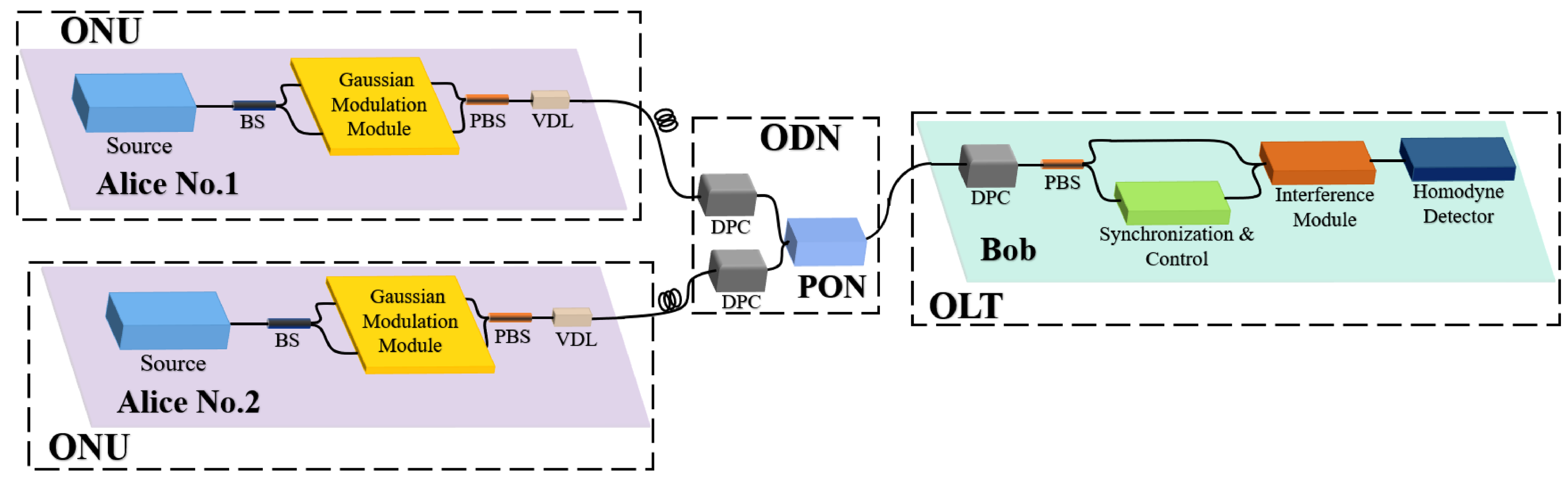

Fig. 3 Schematic set-up of the upstream access network. Alice No.1 and Alice No.2 generate the local oscillators (LOs) and Gaussian modulated coherent states together as the signals. The signals are then simultaneously sent to the ODN where they are combined and forwarded to the OLT. Standard CV-QKD receiver is applied to detect the signals. BS: beamsplitter; PBS: polarization beamsplitter; VDL: variable delay line; DPC: dynamic polarization control.

Experimental results

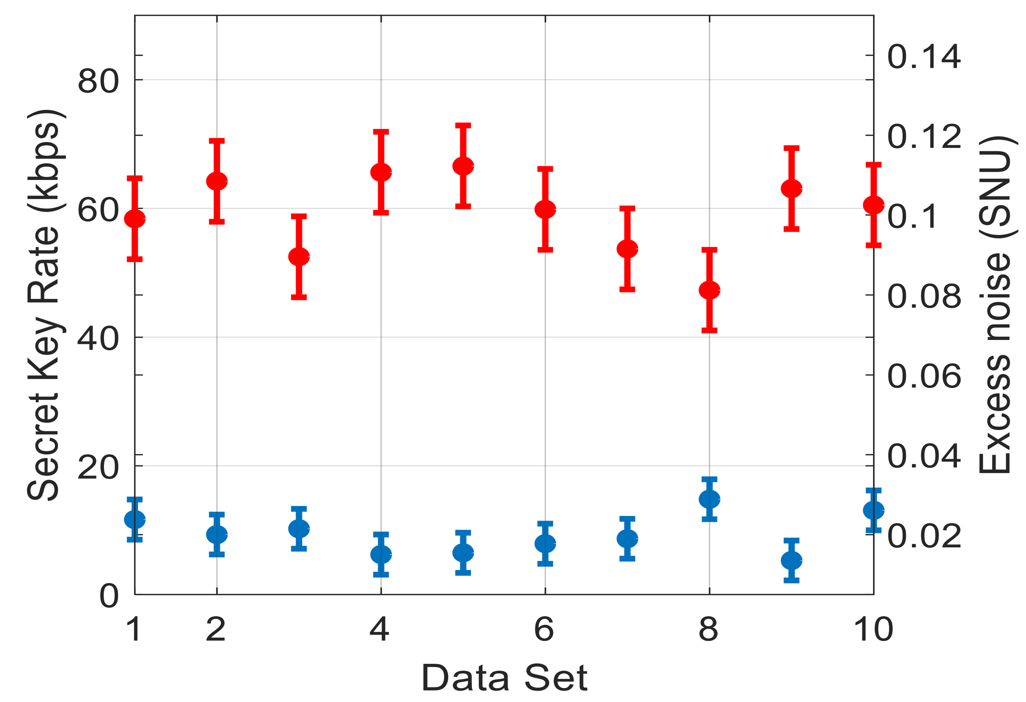

Fig. 4 Experimental results of Alice No.1 of 10 data sets. Upper red marks represent the secret key rates and the lower blue marks represent the excess noise levels.

- The modulation variance is set as V_A=2.3 for both ONUs. The electric noise η_e and the detection efficiency η_d of the homodyne detector is 0.93 and 0.61 respectively, the reconciliation efficiency is around 0.95.

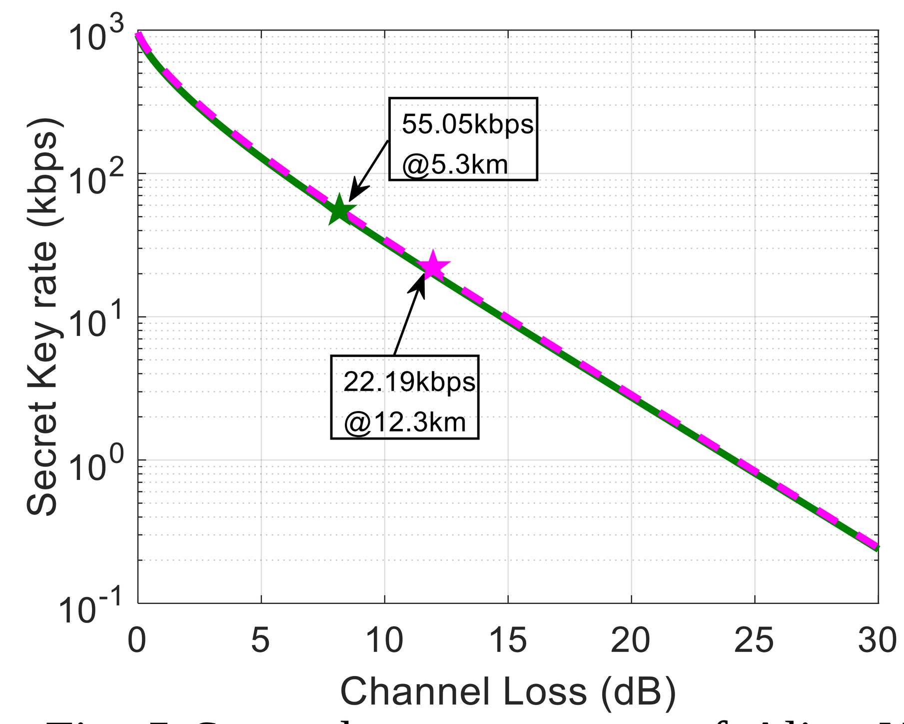

Fig. 5 Secret key rate curves of Alice No.1 and Alice No.2 as a function of the channel loss. The curves are drawn by the practical experimental parameters.

- Green and pink curves are the secret key rates for Alice No.1 and Alice No.2, based on the experiment parameters, average secret key rates of 55kbps (green star) and 22kbps (pink star) are obtained respectively.

Discussion and future work

- The two end-users upstream CV-QKD access network prototype is achieved by using variable delay lines that control the arriving time of the signals from the different ONUs, and applying pre-compensation modules at the ODN that pre-compensate the polarization differences individually.
- The excess noise introduced by the network prototype is relatively stable. Yet, there are small fluctuations in the excess noise and the transmittance of the channel, which result in the fluctuations in the secret key rates. The influence of the LO is not dominated.
- In the future work, we expect to develop fully automatic operations, extend the network to a higher repetition frequency and support more users.

References

[1] Y. Zhang, et al. "Long-distance continuous-variable quantum key distribution over 202.81 km of fiber." Phys. Rev. Lett. 125 010502 (2020).

[2] B. Fröhlich, et al. "A quantum access network." Nature 501 69-72 (2013).