A Quantum Key Distribution simulator for BB84-type protocols with decoy states

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Abstract

The complex relationship of parameters in security proofs for Quantum Key Distribution (**QKD**) protocols often precludes intuitive approaches, thus constituting a high barrier to entry when trying to reason about the performance of QKD systems. We present a software tool with a graphical user interface (GUI) which can aid in interactive evaluation, design and optimization of BB84-type decoy state QKD systems.

Introduction

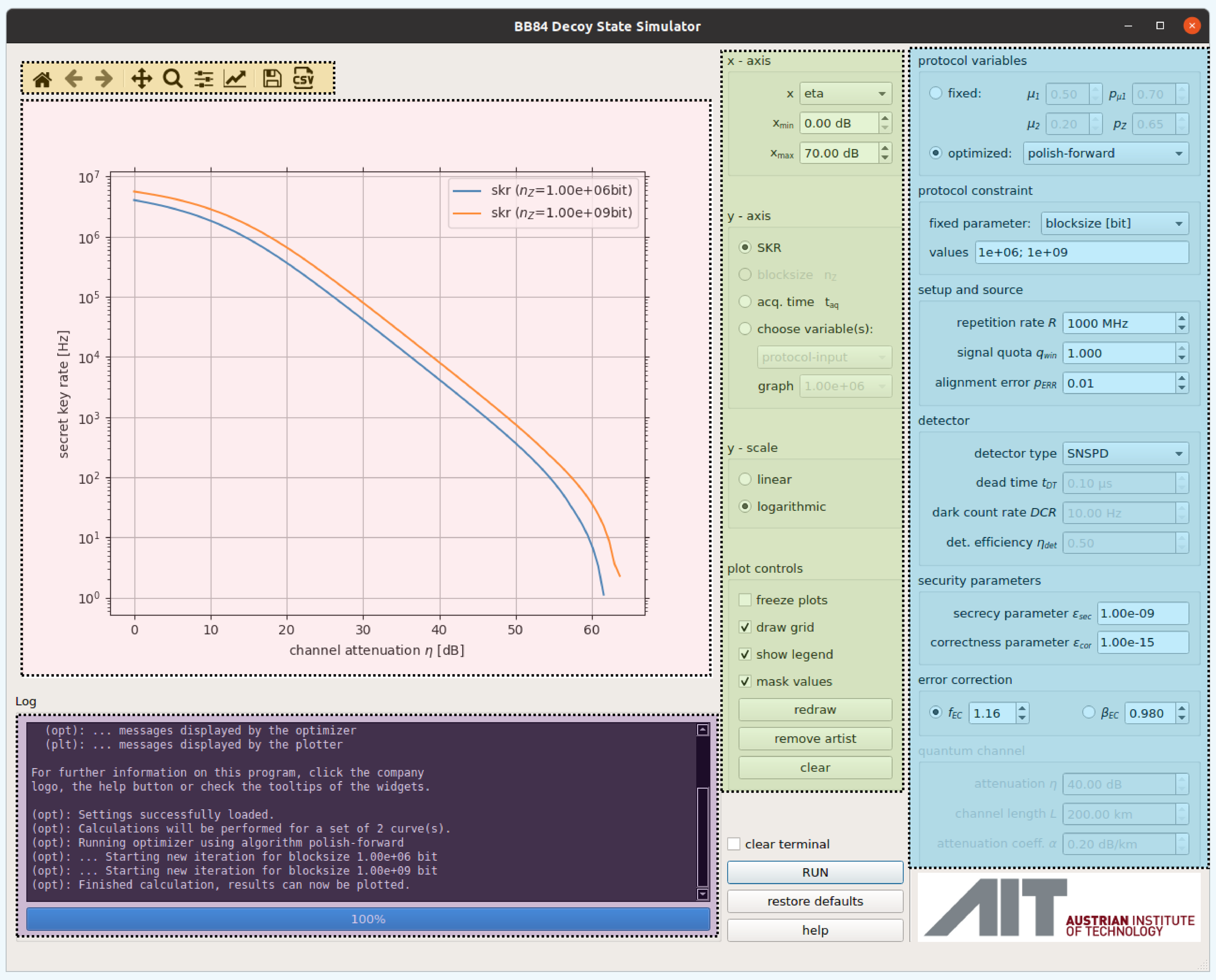
Contemporary implementations of **BB84-type DV-QKD** protocols utilize **weak coherent laser pulses** as the carrier for the encoded information, which however imposes a severe limitation in the maximally achievable transmission distance due to the inherent threat of photon number splitting (**PNS**) attacks. This potential weakness can be elegantly eliminated by the adaption of the protocol to include so-called decoy states (**DS**) in the transmission.

The **additional degrees of freedom** in deciding when to send signal/decoy states and which intensities to use for them however further complicates the already complex task of anticipating protocol performance and finding a set of suitable parameters to achieve optimal secret key rates (**SKR**). In order to predict protocol performance, as a function of characteristics of the QKD setup like channel losses and device imperfections, state preparation fidelity, decoy state parameters and finite size effects, the software simulator ***pyDSsim*** has been developed. The tool is written in Python and implements the **recent security proof framework** introduced in [1,2]. The software can be scripted from the command line or used via a graphical user interface (**GUI**: QT5 framework) for easy exploration via parametrized x-y plots of over 40 different variables, allowing a comprehensive evaluation of their interdependencies.

The main feature however is the option to numerically compute the set of protocol variables for a given QKD-setup which maximizes the secret key rate under constraints typical for practical implementations: fixed block sizes or fixed acquisition times. To this end two different algorithms (differential-evolution [3] and L-BFGS-B [4]) are utilized, allowing for a cross-check of the acquired results and choice between speed and accuracy of the approach.

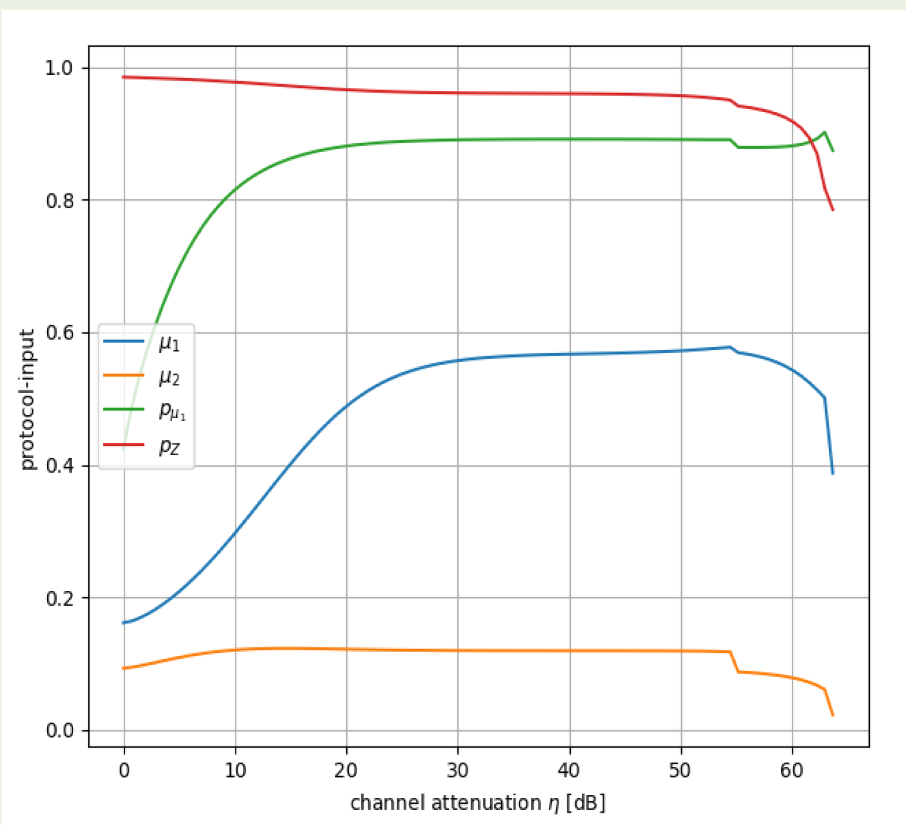
Simulator: GUI overview and workflow

1. The user specifies the **QKD setup** under investigation and fixes the *x*-axis out of the set {η, R, t_{DT}, DCR, β_{EC}}. Important input parameters include:
   a) Protocol variables:
      laser intensities, probabilites for chosing signal/decoy state and X/Z basis
   b) Modes of operation:
      optimized vs. fixed inputs, optimization algorithm, protocol constraint (blocksize vs. acquisition time)
   c) QKD system parameters:
      source rate, detection window (i.e. pulse width and jitter), alignment error, detector properties, channel transmittance
   d) Post-processing parameters
2. After hitting the *RUN* button, any of the over 40 variables of the security proof can be selected as the *y*-axis from the **plot controls**.

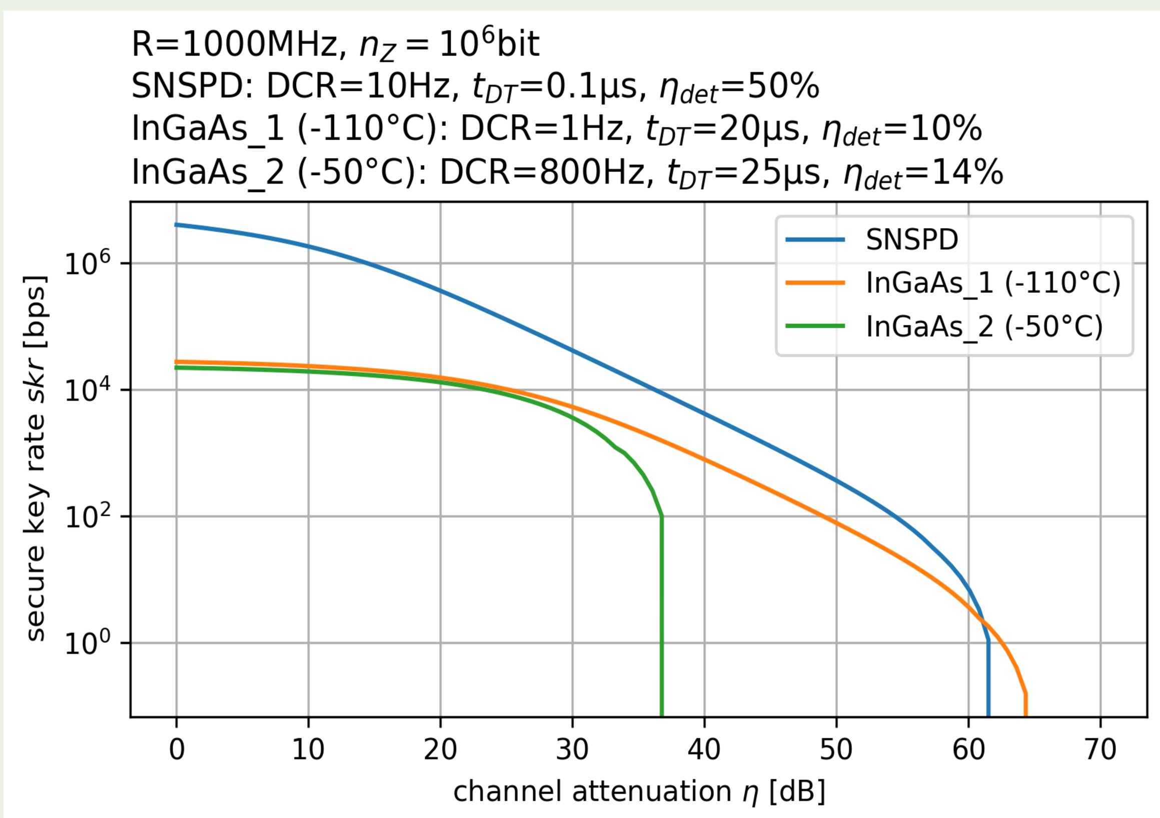


3. The **canvas** is automatically updated for the given *x-y* pair. For direct comparison, plots can be stacked on the canvas and retained between runs of different inputs.
4. The **toolbar** offers fine grained customisation of the plot, saving figures and exporting calculations to **.csv*
5. Additional information about the state of the simulator can be gleaned from the **log** and **progress-bar**.

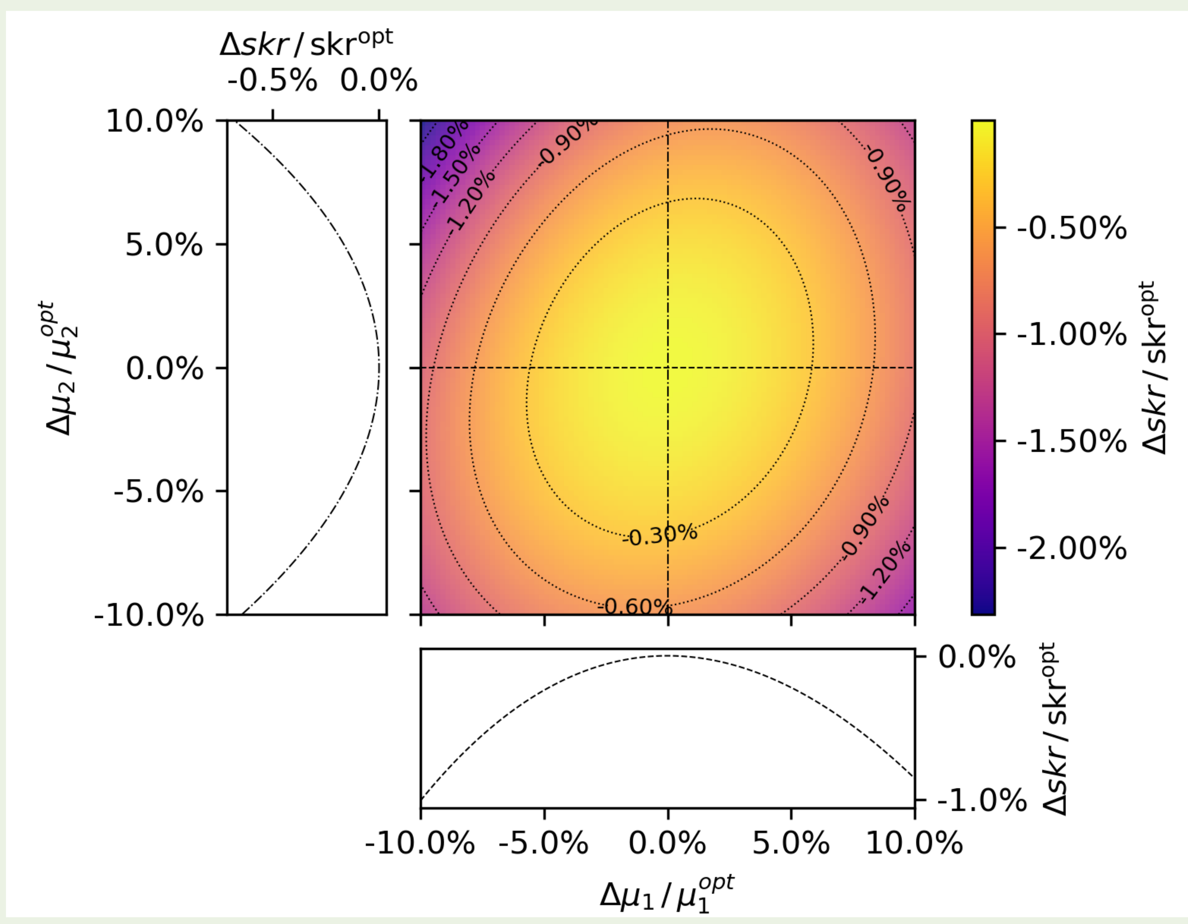
Use case examples



i. Operating a given QKD system: optimal protocol variables for maximum SKR



ii. Detector comparison: superconducting nanowire (**SNSPD**) vs. InGaAs single photon avalanche (**SPAD**)



iii. Sensitivity of secure key rate to non-optimal signal (μ_1) and decoy (μ_2) laser pulse intensities

References

1. Rusca, D., Boaron, A., Grünenfelder, F., Martin, A. & Zbinden, H. Finite-key analysis on the 1-decoy state QKD protocol. Appl. Phys. Lett. 112, 171104 (2018)
2. Lim, C. C. W., Curty, M., Walenta, N., Xu, F. & Zbinden, H. Concise security bounds for practical decoy-state quantum key distribution. Phys. Rev. A 89, 022307 (2014)
3. R. H. Byrd, P. Lu and J. Nocedal. A Limited Memory Algorithm for Bound Constrained Optimization, (1995), SIAM Journal on Scientific and Statistical Computing, 16, 5, pp. 1190-1208.
4. Storn, R and Price, K, Differential Evolution - a Simple and Efficient Heuristic for Global Optimization over Continuous Spaces, Journal of Global Optimization, 1997, 11, 341 - 359

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