Polarization drift compensation using supervised and reinforcement learning

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LAMBDA • HSE

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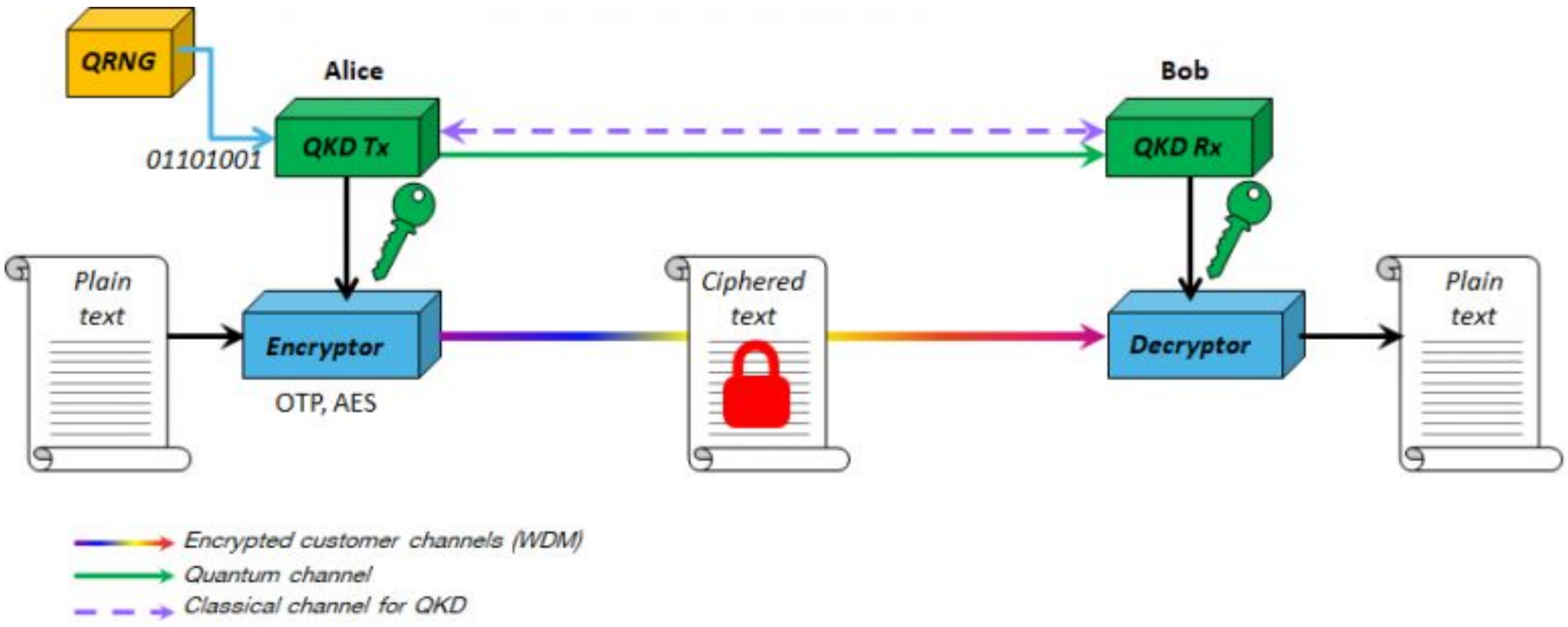
QKD problem

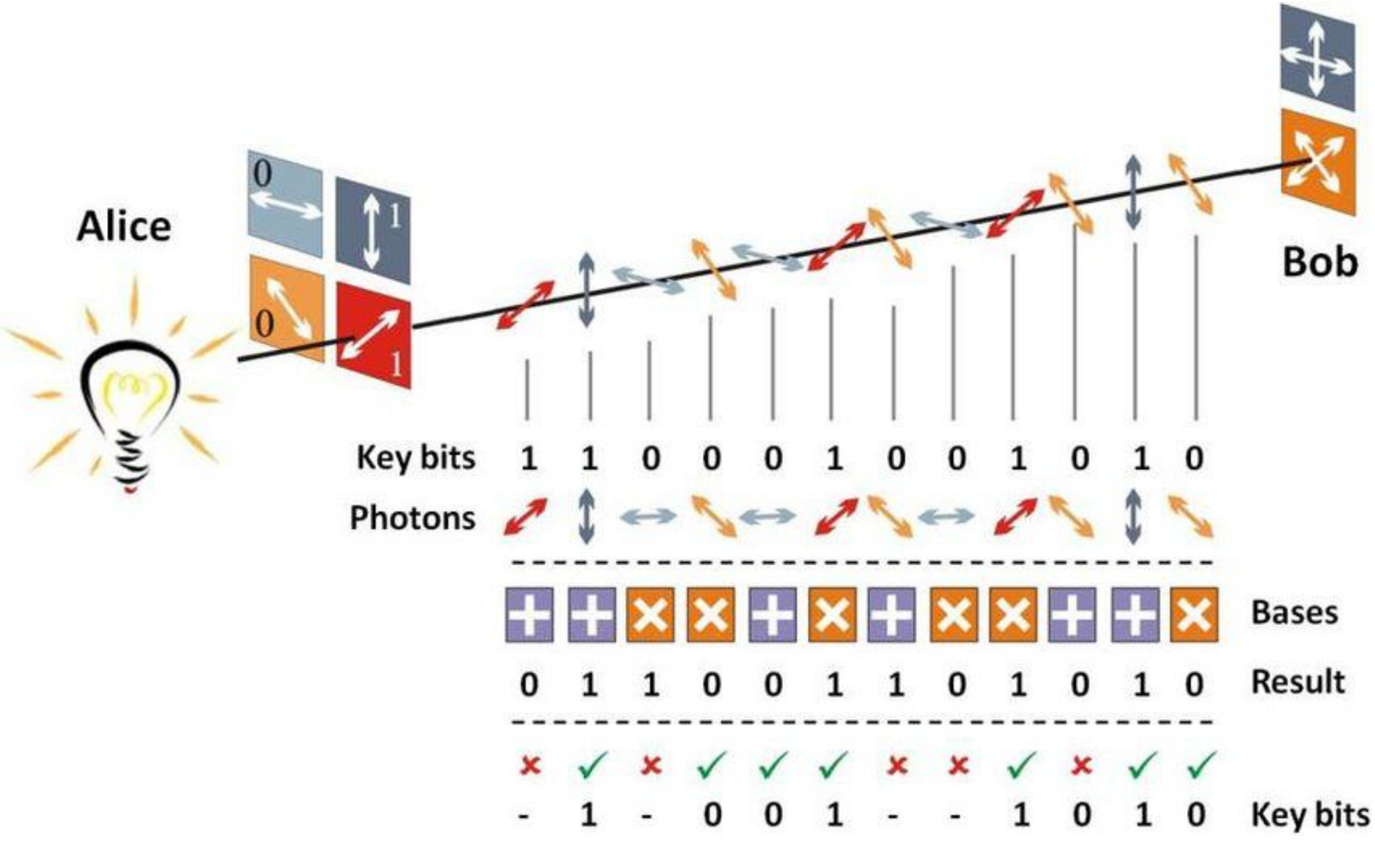
The main task of quantum cryptography - delivering the encryption key, whose safety will be ensured by the laws of quantum mechanics (No-cloning theorem and etc)



Visualization of secure channel

Our setup

- QRate QKD-312 system
- polarization controller General Photonics PSY-201
- BB84 protocol



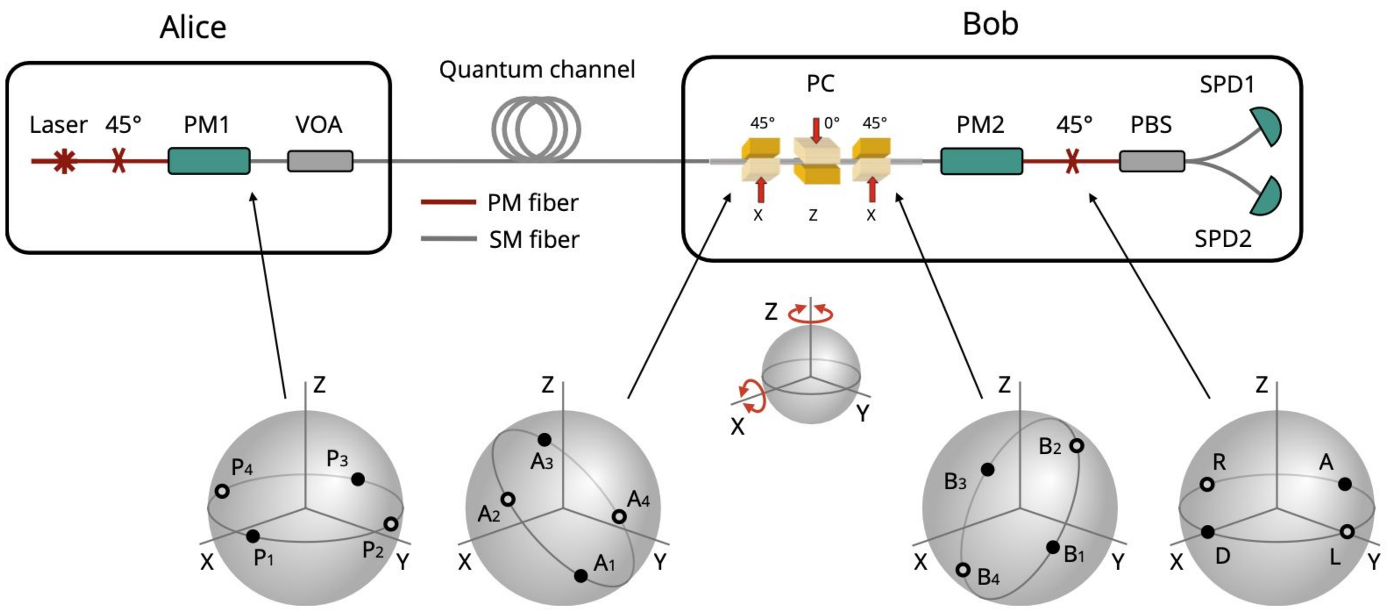
scheme of BB84 protocol

Problem statement

To prevent information loss in quantum channel, the polarization controller is used on the receiving side

We want to solve problem of real-time turing of polarization controllers to reduce the loss

The upper threshold in the BB84 protocol is 11%, above which we do not receive a secret key



Theoretical solution

The main QKD metric quantum bit error rate (QBER) has information about the state of the system

The QBER is a number of wrong bits to the number of total received bits

$$QBER = \frac{1-(A,B)}{2}$$

QBER. A and B are the states of Alice and Bob in Bloch sphere

$$n = -\frac{1}{|\nabla Q|}\begin{pmatrix} Q_x - Q_0 \\ Q_y - Q_0 \\ Q_z - Q_0 \end{pmatrix}$$

normal vector for rotation. Q0 now, Qx/y/z - qber, measured with small rotating angle

$$\phi = arccos(1-2Q_0)$$

rotation angle along n

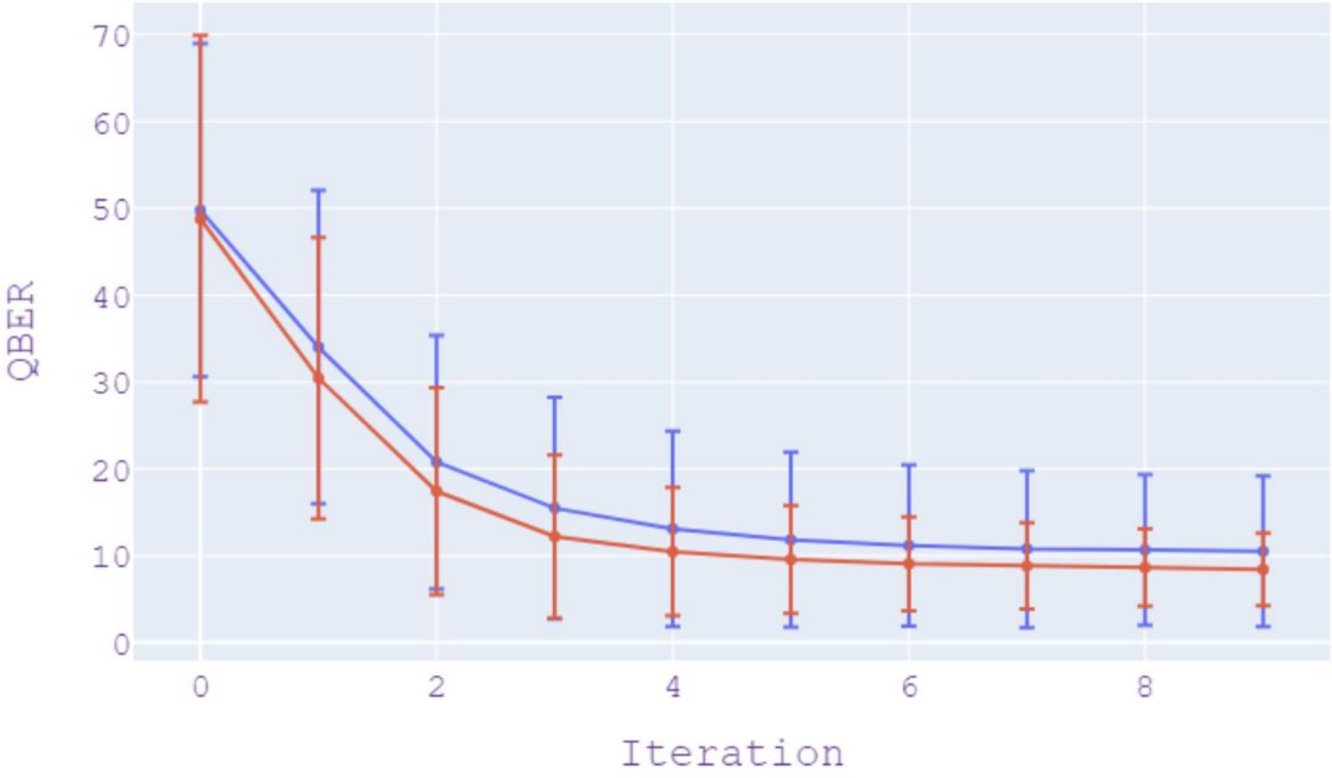
Shakhovoy, Roman; Mayboroda, Vladimir; Rudavin, Nikita; Kupriyanov, Pavel; Fatyanov, Oleg (2024). Analytical solution to the problem of polarization drift compensation in all-fiber QKD system. Optica Open. Preprint. https://doi.org/10.1364/opticaopen.26645338.v2

Supervised learning

We use theoretical solution to create dataset for supervised learning

The model is taking as input the QBERs and returning the actions for polarization controller

Multilayer perceptron was used



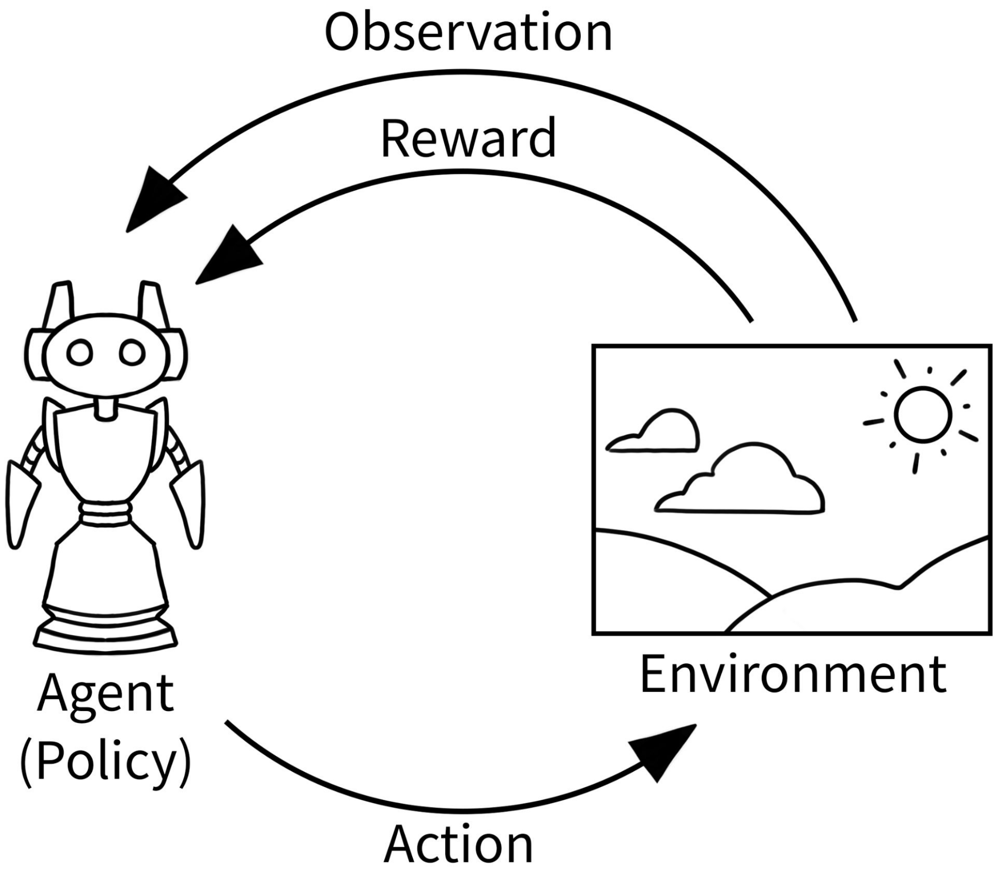
Testing model on setup

Blue - analytical solution
Red - model, trained on dataset

Reinforcement learning

To train RL model we need to create correct training environment

The environment will simulate the polarization controller in real time

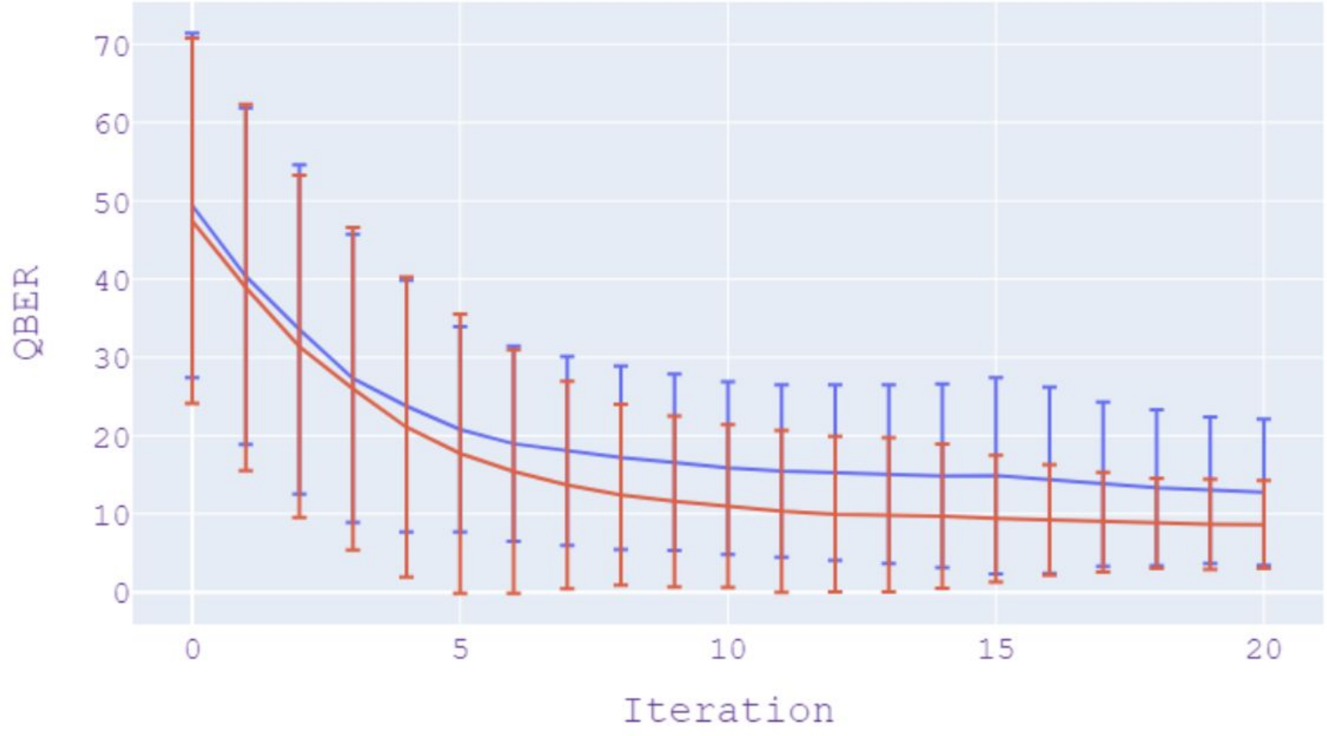


Gymnasium

Reinforcement learning

Multilayer perceptron is used. Training algorithm - PPO

The experiment shows, that RL approach is not more accurate, that supervised



Testing model on setup

Blue - model, trained on dataset
Red - model, trained on dataset and fine-tuned on setup

Conclusion

1) Information about the state of the system is hidden in QBER
2) We proposed the framework for modeling the polarization controller
3) For the first time the ML solutions were used to tune in real-time the polarization controller of QKD setup
4) the JAX framework has great perspective in RL