Pilot-Assisted Local Oscillator Synchronisation for CV-QKD

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1. Introduction

Continuous variable QKD (CV-QKD) is currently thought of to be one of the main contenders for a full-scale deployment of QKD. Its advantages over traditional quit-based implementations are a higher key rate and more importantly the ability to use established photodiode technology rather than complex and costly single-photon detectors. However coherent detection relies on a local oscillator (LO) signal. Previously this strong LO signal was derived directly from the signal laser at the transmitter and was sent over the same transmission line as the quantum signal before being used in a self-coherent detection process. This approach is not viable for longer distances where a very strong LO has to be sent to compensate for losses. Furthermore several side channel attacks haven been proposed that make use of the strong LO signal. Alternatively a true LO derived from an independent laser can be applied in combination frequency and phase drift corrections. Recently such a scheme was proposed and demonstrated [1, 2], where the synchronisation was performed using strong pulses from the signal laser, which were time-multiplexed between the weak quantum signals.

In this work we present a pilot-assisted coherent intradyne reception methodology in which an optically phase-locked reference tone is multiplexed in both, frequency and polarization, to the actual quantum signal. There are several advantages over a time-multiplexed approach. Firstly, in the time multiplexing scheme the additional synchronization pulses will reduce the rate of the quantum signal. Secondly, the quadratures of the quantum signal are not exactly measured at the same time as the synchronization quadratures, i.e. a very fast phase change will not be compensated. In contrast, the pilot-tone scheme allows for an exact phase and frequency estimation simultaneously to the quantum signal thereby not compromising signal bandwidth. Finally the required dynamic range for the receiver can be reduced while in case of time-multiplexed synchronization must be large enough to have unambiguous results of the quadratures. Saturation can therefore easily occur, which is avoided in case of the pilot-assisted scheme where a dedicated phase-locked receiver is used for the pilot tone.

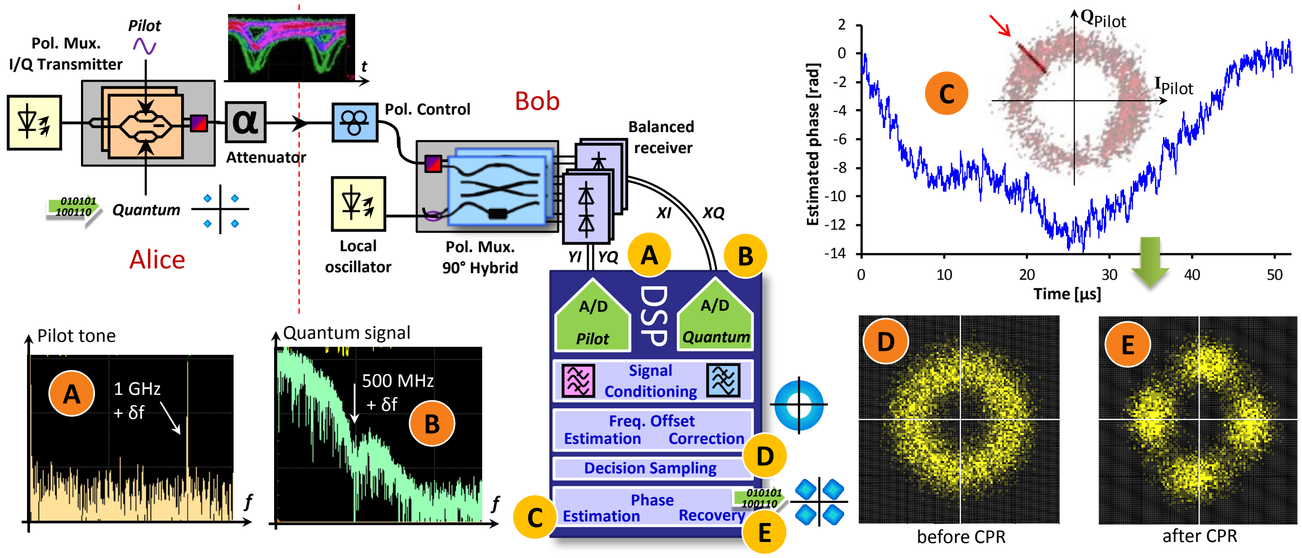

Fig. 1. Pilot-assisted coherent transmission scheme for quantum signals with true local oscillator. Spectrum of pilot tone (A) and quantum signal (B), estimated optical phase of the pilot (C) and quantum signal constellation before (D) and after (E) phase recovery in the digital domain.

2. Pilot-Tone Assisted Coherent Detection Scheme with True LO

The transceiver for the pilot-assisted LO scheme are depicted in Fig. 1. A signal laser at 1550.12 nm with a linewidth of 400 kHz is I/Q modulated in both polarization tributaries by 500 Mbaud data (representing the quantum states) and a 1 GHz tone, respectively, yielding a QPSK quantum signal at the baseband (see eye diagram as inset in Fig. 1) and an optical single-sideband pilot tone multiplexed in frequency and polarisation. While this kind of pilot tone modulation is sufficient in terms of information integrity, it avoids crosstalk from mirror frequencies in case of coherent detection. The signal is then attenuated, transmitted and detected using a LO with a narrow linewidth of <10 kHz tuned to the signal emission wavelength. The LO power was 12 dBm before injection to a photonic-integrated polarization-diversity 90° hybrid used for coherent intradyne detection in both polarization bases. The quantum signal was detected using balanced receivers with a CMRR of >40 dB. Since the optical 90° hybrid performs a heterodyne measurement for each polarization instead of a simple homodyne measurements, the optical output consists of the I_X and Q_X variable. To complete the measurements the optical signals are detected in two sets of balanced receivers, each set optimized for the specific signal properties. The pilot tone at the I_Y/Q_Y plane was detected using standard PIN/TIA receivers. The receiver for the quantum signal has a low noise figure since excess noise will reduce the secure key rate. On the other hand the stronger pilot tone can accommodate more noise but needs a larger bandwidth for detection since the modulation frequency lies above the data signal. The received signal spectra for the 1 GHz pilot tone and the 500 Mbaud QPSK quantum signal are shown in insets A and B, respectively. The electrical I/Q signals are then fed to an off-line DSP to perform signal conditioning by means of filtering, frequency offset estimation and correction between LO and signal emission wavelength and carrier-phase recovery. While the frequency offset can be deduced from the transmitted pilot with the help of a local reference tone, the optical phase drift between the signal laser and LO is quantified by the rotation of the received pilot in the phase space. Since the quantum signal is phase-locked to the pilot and has therefore experienced the same phase changes, the measured I/Q quadratures can be corrected using the acquired rotation of the pilot tone.

3. Experimental Results

The I/Q constellations for the acquired pilot tone and the quantum signal are shown after frequency offset correction and decision sampling in insets C and D/E, respectively. Due to the optical phase drift between LO and signal laser the 1-point constellation of the pilot (C) and 4-point QPSK constellation of the quantum signal (D) is smeared out into a circle. The actual optical phase is then measured from the pilot tone. As can be seen, the drift is 12 radians within 25 µs being also subject to some higher-frequency fluctuations, which needs to be actively corrected. By applying this correction, the sampled pilot tone is fixed in its phase at within the I/Q plane (red arrow in inset C). The obtained phase information is then applied to the quantum signal. With this the donut-like QPSK constellation (D) recovers towards 4 distinguishable modulation symbols (E), as they had been originally transmitted. Note that for the purpose of visibility of the QPSK constellation the delivered power of the received signal has been increased to ~30 photons per symbol. This clearly demonstrates the feasibility of our pilot-tone scheme. As next step this methodology will be implemented inside a fully operational CV-QKD system.

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References

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