Coherent phase fluctuations suppression for real-world twin-field quantum key distribution

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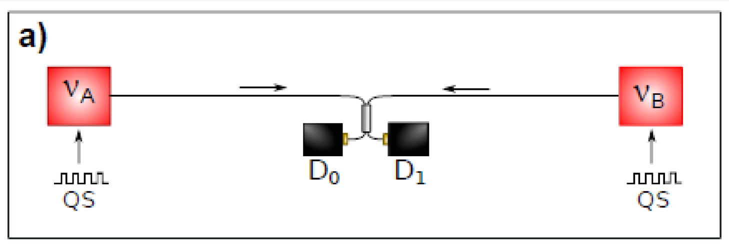
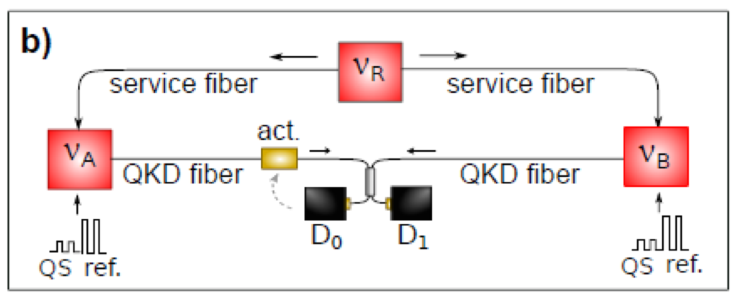
Introduction

Twin-field quantum key distribution is one of the most promising techniques for its implementation on long-distance fibers, but requires stabilizing the optical length of the communication channels between parties. In proof-of-principle experiments based on spooled fibers, this was achieved by interleaving the quantum communication with periodical adjustment frames.
Using interferometry techniques derived from frequency metrology, we develop a solution that ensures longer duty-cycles and a tighter control of the optical phase on long-haul deployed fibers and demonstrate it on a 206 km field-deployed fiber with 65 dB loss. Our technique reduces the quantum-bit-error-rate contributed by channel length variations to <1%, representing an effective solution for real-world QKD

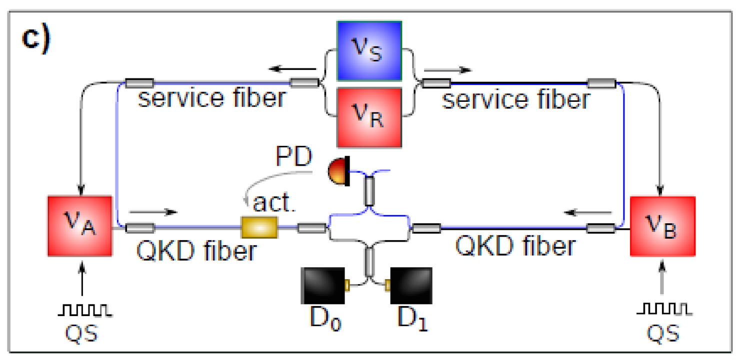
Principle schemes of TF-QKD



a) Ideal TF-QKD: Alice and Bob encode quantum states on local lasers with equal frequencies $\nu_A = \nu_B$

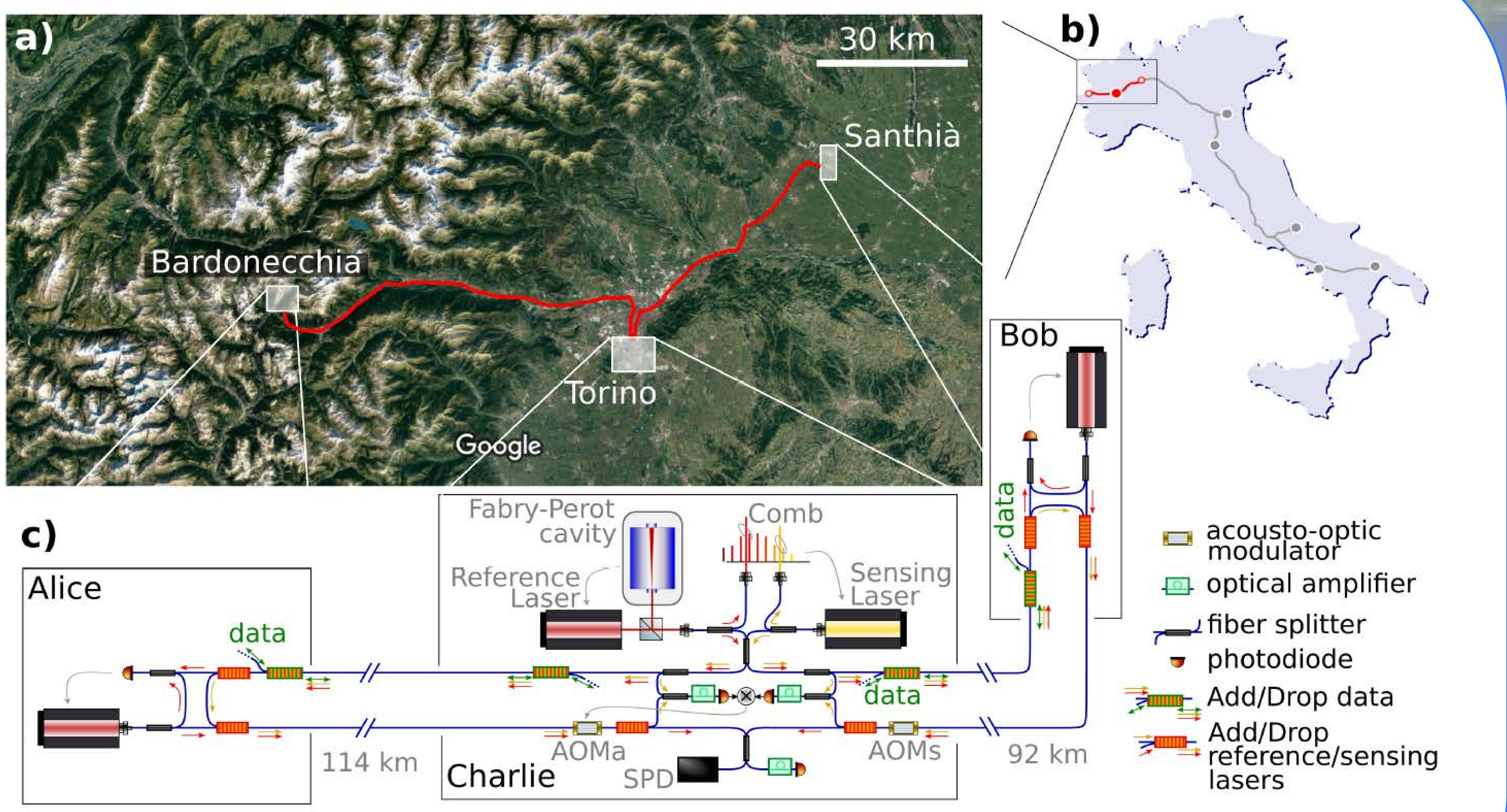


b) Practical implementations: a reference laser with frequency ν_R is sent to Alice and Bob



c) Our approach: an additional sensing laser, with frequency ν_S travels the service fiber with the reference laser, and the QKD fibers together with the QKD lasers

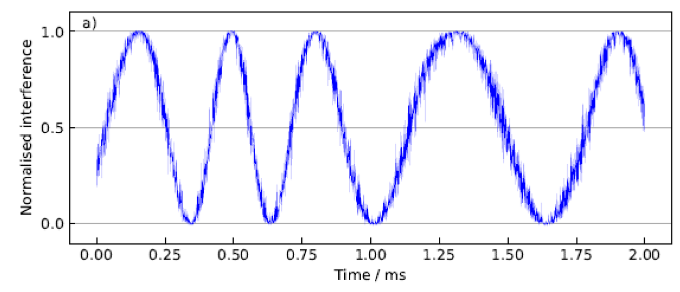
Map and experimental set-up



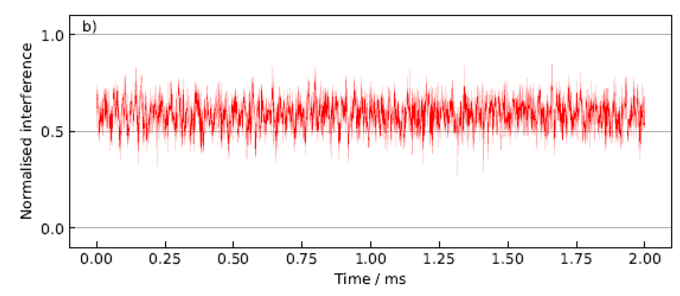
a) The testbed layout, with the Charlie node located at INRIM (Torino) and the Alice and Bob nodes in Bardonecchia and Santhià b) A sketch of the Italian Quantum Backbone c) The experimental setup.

QKD lasers interference

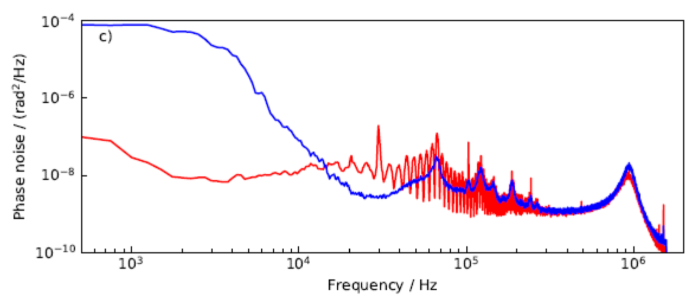
Unstabilized condition: an instantaneous phase drift by 30 rad/ms is observed



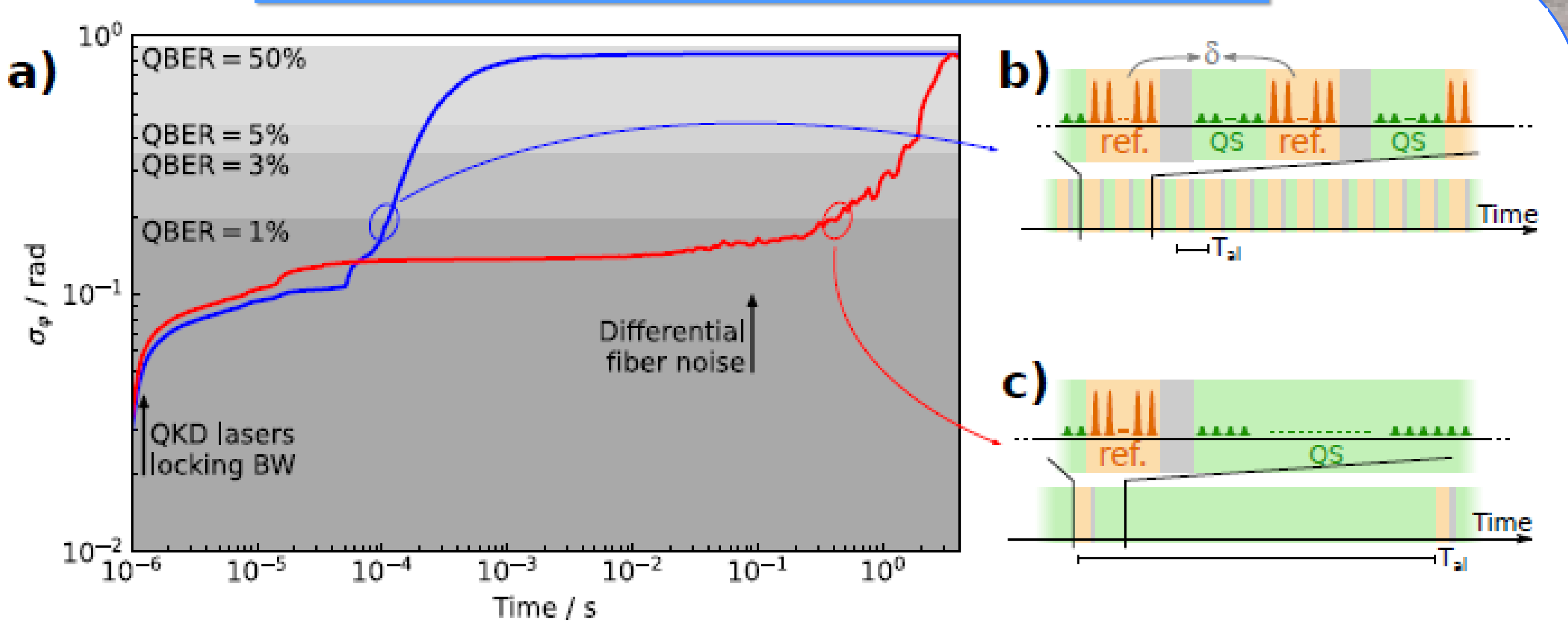
Stabilized condition: the phase remains stable over the whole acquisition frame



The power spectral density of the phase: A significant reduction in the noise is observed in a stabilized condition

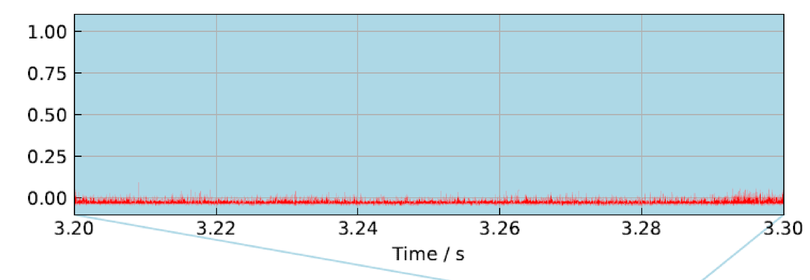


Phase fluctuations over time

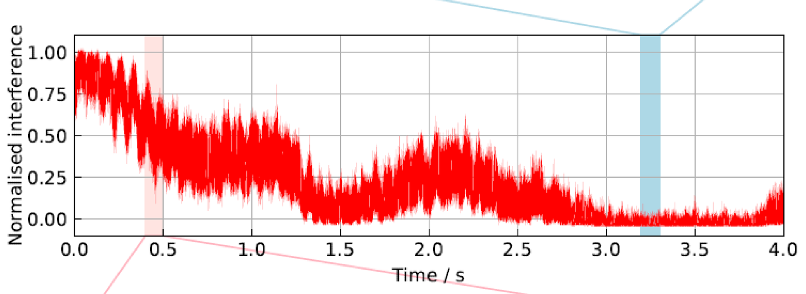


a) Deviation of the phase σ_ϕ between the two QKD lasers interfering in Charlie at different timescales, in an unstabilized (blue) and stabilized (red) condition. The shadowed areas indicate upper thresholds for relevant values of the QBER. The interferometer must be realigned after 100 μs and 0.4 s for a QBER=1% using an unstabilised or stabilised interferometer respectively
b) and c) typical schedule for implementing TF-QKD accordingly: in both cases, realignment frames are required, but this corresponds to much longer times for a stabilised interferometer, effectively enabling duty cycles as high as 98%

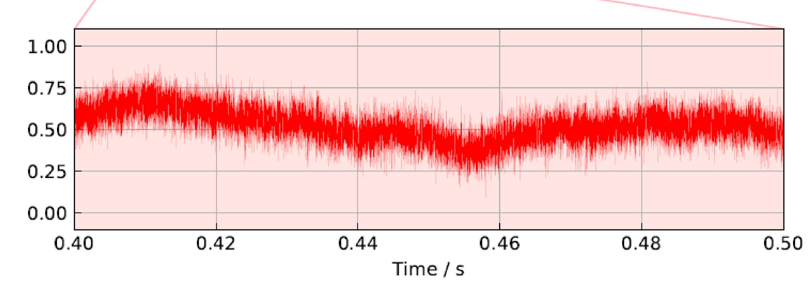
QKD lasers interference on long term



A 100 ms-long fraction of the time interval in which the interferometer operated in the maximum visibility condition



The normalised interference pattern in the stabilized-fiber condition in a 4 s-long time window



A 100 ms-long time interval in which the interferometer operated around the 0.5 visibility

Conclusions

We ensured the phase coherence of interfering lasers over hundreds of milliseconds, i.e. 1000 times more than what reported so far in laboratory trials. In our experiment we were able to maintain the deviation of the phase between the QKD lasers σ_ϕ = 0,13 rad, corresponding to a QBER of 0.5%, for about 100ms. This concurs to increase the effective key rate, which is a major advantage especially on long haul networks, where rather low rates of a few kb/s must be already taken into account due to the fiber losses .

Reference

Cecilia Clivati, Alice Meda, Simone Donadello, Salvatore Virzì, Marco Genovese, Filippo Levi, Alberto Mura, Mirko Pittaluga, Zhiliang L. Yuan, Andrew J. Shields, Marco Lucamarini, Ivo Pietro Degiovanni, Davide Calonico,"Coherent phase transfer for real-world twin-field quantum key distribution", arXiv:2012.15199

Thank you for your interest

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