Dresden University of Technology

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Title: Quantum Synchronisation Technologies for Communication Networks: Theoretical Exploration and TCEP-Based Simulation

Project topic for Oberseminar Informationstechnik 2025/2026

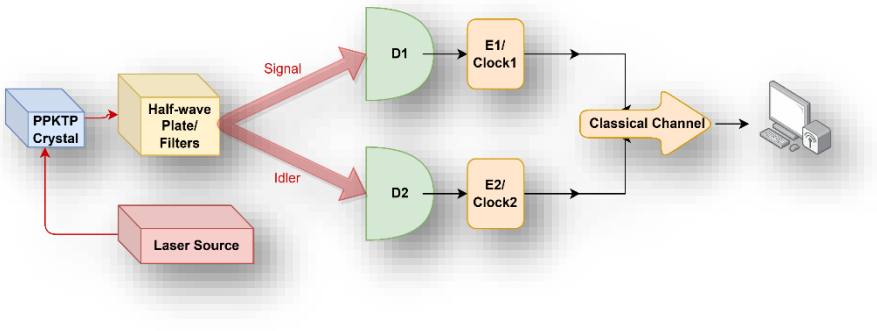
Description:

Synchronisation is fundamental to modern communication networks, supporting accurate timestamping, low-latency transmission, and coordinated operations across distributed nodes. In classical systems, synchronisation relies on protocols such as the Network Time Protocol (NTP), the Precision Time Protocol (PTP), and White Rabbit, which achieve nanosecond-level precision under favourable conditions. However, these methods remain constrained by propagation delay asymmetry, network jitter, and hardware timing noise, limiting their scalability and robustness for future 6G and quantum communication infrastructures.

Emerging quantum synchronisation technologies leverage quantum phenomena such as entanglement, coherence, and dissipative coupling to surpass the precision limits of classical methods.

Key approaches include:

- Entanglement-based synchronisation using Time-Correlated Entangled Photons (TCEP) as shown in the figure below:



TCEP: entangles photons are timestamped at distand nodes and being utilized to determine local clock offset between the respective nodes

- Optical lattice clocks achieving 10^{-18}-level frequency stability, and

- Quantum nonlinear synchronisation in coupled and dissipative qubit systems.

This Oberseminar project introduces students to these synchronisation methods and focuses on a simplified implementation of TCEP-based time synchronisation. Participants will simulate entangled-photon detection events, estimate clock offsets via coincidence correlation analysis, and evaluate precision and stability under realistic noise conditions. The project combines theoretical study with practical quantum network modelling and exploration of synchronisation architectures relevant to quantum-enhanced communication systems.

Tasks:

1. Study and Review
    - Review classical and quantum synchronisation concepts.
    - Summarise main approaches: TCEP, optical lattice clocks, and qubit-based synchronisation.
2. TCEP Simulation
    - Develop a simple simulation of TCEP-based time synchronisation (Python or MATLAB).
    - Generate photon-pair timestamps and include noise factors such as detector jitter and photon loss.
    - Estimate clock offset using correlation between detection events.
3. Analysis and Evaluation
    - Measure synchronisation accuracy using RMSE.
    - Assess timing stability with Allan deviation.
    - Briefly compare results with a classical PTP-like baseline.
4. Reporting
    - Document the model, results, and conclusions clearly.
    - Include plots of correlation peaks, error trends, and stability curves.
    - Present findings in the Oberseminar session.

Keywords: Quantum Synchronisation, Time-Correlated Entangled Photons, Cross-Correlation, Allan Deviation, Quantum Networks, 6G Synchronisation

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