Quantum Networks: Analysis, Simulation, and Applications

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Abstract

Quantum networks provide a rich framework for a wide variety of quantum technologies, with applications in quantum computing, communication, and sensing. We have developed a software toolchain that enables the design and analysis of quantum networks. At its core, the QNET package processes a description of the network, and performs computer-algebraic analysis and model reduction. The toolchain then provides several numerical backends to efficiently simulate the system dynamics as a quantum-stochastic differential equation on a high-performance-computing system. We consider two exemplary applications: entanglement distribution in lossy quantum communication networks, and distributed sensor networks for detecting differential mode disturbances. In both cases, we can provide a realistic numerical model that facilitates the design of a network implementation.

References

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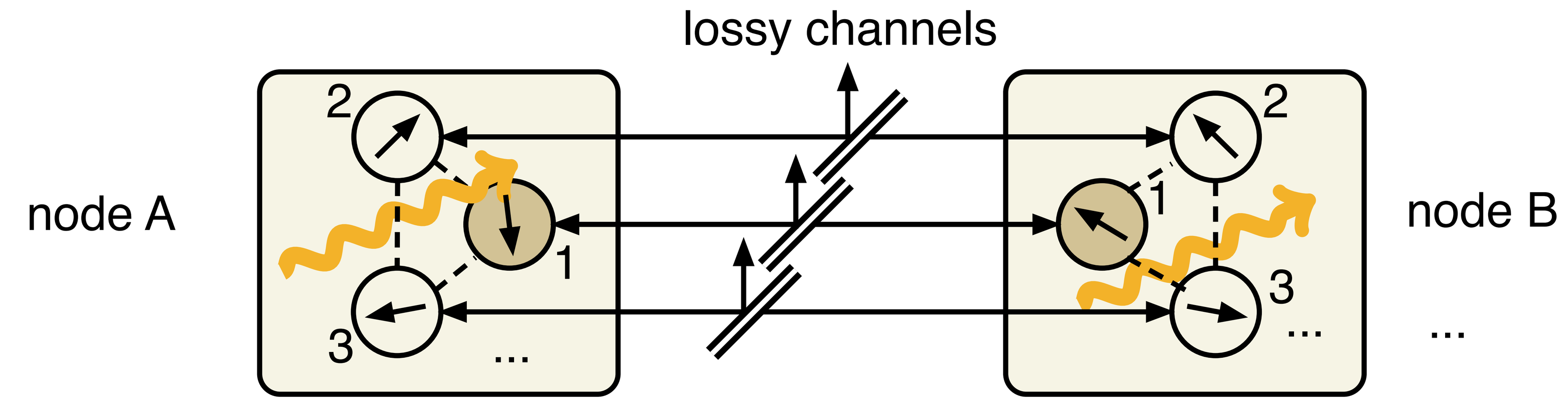
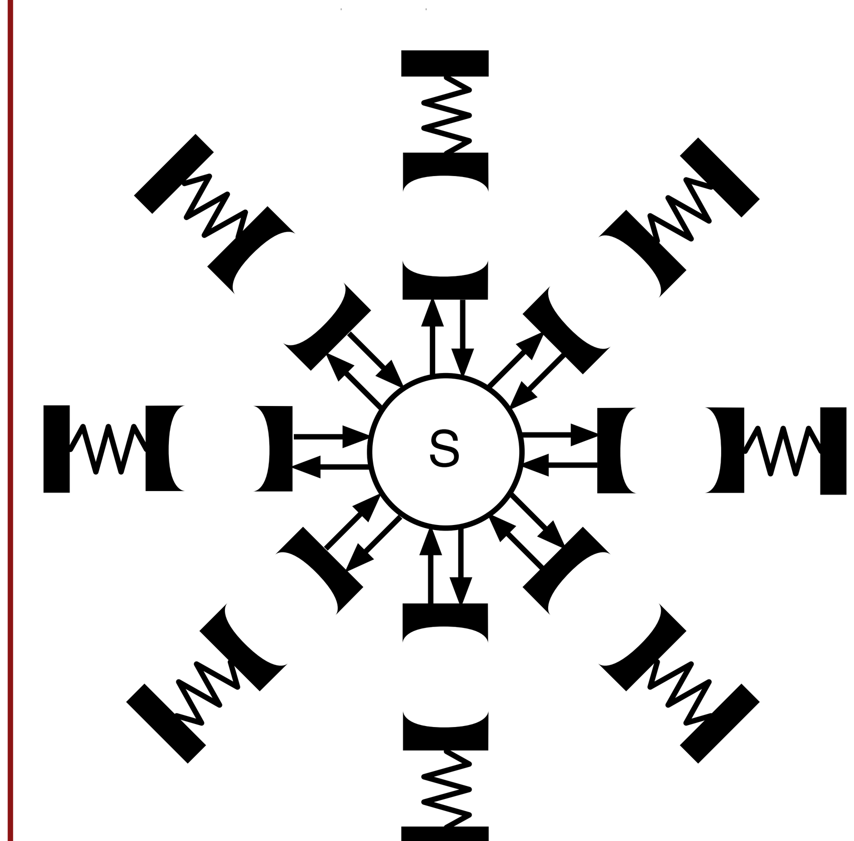
Application: Entanglement Distribution



- Goal: preparation of entangled state between qubit A1, B1, (C1, ...)
- Use qubits 2, 3, ... at each node as distillation resource
- Assume local control of qubits at each node
- Lossy channels between qubit pairs of different nodes
- Decoherence of each qubit into the vacuum mode of the EM field

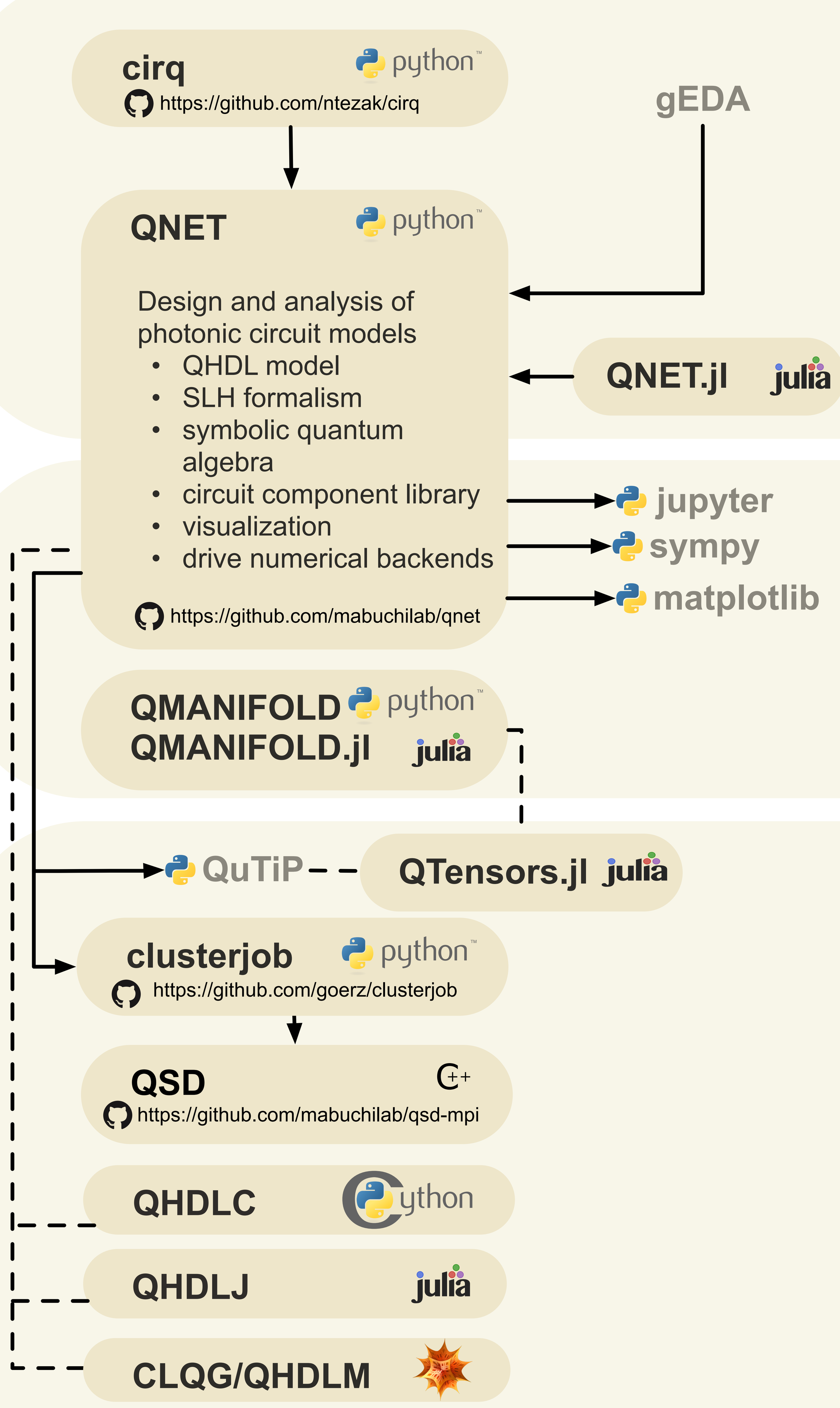
⇒ What are the limits on entanglement distribution in a realistically modeled lossy network?

Application: Distributed Sensor Network



- Star network of optomechanical oscillators
- Output of each oscillator into scatterer S
- Selective feedback (e.g. common mode) from S into all oscillators
- Optomechanical oscillators exhibit bistability
- Network structure suppresses common mode disturbance

Software Toolchain

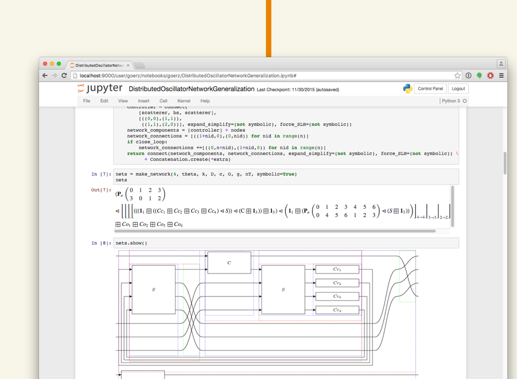


Description

- QHDL: describe physical circuit in terms of components and connections [1]
- SLH formalism: QSDE for network can be derived algebraically from components [2,3]
- ABCD parametrization of QSDE for linear quantum feedback networks
- Semi-classical Wigner-function-based SDE for non-linear coupled mode theory

Analysis

- Model reduction
  - adiabatic elimination
  - coherent manifold approach
- Steady-states, semi-classical fixpoints



Simulation & Optimization

- Quantum Dynamics
  - Master equation (ensemble average)
  - Stochastic quantum trajectories (partial or full measurement of output channels) [7]
  - Coupled quantum-classical simulation through Manifold Tracking Simulation [4]
- Semi-Classical Wigner-SDE integration [5,6]: exploit localization in phase-space
- Solution to quantum coherent LQG control problem. Used in [8]

Simulation with HPC supercomputing resources