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Resilience Metrics for Quantum Network Performance: A Comparative Study via Resilience Curves

Project topic for Oberseminar Informationstechnik 2025/2026

Description:

Students will investigate, formalize, and compare resilience metrics for quantum networks by constructing and analyzing resilience curves—performance vs. stress/fault level—for a range of operating conditions and failure models. Performance may include end-to-end distributed fidelity, task completion latency for entanglement distribution, throughput/secret-key rate, availability, and fairness across flows.

Stress can include link/node failures, stochastic loss, depolarizing/dephasing noise, queue contention, hardware drift, and adversarial disruptions. The goal is a principled, apples-to-apples comparison of metrics that illuminates trade-offs (e.g., fidelity vs. latency) and reveals which metrics are most decision-useful for design and operations.

Tasks:

1. Scoping & Modeling: (i) Define at least three resilience metrics (e.g., fidelity at percentile loss, SLA-style availability under k-failures, latency inflation factor under noise scaling); (ii) Choose two network topologies (e.g., line + mesh, or ring + scale-free) and two traffic patterns (single-pair vs. multi-flow); (iii) Specify stressors and fault models (random vs. targeted failures, noise scaling laws).
2. Simulation Framework: Implement or adapt a simulator to generate entanglement distribution tasks with queues, swapping, purification, and classical-control delays.
3. For each metric, sweep stressors (e.g., increasing loss, failure probability p, or targeted removal fraction) and plot resilience curves; Extract summary statistics (knee points, area-under-curve, worst-p% performance, elasticity/curvature).
4. Compare discriminative power, robustness to modeling assumptions, and sensitivity to topology/traffic, and analyze trade-offs and potential contradictions between metrics (e.g., a design that excels in latency but degrades fidelity).
5. Decision Guide & Validation: Propose a metric selection guide for operators (which metric to use for which objective/regime).

Keywords: Quantum Networks, Entanglement Distribution, Fidelity, Resilience Metrics
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