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Co-opetitive Game Theory for Resilience in Quantum Networks

Project topic for Oberseminar Informationstechnik 2025/2026

Description:

Study quantum network resilience when multiple administrative domains (or services) both compete for scarce quantum resources (repeaters, memory time, purification time) and cooperate to maintain minimum service levels (fidelity/availability) during faults.

Develop a co-opetitive model that blends non-cooperative equilibria (pricing/routing/priority) with cooperative coalitions (mutual aid, shared standby capacity). Prove existence, efficiency, and stability guarantees; characterize when cooperation is self-enforcing; and design cost/reward splits that sustain resilient operation.

Tasks:

1. **Modeling & Payoffs:** Formalize players (domains/flows), actions (capacity reservation, priority bids, aid commitments), and resilience payoffs $u_i(\rho)$ that depend on a metric (e.g., probability performance ≥ threshold) and show u_i is well-posed (continuity, quasi-concavity/convexity as appropriate) under your stress model (random/targeted edge failures).
2. **Non-Cooperative Baseline:** Prove existence of a Nash or generalized Nash equilibrium via Kakutani/Glicksberg (state conditions). Define Price of Anarchy (PoA) and Price of Stability (PoS) for resilience; derive upper/lower bounds on families of graphs or cost functions.
3. **Cooperative Layer (Coalitions & Core):** Define a cooperative game (N, v) where v(S) is the best achievable resilience for coalition S. Prove conditions for non-emptiness of the core (e.g., balancedness à la Bondareva–Shapley or via Scarf's lemma).
4. **Co-opetition Mechanisms (Self-Enforcing Cooperation):** Design side-payment or pricing mechanisms (two-part tariffs, VCG-style transfers with budget balance relaxations) that implement cooperative outcomes in Nash equilibrium; Prove incentive compatibility and coalition stability and analyze when budget balance and efficiency can/cannot coexist.
5. **(Optional) Bargaining Under Stress:** Model "fault state" negotiations as Nash or Kalai–Smorodinsky bargaining over surplus resilience; prove existence/uniqueness and derive closed-form splits on symmetric instances.
6. **(Optional) Synthesis Theorem:** State and prove at least one main theorem of the form: If (structural property of network or payoffs) then (existence of stable co-opetitive contract achieving PoS ≤ α and core-distance ≤ β). Include tightness or impossibility results.

Keywords: Co-opetition; cooperative & non-cooperative games; Nash equilibrium; generalized Nash; quantum networks; Shapley value; nucleolus; bargaining solutions
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