Network Utility Maximization for Optimal Resource Allocation in Quantum Networks

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Abstract
In this work, an optimization framework for designing an efficient and cost-effective quantum mesh network by extending the concept of Network Utility Maximization (NUM) to distributed quantum systems. Given link cost matrices and internode communication requirements, developed a heuristic algorithm that leverages fundamental network design principles and employs utilization as a key performance metric to construct an optimal topology. This approach introduces three quantum utility functions, each based on a different entanglement, measure—distillable entanglement, secret key fraction, and entanglement negativity to evaluate and optimize resource allocation within the network. Incorporating these utility functions into optimization model as systematically explore the trade-off between entanglement distribution rates and fidelity in single-photon-based entanglement generation.

The proposed algorithm is significantly more efficient than existing methods while maintaining solution quality comparable to more computationally intensive techniques. This analysis shows that while utility functions based on distillable entanglement and secret key fraction prioritize fidelity, entanglement negativity provides favourable mathematical properties that emphasize higher entanglement distribution rates. These contrasting behaviours gives valuable insights into selecting appropriate quantum utility definitions based on specific quantum communication applications. This framework facilitates scalable and efficient entanglement distribution but also serves as a foundation for future advancements in quantum network optimization, provides a practical implementations of quantum communication over different networks.

References

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