Unveiling the Importance of Non-Shortest Paths in Quantum Networks

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Extended Abstract

Quantum networks (QNs) exhibit stronger connectivity than predicted by classical percolation, yet the origin of this phenomenon remains unexplored. We apply a statistical-physics model—concurrence percolation—to uncover the origin of stronger connectivity on hierarchical scale-free networks, the (U,V) flowers [1, 2]. These networks allow full analytical control over path connectivity through two adjustable path-length parameters, $U \leq V$. This precise control enables us to determine critical exponents well beyond current simulation limits, revealing that classical and concurrence percolations, while both satisfying the hyperscaling relation, fall into distinct universality classes. This distinction arises from how they "superpose" parallel, non-shortest-path contributions into overall connectivity. Concurrence percolation, unlike its classical counterpart, is sensitive to non-shortest paths and shows higher resilience to detours as these paths lengthen. This enhanced resilience is also observed in real-world hierarchical, scale-free Internet networks. Our findings highlight a crucial principle for QN design: when non-shortest paths are abundant, they notably enhance QN connectivity beyond what is achievable with classical percolation.

Although our work is purely theoretical and its applications remain long-term, advances in quantum network resilience carry potential implications that should be considered in future developments.

References

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[2] Xiangyi Meng, Jianxi Gao, and Shlomo Havlin. "Concurrence percolation in quantum networks". In: *Physical Review Letters* 126.17 (2021), p. 170501.

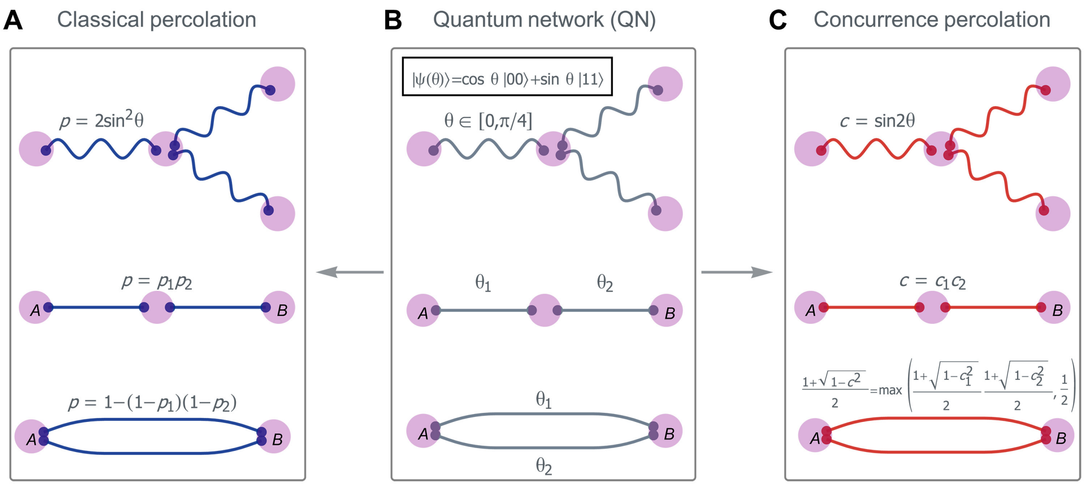

Figure 1: **Percolation mappings of a quantum network (QN).**