A Heuristic approach for resource generation in a quantum network with purifications

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1 Research Question

How can we find a policy to minimize the average time for generating multiple links?

2 Problem Setting

Markov Decision Process

- The links suffer from depolarizing noise for each timestep.
- Links with a lower fidelity than the threshold F_{th} are discarded.
- Fidelity bin is the discrete lifespan of an existing link.

State Space

- The current state is the set of fidelity bins for each link in the register.

Action Space

- Each entanglement generation attempt is an action (p_a, F_a) with probability p_a to generate a link with fidelity F_a.
- Heralded entanglement generation offers a continuous action space:

$$\mathcal{A} = \{(p_a, F_a) \in (0,1)^2 : F_a = 1 - \lambda p_a\}.$$

3 Entanglement Purification

- Entanglement purification can bring low-fidelity entangled links to higher fidelity with some success probability.
- Two schemes are used here: EPL-D and DEJMPS [1].
- Input: two identical states with fidelity F
- Output: one new link with some probability
- EPL-D creates a perfect entangled link with probability $\frac{F^2}{2}$
- DEJMPS creates a link with fidelity $\frac{10F^2-2F+2}{8F^2-4F+5}$ with probability $\frac{8F^2-4F+5}{9}$

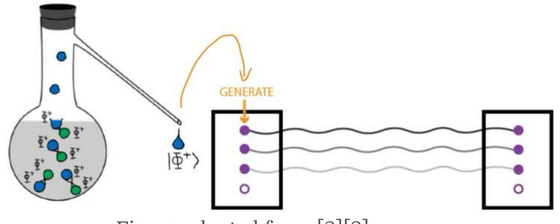

Figure adapted from [2][3]

4 Methodology

- We can find an optimal action for all actions with the same fidelity bin $(p_N, F_N)_{optimal} = argmax\{p_a : a \in \mathcal{A}, n(F_a) = N\}$ and the continuous action space is reduced:

$$\mathcal{A}^* = \{(p_N, F_N)_{optimal} : N \in Bin\}.$$

Heuristic

- We generate links with fidelity bin proportional to the estimated time to generate future links.

$$\boldsymbol{n(F_{current}) = \alpha \cdot t_{ahead}}$$

- A policy can be derived using dynamic programming with a tunable factor α.

Purification

- With purification, we assume each action will produce two identical link copies upon success
- First approach: Purify on arrival using EPL-D scheme. We model the purification as part of the action
- Second approach: Purify in the end, where we automatically purify links that about to expire

6 Summary and future goals

- The heuristic performs well particularly for generating large number of links.
- Generating too many links will reduce the heuristic to fixed actions.
- Entanglement purification can speed up generation.

- Non-linear trade-off functions can be explored for more realistic simulations.
- A non-static policy where t_{ahead} is estimated based on the current state can improve the performance.
- More purification schemes can be explored.

References

[1] F. Rozpędek, T. Schiet, L. P. Thinh, D. Elkouss, A. C. Doherty, and S. Wehner, 'Optimizing practical entanglement distillation', Phys. Rev. A, Jun. 2018
[2] ChunYang Ding. Distillation method strengthens quantum entanglement in a single pair of photons. Physics world, 2021
[3] Adapted from B. Davies with permission

5 Results