Multiparty Continuous-Variable Microwave Entanglement Distribution for Quantum Teleportation

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***Abstract*—We study multiparty continuous-variable quantum entanglement in a star topology network using open-air microwave channels. A central node with N Josephson parametric amplifiers (JPAs) generates two-mode squeezed thermal states distributed to peripheral parties via 5 GHz microwave links. Unlike previous studies focused on two-party systems, our work addresses the need for multiparty connectivity in distributed quantum computing. We analyze the impact of noise from multiple JPAs and environmental factors on the fidelity of teleportation. Our findings show that, even with up to 10 parties and distances of 400 m, fidelity degrades by less than 0.1% per party, maintaining quantum advantage ($F > 0.5$). Air thermal noise significantly outweighs source noise, confirming that multiparty microwave quantum networks are primarily limited by distance rather than the number of parties. The star topology's independent channels help mitigate cumulative noise issues seen in linear architectures, suggesting that distributed quantum networks can effectively support 10 or more parties.**

I. INTRODUCTION

Recent studies have demonstrated that quantum entanglement can be distributed over open-air microwave links [1], enabling continuous-variable quantum teleportation directly at microwave frequencies. This is particularly beneficial for superconducting quantum systems that operate in this regime.

Most existing research has centered on two-party scenarios, but practical quantum communication and distributed quantum computing require multi-user connectivity. Thus, extending open-air microwave entanglement distribution to N-party configurations is crucial for scalable quantum networks.

In this study, we investigate an N-party star-topology network where a central node (Alice) distributes entangled microwave modes to multiple peripheral nodes. This configuration simplifies link complexity and allows simultaneous connections among users. However, it also necessitates multiple Josephson parametric amplifiers (JPAs) as entanglement sources, introducing additional correlated noise due to finite squeezing and inter-device interference.

Our analysis focuses on how these noise factors impact entanglement quality and transmission fidelity as the number of parties increases, aiming to uncover scalability limits and performance trade-offs for future wireless superconducting quantum communication systems.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. Network Topology and Architecture

We consider a star-topology quantum network where a central node (Alice) distributes entanglement to N peripheral parties via independent microwave links. Alice uses N JPAs at approximately 50 mK to create N two-mode squeezed thermal (TMST) state at a frequency of $\omega_c = 2\pi \times 5$ GHz. Each party operates at cryogenic temperatures to process the quantum signals. This star topology is well-suited for distributed quantum computing, as it prevents channel noise accumulation that occurs in chain topologies.

Each link has a distance L_i with an effective transmissivity given by

$$\eta_{\text{eff}}(L_i) = 1 - e^{-\mu L_i}(1 - \eta_{\text{ant}}), \tag{1}$$

where $\mu = 1.44 \times 10^{-6}$ m^{-1} represents atmospheric absorption at 5 GHz. At ambient temperature $T_{\text{air}} \approx 300$ K, there are approximately $N_{\text{th}} \approx 1250$ thermal photons. For simplicity, we analyze the case where all $L_i = L$.

B. Noise Model

1) Source noise: Operating N JPAs adds cumulative noise:

$$n_{\text{cent}}(N) = n_0 + \delta n(N - 1), \tag{2}$$

with $n_0 = 0.01$ (baseline thermal photons) and $\delta n \approx 0.005$ accounting for crosstalk, flux coupling, dissipation, and pump fluctuations [2], [3] ($\sim$0.003–0.01 range).

2) Channel noise: Each link suffers air thermal noise $N_{\text{th}} \approx 1250$ and propagation loss via (1).

C. Teleportation Fidelity Analysis

Covariance matrix terms for party i:

$$\alpha_i = (1 + 2N_{\text{th}})\eta_i + (1 + 2n_{\text{cent}})(1 - \eta_i)\cosh(2r), \tag{3}$$

$$\beta_i = (1 + 2n_{\text{cent}})\cosh(2r), \tag{4}$$

$$\gamma_i = (1 + 2n_{\text{cent}})\sqrt{1 - \eta_i}\sinh(2r), \tag{5}$$

where $\eta_i = \eta_{\text{eff}}(L_i)$ and r is the squeezing. Fidelity:

$$F_i = \frac{2}{2 + \alpha_i + \beta_i - 2\gamma_i}, \tag{6}$$

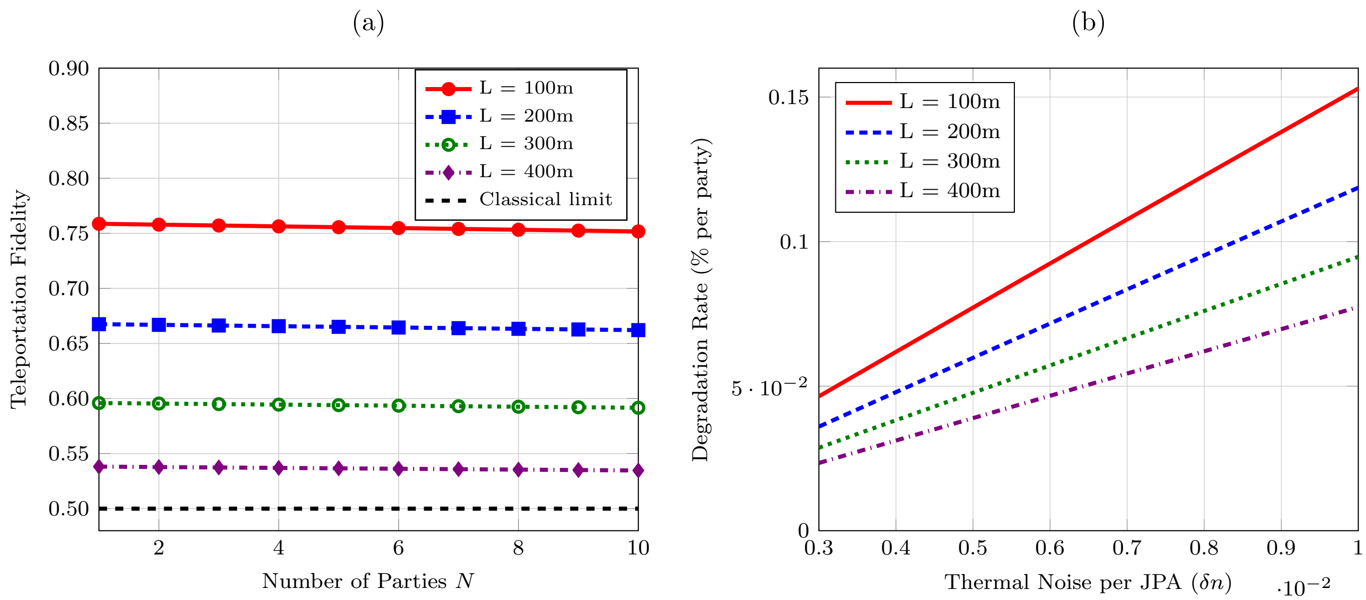

Figure 1. (a) Teleportation fidelity F versus number of parties N for different link distances L. (b) Degradation rate of fidelity per additional party versus source noise increment δn_{JPA}.

with quantum advantage if $F > 0.5$. We analyze how F scales with N, which noise dominates, and feasible regimes where $F > 0.5$.

III. Results and Discussion

We analyze teleportation fidelity using parameters from recent microwave quantum communication experiments: squeezing parameter $r = 1$, thermal photons $n_0 = 0.01$ at 50 mK, air thermal photons $N_{\mathrm{th}} = 1250$, atmospheric absorption $\mu = 1.44 \times 10^{-6}$ m^{-1}, antenna coupling loss $\eta_{\mathrm{ant}} = 0$, and source noise $\delta n = 0.005$ photons per additional JPA.

Figure 1(a) shows teleportation fidelity versus party number N for distances of 100m to 400m. Fidelity degrades by less than 0.1% per party, even at $N = 10$ and 400 m, with $F \approx 0.54 > 0.5$. The distance affects performance more than the number of parties, as thermal noise from air ($N_{\mathrm{th}} = 1250$) vastly exceeds source noise (0.055 photons for $N = 10$), resulting in a ratio of approximately 1:22,700.

Figure 1(b) evaluates sensitivity to source noise $\delta n \in [0.003, 0.01]$. Degradation is linear with δn, yet remains under 0.2% per party in the worst-case scenario. Shorter distances are more sensitive due to the larger impact of source noise when channel quality is high.

The results indicate strong scalability; the network maintains a quantum advantage for $N \leq 10$ up to 400 m. The star topology's independent channels mitigate noise accumulation seen in chain architectures. With a significant channel-to-source noise ratio, the focus for network engineering should be on reducing distance and enhancing antenna coupling rather than on improving source performance. Overall, multiparty CV microwave quantum networks can effectively support distributed quantum computing in campus-scale environments without significant source-related limitations.

IV. Conclusion

We investigated the scalability of multiparty continuous-variable microwave quantum teleportation networks using a star topology with independent air links. Our findings show that teleportation fidelity decreases by less than 0.1% per additional party, even at distances up to 400m, maintaining a quantum advantage ($F > 0.5$) for $N \leq 10$. The main noise source is air thermal noise, which outweighs cumulative source noise from multiple JPAs by over 1:22,700. Sensitivity analysis confirms these results across realistic parameter variations, indicating that these networks are distance-limited rather than party-count-limited, suggesting strong scalability for distributed quantum computing in campus environments.

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