Towards Quantum Teleportation based Barrage Relay Networks

Dev Gurung and Shiva Raj Pokhrel
School of IT, Deakin University, Geelong, Australia

***Abstract*—In this research, we are the first to examine the potential and practicality of achieving a quantum computing advantage within communication relay networks. Barrage Relay networks (BRNs) offer a low-latency and resilient network structure capable of preventing collisions through self-directed cooperation, thus enabling a robust low-latency broadcast system. We extend BRN by designing a multi-hop quantum teleportation-based relay network. This work discovers a theoretical framework for a multi-relay strategy for quantum teleportation tailored for tactical ad-hoc networking in the post-quantum era, utilizing quantum devices along with preliminary experimental analyses to support our proposed protocol using Qiskit.**

***Index Terms*—Quantum Computing, Teleportation, MANETs, Barrage Relay Networks**

I. Introduction

The deployment of mobile ad hoc networks (MANETs) in tactical and defense environments presents challenges that stem from high mobility [1], limited spectrum, multipath fading, heterogeneous mission profiles, and frequent reconfiguration [2]. Traditional multihop IP routing requires continuous link-state maintenance, which becomes burdensome under rapid topology changes and scales poorly with network size.

Barrage relay networks (BRNs), a type of MANET, enable autonomous cooperative communication among arbitrary numbers of radios [3], [4]. BRNs support uncoordinated transmissions to one or more receivers, favoring capture over collision and producing spatial propagation waves. This yields robust, low-latency broadcast with minimal state and reactive protocol design.

Quantum computing is poised to drive the next technological revolution, with broad cross-sector impact [5]. By exploiting superposition and entanglement, it enables certain types of computation with exponential speedups over classical methods. Early applications include federated quantum learning [6] and ground-to-satellite quantum teleportation [7].

A. Novelty and Originality

This is the first work to investigate the potential for quantum advantage in relay networks. Specifically, it examines the feasibility of integrating quantum-mechanical primitives such as entanglement and teleportation [8] into relay or routing mechanisms, and proposes a quantum protocol for relaying quantum information.

The contribution of this work can be summarized as follows.

Authors are from the IoT and Software Engineering Research Lab, Deakin University, Australia. This research was supported by an Australian Government Research Training Program (RTP) Scholarship.

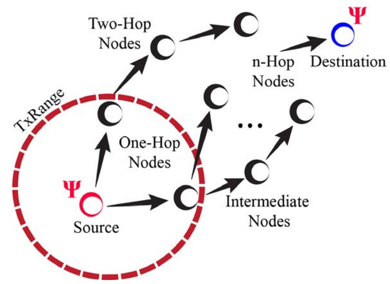


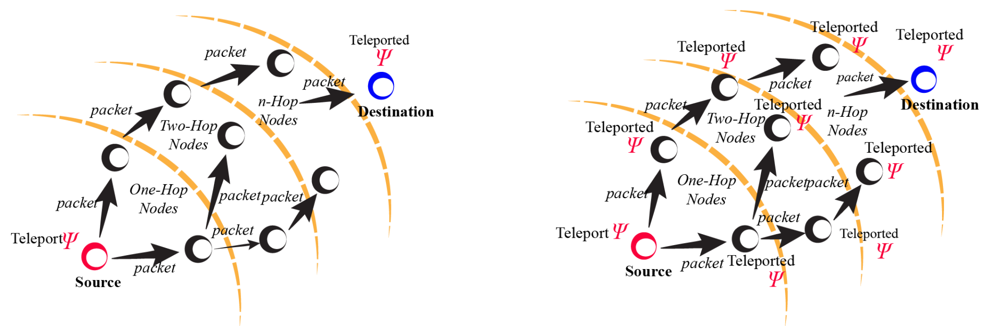
Fig. 1: Quantum Relay Networks with teleportation for successful and secure information transfer.

1) We propose a Quantum Relay Network (QRN), a barrage relay network founded on quantum teleportation, a multi-hop quantum teleportation-based relay network.
2) We validate our proposed QRN both experimentally and theoretically, exploring its practicality and feasibility in the quantum era.

B. Background

MANETs are decentralized wireless networks that do not require existing infrastructure [9]. They are self-forming and self-healing networks whose topology can continue to change without any interruption in connectivity, and participating devices can move freely. There are different types of relaying strategies for wireless networks such as Amplify-and-forward, Decode-and-Forward, and Decode-and-Reencode [10].

The main features of BRNs include robustness in the PHY-Layer, cooperative communications, and the BRN broadcast protocol [3]. The barrage relay eliminates the main need for routing protocols for constant mobility and scalability and does not require unique hardware for optimization. BRNs uses TDMA (Time Division Multiple Access), a channel access method for shared-medium networks where several users share the same frequency channel by dividing signal info into different time slots transmitting one after another in rapid succession using their own time slot. BRNs function by enabling multiple nodes to simultaneously transmit and receive the same signal, creating a robust, cooperative communication system that amplifies the reach and reliability of the signal through synchronized transmission. Each node forwards the signal in a floodlike manner without predefined routing and thus is ideal for challenging environments such as military operations or disaster response [11].



(a) In-between Classical Relay

(b) Full Quantum Relay

Fig. 2: Quantum Relay Networks: (a) Quantum relay network with only source and destination as quantum devices and (b) with all participating nodes as quantum devices.

Teleportation allows a protocol through which an unknown quantum state can be sent to a distant friend using a shared entangled state [8]. In doing so, it also requires a supplementary classical communication channel to transfer classical measurement information. More details are provided in Section II-A

Algorithm 1 Quantum Relay Network

```
Input: Number of nodes N, Source S, Destination D, Relay Nodes {R_1, ..., R_n}, Tx range R.
Generate angles θ ∈ [0, π], φ ∈ [0, 2π] uniformly at random.
Initialize secret qubit state |ψ⟩_Q = cos(θ/2)|0⟩ + e^{iφ} sin(θ/2)|1⟩.
for each node i = 0 to N − 1 do
    Approach 1: Classical Relay
    S and D are quantum; R_i are classical.
    S measures |ψ⟩_Q in basis |0⟩, |1⟩, sends results to R_i.
    R_i relay measurement outcomes classically.
    D applies unitary U_D conditioned on received measurements.
    Approach 2: Quantum Relay
    All nodes S, R_i, D are quantum.
    Create entangled state |Φ+⟩_ij = (|00⟩+|11⟩)/√2 between nodes i and j via Hadamard and CNOT.
    Apply unitary U(θ, φ) to node i's qubit: U|ψ⟩_i = |ψ⟩_i.
    Entangle |ψ⟩_i with node i's qubit of |Φ+⟩_ij.
    Measure node i's qubits in |0⟩, |1⟩ basis, store results in classical registers.
    Apply Pauli gates X^{m_1} Z^{m_2} on node j's qubit, where m_1, m_2 are measurement outcomes.
    Repeat same for all pairs (i, j).
end for
```

II. Proposed Framework: Quantum Relay Network

We introduce an extension for relay networks that uses quantum teleportation to accommodate quantum devices. Within this framework, two primary components are identified:

1) **Relay Protocol**: This protocol employs a classical multi-hop strategy with time-delayed communication. Each node R_i at hop k waits to receive a classical message m from the previous node R_{i-1} at hop $k-1$, relaying it toward the destination D. The process incurs a latency proportional to the number of hops, with time complexity $O(N_h)$, where N_h is the number of hops. In terms of protocol, we follow barrage based TDMA approach and call the approach Quantum barrage relay network (QBRN) while in other approach, we simply follow time delayed approach termed as quantum relay network (QRN).
2) **Quantum Relay Protocol**: This protocol enables quantum state transfer from source S to destination D via intermediate nodes $\{R_i\}$. Two approaches are defined:
   - **Classical Relay**: Only S and D are quantum devices. S prepares a qubit state $|\psi\rangle = \cos(\theta/2)|0\rangle + e^{i\varphi}\sin(\theta/2)|1\rangle$, measures it in the computational basis, and sends classical outcomes m_1, m_2 through $\{R_i\}$ to D. D applies Pauli gates $X^{m_1}Z^{m_2}$ to reconstruct $|\psi\rangle$. The time complexity is $O(N_i)$, where N_i is the number of quantum nodes.
   - **Quantum Relay**: All nodes $\{S, R_i, D\}$ are quantum devices. S entangles $|\psi\rangle$ with R_1 via a Bell state, e.g., $|\Phi^+\rangle = \frac{|00\rangle+|11\rangle}{\sqrt{2}}$. Each R_i measures its qubits, forwarding classical outcomes to R_{i+1}, which applies $X^{m_1}Z^{m_2}$ to reconstruct $|\psi\rangle$. This repeats until D. This approach, with time complexity $O(N)$, is computationally intensive but necessary when all nodes require $|\psi\rangle$.

A. Details of QRN process

The teleportation protocol in QRN between two devices is depicted in Figure 3. Let us suppose that the source node S and the destination node D. The goal is to transfer quantum information from S to D and due to spatial space between the two, n intermediate relay nodes $\{R_1, R_2, ..., R_n\}$ are available in mobile approach. S has a qubit Q that is in state $|\psi\rangle_Q = \alpha|0\rangle_Q + \beta|1\rangle_Q$. The values of α and β are unknown to S or D. Before the process can move ahead, S and D require having a shared pair of entangled qubits that is prepared in one of the Bell states termed entangled paired bit (EPR) as $|\phi\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$ where, S and D both keep the first qubit and the second one separately [12]. This can be assumed that initially these two parties were together, they entangled two qubits and later went to their own places, i.e. distant apart.

If we suppose that both qubit states are at $|0\rangle$ then the above entanglement works first by S applying the H gate on its qubit,

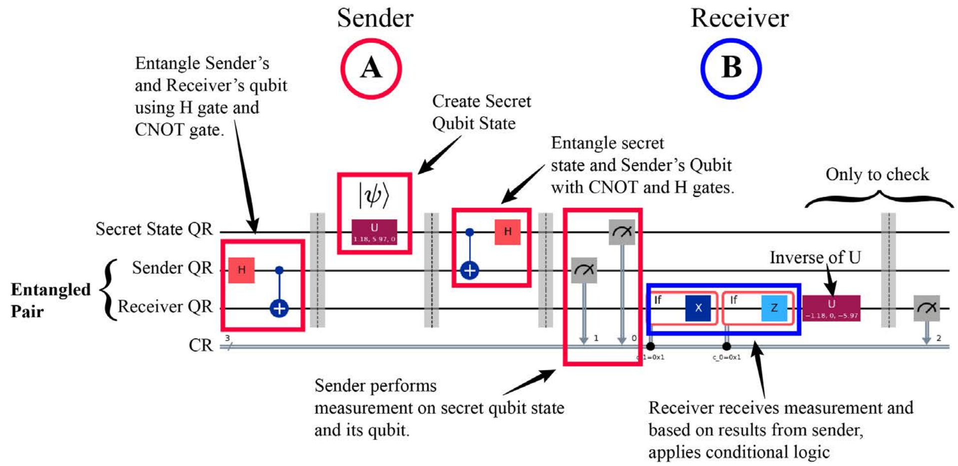


Fig. 3: Quantum teleportation protocol: A quantum teleportation depicted where a number of multiple steps are involved such as entangling qubit pair, creating secret qubit state to be teleported, performing measurements, applying conditional logic etc. through various gates like CNOT, H and U gates.

which is followed by application of the CNOT gate as S qubit as control qubit and D qubit as target as

$$
\begin{aligned}
&CNOT(S,D)H_S|0\rangle_D|1\rangle_S \\
&= CNOT(S,D)|0\rangle_D\frac{1}{\sqrt{2}}(|0\rangle_S+|1\rangle_S) \\
&= \frac{1}{\sqrt{2}}(CNOT(S,D)|0\rangle_D|0\rangle_S + CNOT(S,D)|0\rangle_D|1\rangle_S) \\
&= \frac{1}{\sqrt{2}}(|0\rangle_D|0\rangle_S+|1\rangle_D|1\rangle_S)
\end{aligned}
$$

Now, the quantum state of three qubits Q, S and D can be written as,

$$|\psi\rangle_{SD}|\psi\rangle_Q = \frac{1}{\sqrt{2}}(|0\rangle_D|0\rangle_S+|1\rangle_D|1\rangle_S)(\alpha|0\rangle_Q+\beta|1\rangle_Q)$$

The goal here is to move the information on Q from the source S to the location of D. Now, the source node S entangles its qubit and qubit Q using the CNOT gate with its own qubit as control and Q as target; then the Hadarmard gate is applied to Q, then the state of three qubits after the operation can be expressed as

$$
\begin{aligned}
&H_Q CNOT(S,Q)|\psi\rangle_{SD}|\psi\rangle_Q \\
&= H_Q CNOT(S,Q)\frac{1}{\sqrt{2}}(|0\rangle_D|0\rangle_S+|1\rangle_D|1\rangle_S)(\alpha|0\rangle_Q+\beta|1\rangle_Q) \\
&= \frac{1}{2}\big[(\alpha(|0\rangle+|1\rangle)(|00\rangle+|11\rangle) \\
&+\beta(|0\rangle-|1\rangle)(|10\rangle+|01\rangle))\big]
\end{aligned}
$$

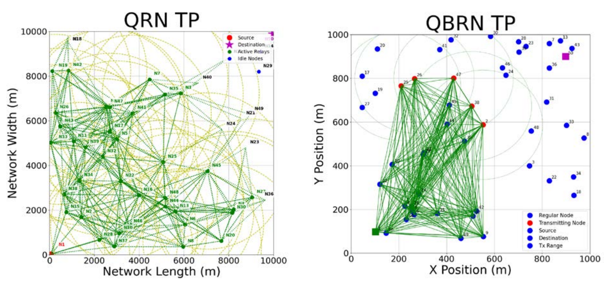
At this stage, S measures the qubits S and Q. There can be four possible outcomes $|0\rangle_S|0\rangle_Q, |0\rangle_S|1\rangle_Q, |1\rangle_S|0\rangle_Q, |1\rangle_S|1\rangle_Q$. Now, based on these measurements, D performs operations on its own EPR bit as if $|0\rangle_S|0\rangle_Q \rightarrow$ Do Nothing, $|0\rangle_S|1\rangle_Q \rightarrow$ Z gate, $|1\rangle_S|0\rangle_Q \rightarrow X$ gate, $|1\rangle_S|1\rangle_Q \rightarrow X$ and Z. In the relay network, as shown in Figure 2, there can be two methods for QRN. As depicted in Figure 2a, for the classic relay approach, only the source S and the destination D are quantum devices, with relay nodes R_i operating classically. The teleportation protocol is shown in Figure 3. The source S measures its qubit state $|\psi\rangle$ in the computational basis, transmitting classical outcomes to D via R_i. The destination D applies conditional Pauli operators based on received measurements. However, for the quantum relay approach, as shown in Figure 2b, all nodes S, R_i, D are quantum devices. Each node participates in the quantum state transfer. The source S initializes a qubit in state $|\psi\rangle = \cos(\theta/2)|0\rangle + e^{i\varphi}\sin(\theta/2)|1\rangle$ and entangles it with a relay node R_i through a Bell state, for example, $|\Phi^+\rangle = \frac{|00\rangle+|11\rangle}{\sqrt{2}}$. Node R_i measures its qubits and sends classical outcomes to the next node, which applies conditional Pauli operators $(X^{m_1}Z^{m_2})$ to reconstruct $|\psi\rangle$. This process repeats over multiple hops, requiring multipair entanglement for N nodes.

III. Experimental Analysis

We recognize real challenges in the practical application of the teleportation protocol within the suggested framework [7]. Here, we present the initial findings of our experimental simulation using Qiskit[1]. In the context of relay network design, we have adopted two implementations: one is the QRN, in which the relay experiences a time delay. The source broadcasts packets to nodes within its transmission range. The other implementation resembles a barrage relay network [3], which employs a TDMA approach with multiple slots across frames. We then integrate a teleportation protocol for QBRN. The simulation visualization for QRN is shown in Figure 4b and for QBRN in Figure 4a. In Figures 5b and 5a, simulation effects on the measurement process are presented during a teleportation protocol using AerSimulator. It is evident that altering the number of sampler shots from

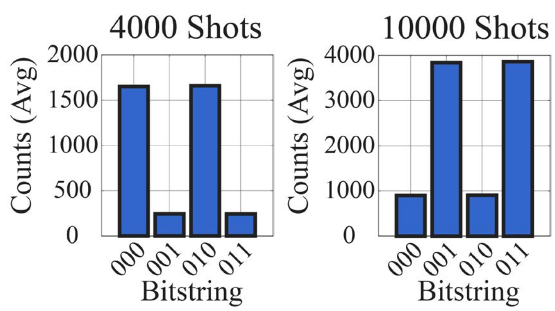
[1]https://qiskit.org/

4000 to 10000 produces varying results. Similarly, in Figures 6a and 6b, we observe the impact on the time required to complete the simulation, depending on the number of devices ranging from 20 to 700. A larger number of devices result in communication overhead as expected. Although teleportation or any other quantum protocols are performed in quantum computers, especially quantum processing units, we present the result on how CPU usage is affected with or without teleportation in our simulation framework, as shown in Figure 7. We can observe that in terms of CPU usage, there is not much difference in our preliminary results. The results showing the frames from 0 to 60 are three sets of experiments repeated with the same settings. In second and third repetitions from frames (20-40) and (40-60), simulation with TP (with TP) shows slightly more CPU usage than without TP (No TP).



(a) QRN (b) QBRN

Fig. 4: Visualization of relay networks

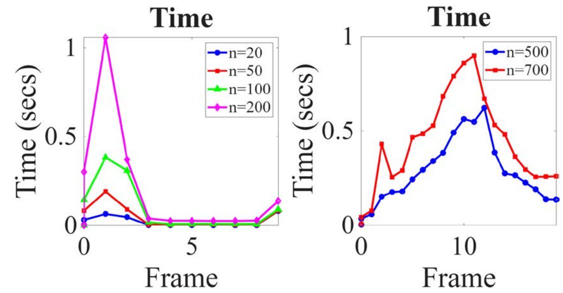


(a) 4000 Shots (b) 10000 Shots

Fig. 5: Simulation results of teleported circuit with varying number of shots

IV. Conclusion

In this study, we introduced relay network mechanisms founded on quantum teleportation: the quantum relay network (QRN) and the quantum barrage relay network (QBRN). Given recent developments in quantum computing, we find it crucial to explore its potential applications and the formulation of new protocols. Through theoretical and experimental evaluations, we investigate quantum relay networks that are capable of interfacing with both quantum and classical devices in the context of communication protocols.



(a) 10 frames (b) 20 frames

Fig. 6: Impact of number of devices on Simulation Time

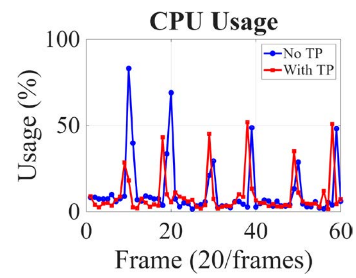


Fig. 7: CPU Usage

References

[1] S. R. Pokhrel and S. Shakya, "Enhanced optimization of field based routing for macro mobility in ieee 802.11 s mesh," in *2013 Tenth International Conference on Wireless and Optical Communications Networks (WOCN)*. IEEE, 2013, pp. 1–5.

[2] A. Blair, T. Brown, K. M. Chugg, and M. Johnson, "Tactical Mobile Mesh Network System Design," in *MILCOM 2007 - IEEE Military Communications Conference*, Oct. 2007, pp. 1–7.

[3] A. Blair, T. Brown, K. M. Chugg, T. R. Halford, and M. Johnson, "Barrage relay networks for cooperative transport in tactical MANETs," in *MILCOM 2008 - 2008 IEEE Military Communications Conference*, Nov. 2008, pp. 1–7.

[4] T. R. Halford and K. M. Chugg, "Barrage Relay Networks," in *2010 Information Theory and Applications Workshop (ITA)*, Jan. 2010, pp. 1–8.

[5] C. P. Williams, *Explorations in Quantum Computing*, ser. Texts in Computer Science. London: Springer, 2011.

[6] D. Gurung and S. R. Pokhrel, "Chained continuous quantum federated learning framework," *Future Generation Computer Systems*, vol. 169, p. 107800, Aug. 2025.

[7] J.-G. Ren, P. Xu, and et al., "Ground-to-satellite quantum teleportation," *Nature*, vol. 549, no. 7670, pp. 70–73, Sep. 2017.

[8] C. H. Bennett, G. Brassard, C. Crépeau, R. Jozsa, A. Peres, and W. K. Wootters, "Teleporting an unknown quantum state via dual classical and Einstein-Podolsky-Rosen channels," *Physical Review Letters*, vol. 70, no. 13, pp. 1895–1899, Mar. 1993.

[9] S. R. Pokhrel, S. Verma, S. Garg, A. K. Sharma, and J. Choi, "An efficient clustering framework for massive sensor networking in industrial internet of things," *IEEE Transactions on Industrial Informatics*, vol. 17, no. 7, pp. 4917–4924, 2021.

[10] P. Herhold, E. Zimmermann, and G. Fettweis, "Cooperative multi-hop transmission in wireless networks," *Computer Networks*, vol. 49, no. 3, pp. 299–324, Oct. 2005.

[11] T. A. Brown, T. R. Halford, and M. L. Johnson, "Method and system for coordinating access to a barrage relay network," *US Patent: US8873391B2*, 2012. [Online]. Available: https://patents.google.com/patent/US8873391B2/en

[12] J. Stolze, D. Suter, and D. Divincenzo, "Quantum computing: A short course from theory to experiment," *American Journal of Physics - AMER J PHYS*, vol. 73, pp. 799–800, 08 2005.