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Research Project – Topic Brief

INTRO

The Vehicle Routing Problem (VRP) is a fundamental combinatorial optimization challenge in logistics, aiming to determine the most efficient routes for a fleet of vehicles to service a set of customers. Over the years, VRP and its different versions have become a popular topic in research. However, since the problem can be defined in many versions (many ways with many different assumptions), researchers need to be aware that VRP itself has a broad range of variants [1]. Given its NP-hard nature, classical algorithms often struggle with large-scale instances due to computational limitations.

Quantum computing offers a paradigm for approaching and solving such problems. Algorithms like the Quantum Approximate Optimization Algorithm (QAOA) [2] and Quantum Walk-based Optimization [3] have shown promise in tackling NP-hard tasks. This research proposes to explore these quantum techniques to develop efficient approximation methods for the VRP.

BACKGROUND

Classical Approaches to VRP

Traditional methods for solving the VRP include:

- Exact Algorithms: Techniques such as Branch-and-Bound for CVRP [4]
- Metaheuristic Approaches: Algorithms like Genetic Algorithms (GA) and Ant Colony Optimization (ACO) offer approximate solutions more feasibly but may not guarantee optimality [5]

Quantum Programming Approaches to VRP

Quantum Optimization Techniques offer a better solution than a classical one:

- Quantum Approximate Optimization Algorithm (QAOA): QAOA is designed to find approximate solutions to combinatorial problems by leveraging quantum superposition and entanglement [6].
- Quantum Walk-based Optimization: Quantum walks, the quantum analog of classical random walks, have been applied to search and optimization problems, offering potential speedups over classical methods [7].
- Variational Quantum Eigensolver (VQE): VQE is another quantum algorithm that has been studied for solving VRP. Currently, Noisy-Intermediate Scale Quantum (NISQ) devices can only handle small VRP instances, but as quantum hardware improves, both VQE and QAOA are expected to perform better and potentially surpass classical methods. [8]

PROPOSED RESEARCH OBJECTIVES

1. Develop quantum optimization approaches for VRP using QAOA and Quantum Walk-based methods.
2. Compare quantum and classical algorithms by analyzing solution quality, computational efficiency, and scalability.
3. Investigate the effectiveness of quantum approximations in solving VRP and their ability to find near-optimal solutions.

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4. Implement a quantum-based VRP solution with the potential to outperform classical methods in specific scenarios.

PROPOSED METHODOLOGY

Quantum Computing Approaches

- Formulation: Represent the VRP in a quantum framework suitable for QAOA, Quantum Walk algorithms, and VQE.
- Theoretical Calculations: Analyze mathematical models and complexity to understand how quantum algorithms can outperform classical methods in VRP domain. This includes identifying cases where quantum optimization provides faster solutions or better approximations.
- Implementation: Develop and simulate quantum circuits using platforms like PennyLane or Qiskit (or other compatible library)

Benchmarking Strategy

- Classical Comparison: Utilize established solution using classical methods to obtain baseline solutions.
- Performance Metrics: Compare quantum and classical approaches based on solution quality, computational time, and scalability.

Datasets

- Data Acquisition: Employ real-world datasets from sources like Victoria's open data portal. [9]
- Data Processing: Transform raw data into graph representations that will be compatible with quantum algorithms.

EXPECTED OUTCOMES, CONTRIBUTIONS, AND CHALLENGES

Expected Outcomes and Contributions

- Development of quantum-based approximation methods: Providing new strategies for solving VRP using quantum computing.
- Comparative Analysis: Offering insights into the practical advantages and limitations of quantum versus classical approaches for VRP.

Challenges and Limitations

Quantum Hardware Constraints: Real quantum cloud is expensive. Use a simpler graph to simulate in real quantum computer and use a simulator to simulate bigger graph.

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