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IEG 313 COURSE PROJECT

TEAM QUANTZZZ

TOPIC : QUANTUM BASED TRAFFIC LIGHT SYSTEM

Report on Quantum Traffic Light System

1. Abstract

This project presents a **Quantum Traffic Light System** that leverages quantum computation principles to model and regulate traffic signal timing at a three-way intersection. Unlike traditional fixed-time or rule-based traffic signal systems, the proposed model utilizes **quantum superposition** and **probabilistic measurement** to dynamically determine which road receives the green signal and for how long. A feedback-based learning mechanism adjusts quantum rotation parameters iteratively to reflect varying traffic conditions. Experiments using Qiskit's Aer simulator demonstrate that the system adaptively distributes green time based on inferred demand, maintains fairness, and avoids deterministic cycling. The findings suggest that quantum-inspired decision models can offer efficient and flexible traffic control strategies compared to classical methods.

2. Introduction

2.1 Motivation

Urban intersections frequently experience uneven and unpredictable traffic patterns. Static traffic light systems assign fixed durations to each road regardless of real-time congestion, leading to avoidable delays and increased fuel consumption. Adaptive signal systems exist but typically rely on heavy infrastructure (cameras, loop sensors) or compute-intensive optimization algorithms. This motivates the search for a **lightweight, flexible, and self-adjusting traffic control mechanism**.

2.2 Relevant Literature / Related Work

- Computer-controlled adaptive systems such as **SCATS** and **SCOOT** adjust traffic signals based on sensor data but require expensive installation and maintenance.

- Probabilistic and reinforcement learning-based traffic controllers offer dynamic behavior but demand large training datasets and continuous optimization.

- Emerging research in **quantum-inspired optimization** suggests that probabilistic superposition and entanglement mechanisms can support adaptive multi-choice decision systems.

However, the application of **quantum principles to real-time traffic signal control** remains largely unexplored.

2.3 Overview of Report

Section	Description
Problem Statement	Defines the core inefficiency in traditional traffic signal systems.
Current Research Gap	Examines limitations in existing adaptive control approaches.
Proposed Methodology	Describes the quantum circuit model and feedback-based adaptation.
Experimental Details	Explains tools, simulation settings, and execution steps.
Results and Discussion	Presents findings and analyzes system behavior.
Future Directions	Suggests improvements and extensions.
References	Cited works used in the background.

3. Problem Statement

Traffic signal systems based on fixed-time cycles fail to respond to fluctuating traffic densities across different roads. This often results in unnecessary waiting time for vehicles on less congested paths and excessive congestion on heavily trafficked ones. Conventional adaptive systems require costly sensing infrastructure and computationally heavy optimization logic.

Problem:
How can traffic signal control be made dynamically adaptive without relying on complex hardware sensors or high computational overhead?

4. Current Research Gap

Existing adaptive systems rely heavily on:

- **Physical sensors** (expensive and maintenance-intensive),
- **Centralized optimization algorithms** (computationally slow for real-time use),
- **Pre-trained models** (which may fail under sudden pattern changes).

There is **no widely explored traffic control method** that:

- Uses as well as implements **probability-driven decision-making**,
- **Self-adjusts** from feedback alone,

- Avoids deterministic cycling,
- Requires **minimal infrastructure**.

5. Proposed Model / Methodology

State Encoding

A 2-qubit system encodes intersection states:

The traffic light controller is modeled using a two-qubit quantum system. Each qubit can exist in the state $|0\rangle$ or $|1\rangle$, and together, the two qubits form a quantum state in a four-dimensional Hilbert space. These four possible basis states are used to represent the traffic signal choices for the three roads in a three-way intersection.

The state $|00\rangle$ is assigned to Road A, meaning that when the quantum measurement collapses to this state, Road A receives the green signal. Similarly, the state $|01\rangle$ corresponds to Road B, and $|10\rangle$ corresponds to Road C, granting them the green signal when measured. The remaining basis state $|11\rangle$ is not assigned to any road; instead, it represents a RESET or all-red safety interval, during which all signals remain red. This state acts as an interlock condition and allows the system to safely stabilize in situations where the probability distribution is uncertain or fluctuating.

Thus, the mapping between quantum states and road signals is as follows:

- $|00\rangle \rightarrow$ Road A receives the green signal
- $|01\rangle \rightarrow$ Road B receives the green signal
- $|10\rangle \rightarrow$ Road C receives the green signal

- |11⟩ → All roads red temporarily (safety/reset condition)

This encoding ensures that the complete decision logic for the traffic light is compactly captured within the quantum measurement outcomes, eliminating the need for explicit classical rule-based control transitions.

Circuit Construction

1. **Superposition** (Hadamard gates) ensures all roads initially share equal probability.

2. **RY rotation gates** adjust selection bias based on inferred congestion.

3. Optional **controlled entanglement** models correlated traffic behavior.

Decision Process

- Circuit is executed → Measurement yields probability distribution.

- Probabilities → Converted to signal timing.

- A **softmax sampling** mechanism prevents road starvation.

- A **persistence factor** avoids rapid flickering or oscillation.

Adaptive Learning Loop

- After each cycle, selected road influences adjustments to rotation angles.
- System **self-tunes** to prioritize busier roads over time.

6. Experimental Details

The experiments were carried out entirely in a simulated environment using Python and the Qiskit quantum computing framework. **Since the system is driven by probabilistic logic rather than real-world traffic counts, no external dataset was required.** Instead, the model implicitly generates traffic variations through adjustments in the quantum rotation parameters and adaptive feedback. This allows the system to simulate both balanced and congested traffic conditions without needing recorded sensor input.

The simulation uses a **three-way traffic intersection** modeled with a **two-qubit quantum circuit**, where each qubit configuration corresponds to a specific road receiving a green signal. The experiments were conducted using the **Qiskit Aer Simulator**, which provides a high-fidelity classical emulation of real quantum hardware. Each quantum circuit was executed multiple times (typically 2,048 to 4,096 measurement shots per iteration) in order to obtain a statistically meaningful probability distribution over the possible outcomes.

The model was evaluated across several operational phases. First, the **equal superposition condition** was tested to validate that the circuit correctly assigns equal priority to all roads when no bias is introduced. Next, the **biased traffic scenario** was simulated by increasing the rotation on one qubit to represent heavier traffic on a particular road. Finally, the **adaptive learning mechanism** was run over multiple iterations to observe how the system adjusts signal durations based on previous outcomes. Throughout the experiments, **NumPy** was used for numerical computation and probability manipulation, while **Matplotlib** was used to generate visualizations of probability shifts, green-light duration allocation, and entropy trends.

By structuring the environment in this way, the experiment ensures that the model can be reproduced consistently across different systems, requires no specialized sensing hardware, and remains computationally efficient while still capturing realistic adaptive signal behavior.

7. Results and Discussion

Equal Superposition Test

- All roads received nearly equal probability.
- Corresponding durations were balanced → system fairness confirmed.

Biased Traffic Scenario

Increasing RY rotation on qubit-1 resulted in:

- Higher probability for Road B,
- Longer green-light time for Road B,
- Demonstrating correct congestion-based prioritization.

Adaptive Feedback Experiment

Over multiple cycles:

- Probabilities converged toward the consistently busier road.
- Entropy decreased, showing **confident preference** formation.
- No starvation occurred due to controlled randomness.

Conclusion:
The system successfully behaves as a **self-regulating traffic controller** without needing sensors or classical optimization.

8. Future Directions

The system can be extended by:

- Integrating **live traffic sensors** to dynamically update rotation parameters.
- Scaling to **multi-intersection networks** using multi-qubit entanglement.
- Deploying on **real quantum hardware** to evaluate noise resilience.
- Incorporating reinforcement learning for hybrid quantum-classical optimization.

9. References

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