Decentralized Federated Learning Framework for Traffic Optimization in Smart Cities
Project Proposal | Tyler Trott
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Problem Definition

Urban centers increasingly suffer from inefficient traffic light synchronization, leading to congestion and unnecessary delays. Traditional sensor-based systems at intersections often fail to capture the broader dynamics of city-wide traffic flows, resulting in suboptimal signal timing and exacerbated commuter frustrations. This project addresses these shortcomings by proposing a decentralized framework that leverages IoT devices and federated learning to dynamically adjust traffic signals. By enabling secure, peer-to-peer data sharing and real-time analysis through inflow-outflow models, the framework aims to optimize urban traffic flow and reduce delays.

Background and Related Work

Urban traffic management has long been a challenge in smart city planning. Centralized traffic control systems, while prevalent, often lack the flexibility and scalability needed to adapt to fluctuating conditions across an entire city. With the advent of IoT devices and the emergence of federated learning techniques, researchers have begun exploring decentralized approaches that promise greater responsiveness and robustness. This project builds on prior research in decentralized network architectures and federated learning, incorporating insights from recent advances in mathematical modeling and real-world simulation to propose a novel solution for traffic light synchronization.

Proposed Approach

This project will develop a decentralized federated learning framework designed to optimize traffic signal timings in smart cities. The approach involves:

- **Decentralized Network Architecture:** Designing a secure, self-contained network of IoT devices installed at intersections. These devices will communicate exclusively with one another and with a central learning algorithm, ensuring robust peer-to-peer data exchange free from external interference.
- **Federated Learning and Mathematical Modeling:** Leveraging real-time traffic data alongside inflow-outflow equations to dynamically adjust signal timings. The project will

develop mathematical proofs (integrated within the CSC 431 curriculum) to support the theoretical underpinnings of the proposed model.
- **Simulation and Evaluation:** Utilizing an open-source traffic light simulation tool to model and analyze the performance of the decentralized system.
  View Traffic Light Simulation

This multifaceted approach will allow for both theoretical exploration and practical validation of the framework's efficacy.

Expected Deliverables

The primary deliverable will be a comprehensive final report detailing the design, theoretical proofs, simulation results, and practical insights of the decentralized federated learning framework. Additional deliverables include:

- A project website that documents the research and development process.
- A detailed logbook tracking research progress, experiments, and findings.
- A midterm presentation to outline initial results and receive feedback.
- A final presentation summarizing the complete project, including recommendations for future implementation.

Project Timeline

February 7 – February 21

- Conduct initial research and literature review on decentralized systems, IoT devices, and federated learning frameworks.
- Begin drafting the project proposal and identifying key project components.

February 22 – March 7

- Develop a detailed plan for the decentralized network architecture.
- Initiate work on mathematical proofs for traffic optimization and review an open-source traffic light synchronization project.

March 8 – March 21

- Refine the network architecture and mathematical models.
- Conduct simulations and experiments to validate the proposed models, document findings, and adjust the project plan as needed.

March 22 – April 4

- Finalize the proof of concept and prepare detailed implementation documentation.
- Outline potential challenges and begin drafting the final project report.

April 5 – April 11

- Complete the final report, incorporating all findings, proofs, and implementation details.
- Prepare and deliver a comprehensive final presentation.

Resources and Requirements

This project will require access to:

- A set of IoT devices or a simulated environment to mimic intersection controllers.
- An open-source traffic light simulation tool to evaluate the performance of the proposed framework.
- Computational resources for running simulations and processing real-time traffic data.
- Academic literature and research on decentralized network architectures and federated learning techniques.
- Collaboration and feedback opportunities through the CSC 431 course to refine Machine Learning Theory, mathematical proofs and theoretical models.

References

Albogami, N. N. (2025, February 3). Intelligent Deep Federated Learning Model for Enhancing Security in internet of things enabled Edge computing environment. Nature News. https://www.nature.com/articles/s41598-025-88163-5