FLUERE: Traffic Routing Optimization with SDN and Fog Computing

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Abstract

This paper presents a comprehensive study on the integration of Software-Defined Networking (SDN) and Fog Computing in urban traffic management. Our proposed system, FLUERE, is designed to optimize emergency vehicle routes and enhance overall traffic flow through intelligent rerouting and rapid response measures. The collaboration between SDN and Fog Computing enables real-time monitoring, analysis, and dynamic traffic flow adjustments. We employ an SDN controller to manage network routing and traffic prioritization, while fog nodes at the network edge analyze real-time traffic data, identify emergency scenarios, and adapt routing decisions to ensure the quickest possible passage for emergency vehicles. Additionally, the system uses intelligent routing techniques to optimize traffic flow during peak periods by diverting vehicles away from congested roads and adjusting traffic signals dynamically. Our approach demonstrates improvements in emergency response times and traffic flow efficiency, proving the viability and effectiveness of this integrated solution in addressing urban traffic challenges.

1 Introduction

Urban traffic congestion remains a persistent challenge due to the rapid increase in the number of vehicles on city roads. This is exacerbated by the critical need for efficient emergency vehicle response, where delays can have severe consequences. Traditional traffic management systems struggle to adapt to the growing demands, especially in scenarios requiring optimized routing for emergency services. These systems often lack the real-time processing capabilities and dynamic decision-making required to handle the complexities of urban traffic.

The significance of this problem is underscored by the challenges posed by increasing urbanization. As cities grow denser and vehicle counts rise, existing traffic management strategies become increasingly ineffective. Rapid response measures are essential to reduce delays, improve traffic flow, and ensure emergency services reach their destinations swiftly and safely.

Addressing this issue requires synergizing Software-Defined Networking (SDN) and Fog Computing. However, this integration presents several challenges: coordinating the centralized control of SDN with the distributed processing of Fog Computing, ensuring a real-time response to changing traffic conditions, and maintaining data security and privacy. Overcoming these challenges is crucial to develop a comprehensive traffic management solution capable of significantly improving urban mobility and emergency response.

Our code is in this repository Visit our GitHub repository

2 Related work

Integrating SDN and Fog Computing into vehicular networks enhances VANET by combining SDN's oversight with Fog's quick processing[2], improving vehicle communication and infrastructure. This integration benefits applications such as data sharing and lane-change assistance. The OHD-SDN approach[1] uses SDN for better network transitions in vehicles, optimizing based on real-time data. These developments underscore SDN and Fog's importance in addressing VANET issues and lay the foundation for research aimed at improving urban traffic management through smarter solutions.

3 Methodology

Our methodology leverages Simulation of Urban MObility (SUMO), Fog Computing, and Mininet-WiFi to create a robust urban traffic management system that efficiently handles normal traffic conditions and emergency scenarios.

- **SUMO**

  Traffic Network Simulation: We configured a traffic network simulation environment within SUMO using roads, lanes, traffic lights, and various vehicle types. The initial map data was imported from OpenStreetMap and subsequently converted to formats compatible with SUMO. This ensures a realistic representation of an urban environment.

  Traffic Flow Scenarios: To simulate typical urban traffic conditions, we implemented scenarios that represent peak and off-peak traffic periods. The simulation includes 100 regular vehicles and two emergency vehicles to demonstrate the system's response to emergencies.

  Emergency Response Logic: Using the Traffic Control Interface (TraCI), we dynamically modified traffic signals and controlled vehicle behaviors to prioritize emergency responses. This includes altering traffic lights and rerouting vehicles to expedite the passage of emergency vehicles.

- **Fog Computing Nodes**

  Definition and Deployment: Fog nodes can be simulated as virtual servers within the network, often deployed at key traffic points like intersections or road exits to serve as real-time traffic data processing units.

  Data Collection and Processing: Fog nodes collect data from vehicles and sensors through V2X communication and apply predefined algorithms to process the data in real-time, providing decision recommendations for emergency and regular traffic flow optimization.

- **Mininet-WiFi Integration**

  Communication Method: Simulate RSUs or fog nodes as WiFi access points in Mininet-WiFi, using WiFi protocols or V2X communication to simulate interactions between vehicles and RSUs. The POX controller can be used to implement SDN control.

  SDN Network Simulation: We simulated a Software-Defined Networking (SDN) environment using Mininet-WiFi that connects vehicles, RSUs, and data centers. This network supports the intricate data flow required for real-time traffic management.

  Configuration of SDN Controller: The POX SDN controller was configured to manage and route network traffic effectively. This includes the prioritization of emergency-related data packets, ensuring that communication related to emergency services is expedited.

4 Implementation

This section delineates the practical aspects of our intelligent traffic optimization system, elaborating on the tools, technologies, and methodologies employed to realize the theoretical models discussed previously. Here, we describe the integration of Mininet-WiFi for network simulation, SUMO for traffic dynamics, and the POX controller for managing network decisions. The specifics of configuring fog computing nodes, setting up network topologies, and the algorithms driving emergency vehicle priority policies are outlined. This exposition aims to provide a comprehensive understanding of the system's architecture and operational mechanisms, illustrating how each component contributes to the overarching goal of enhancing traffic flow and emergency response efficacy in urban environments.

- Mininet-WiFi Network Simulation:

  The setup includes simulating an SDN network that connects vehicles, Roadside Units (RSUs), and data centers, facilitating a high level of control and responsiveness over network traffic.

- POX Controller:

  Dijkstra Algorithm: We implemented a function in the POX controller that utilizes the Dijkstra algorithm to calculate the shortest path between two nodes. This is crucial for dynamically routing emergency vehicles during crises.

- Receive Decisions:

  The controller is configured to react upon receiving external decisions regarding emergency vehicle routing. Using the Dijkstra algorithm, it swiftly computes the optimal path for these vehicles.

- Update Flow Rules:

  Based on the path determined, the POX controller updates the OpenFlow rules to clear the route for the emergency vehicle. This includes modifying traffic lights and reconfiguring network paths to ensure an unobstructed route for emergency responders.

- Decision Listening System:

  Fog Node Processing: Fog nodes are deployed strategically to process data at the edge, reducing latency and enhancing real-time decision-making capabilities.

- Sending Traffic Data:

  These nodes also handle the task of sending traffic data, which includes vehicle density, speed, and other relevant parameters, back to the central system for further processing.

- Maximize LcKeepRight:

  Initially, the system maximizes the LcKeepRight parameter, which encourages drivers to keep to the right, making room for emergency vehicles to pass. This setting adjusts the tendency of drivers to move right, with 1 being the maximum inclination.

- Change Lane Using ChangeLane:

  If the system detects congestion ahead of the emergency vehicle, it employs the ChangeLane function. This built-in SUMO function allows vehicles to safely and efficiently move to the right, thereby clearing the path.

- Traffic Light Control:

  As a final measure, if the previous strategies prove insufficient, the system checks the road's occupation state to determine if there is a need to switch traffic lights from red to green. This measure is designed to clear the traffic flow, ensuring that emergency vehicles have a clear path through congested intersections.

Through these mechanisms, the system ensures that emergency vehicles can navigate urban environments swiftly and effectively, reducing response times and enhancing overall traffic safety. The implementation of these advanced traffic management strategies showcases our system's capability to adapt to dynamic urban conditions and prioritize critical emergency responses.

5 Results and Analysis

This section outlines the outcomes of our implemented traffic management system, focusing on emergency handling metrics and the impact on general traffic flow. The provided data points and the graph indicate how the system has improved emergency response times and overall traffic conditions.

- Average Speed: Initially, the average speed across the network was 11.2219 km/h. Post-implementation, this increased slightly to 11.2684 km/h, marking a 0.414% increase. While modest, this improvement in speed suggests that even with increased vehicle counts, the traffic flow efficiency was maintained.

- Average Occupancy: There was a significant increase in road occupancy, from 0.01261 to 0.02528, reflecting a 100.503% rise. This indicates a higher utilization of road capacity, which can be attributed to more efficient routing and prioritization of vehicles through the network.

- Emergency Vehicle Response Time: Notably, the response time for emergency vehicles halved from 200 seconds to 100 seconds, demonstrating the effectiveness of our traffic management strategies in critical scenarios.

6 Conclusion

In this paper, we presented the development and implementation of an intelligent traffic optimization system that leverages Software-Defined Networking (SDN), Fog Computing, and Vehicle-to-Everything (V2X) communication technologies. The system aims to address the critical challenges of urban traffic congestion and inefficient emergency response. By employing Mininet-WiFi for network simulation, SUMO for traffic dynamics, and POX for SDN control, we successfully demonstrated how these technologies can work together to create a comprehensive solution.

Our system dynamically optimizes traffic flow based on real-time data analysis, providing emergency vehicles with priority routing and offering drivers intelligent lane change recommendations. The integration of fog nodes at key intersections allows for decentralized processing and swift decision-making, reducing the latency associated with centralized traffic management systems. This approach not only enhances emergency response times but also significantly reduces congestion.

Future research can expand upon this work by exploring more sophisticated machine learning models for traffic pattern prediction, enhancing the robustness of lane change recommendations, and integrating additional data sources like weather or social media trends. The continuous advancement of SDN, Fog Computing, and V2X technologies promises exciting opportunities for the future of smart traffic management systems. With further development, this system can play a significant role in creating safer, more efficient, and intelligent urban transportation networks.

7 Future Directions

The successful implementation of our traffic management system using SDN and Fog Computing sets a solid foundation for future enhancements and research. Here are several directions we aim to explore to further advance our system's capabilities

- **Expansion to Larger Urban Areas:**
  - To validate the scalability and robustness of our system, future testing will involve deploying it in larger and more complex urban settings. This will allow us to assess its adaptability to varied traffic conditions and diverse urban layouts, ensuring that the system remains efficient in different environmental contexts.
- **Integration with IoT and Smart City Infrastructure:**
  - By integrating with Internet of Things (IoT) devices and other smart city infrastructure, our system can gain access to a wider array of data sources, such as real-time weather conditions, road maintenance updates, and pedestrian traffic flows. This information can be used to further refine traffic management decisions, providing a more holistic approach to urban planning and management.
- **Machine Learning for Predictive Traffic Management:**
  - Implementing machine learning algorithms can enable our system to predict traffic patterns and potential congestion points before they occur. By analyzing historical and real-time traffic data, the system can proactively adjust traffic signals and suggest alternate routes, potentially preventing congestion and enhancing the efficiency of emergency responses.
- **Enhanced Communication Protocols:**
  - Future work will also focus on enhancing the communication protocols between Mininet-WiFi and SUMO. Improving these protocols will ensure more seamless data transfer and integration, leading to quicker response times and more accurate traffic management.
- **Development of Multi-modal Transportation Models:**
  - Expanding the system to accommodate not just vehicular traffic but also bicycles, electric scooters, and public transit can provide a more comprehensive traffic management solution. This involves developing multi-modal transportation models that consider the interactions between different

types of road users and optimize traffic flow for all.

- **Automated Emergency Response Coordination:**
  - Further development could automate the coordination of emergency services by integrating with emergency dispatch systems. This would enable automatic rerouting of traffic as soon as an emergency call is received, optimizing the route for emergency vehicles instantaneously based on the current traffic situation.
- **Public Engagement and Feedback Mechanisms:**
  - Incorporating public feedback mechanisms into the system can help gather data on user satisfaction and system performance. Engaging with the public to report traffic incidents and feedback on traffic conditions can also enhance the accuracy of traffic management strategies.

8 References

[1] C.-M. Huang, M.-S. Chiang, D.-T. Dao, H.-M. Pai, S. Xu, and H. Zhou. Vehicle-to-infrastructure (v2i) offloading from cellular network to 802.11p wi-fi network based on the software-defined network (sdn) architecture. *Vehicular Communications*, 9:288–300, 2017.

[2] N. B. Truong, G. M. Lee, and Y. Ghamri-Doudane. Software defined networking-based vehicular adhoc network with fog computing. pages 1202–1207, 2015.