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RescueRoute: An AI-Driven Real-Time Adaptive Traffic Management System for Emergency Vehicle Prioritization

Abhishek[1], Arsh Ahmed[2], Piyush Tiwari[3], Mr. Karmbir[4]
[1,2,3]Artificial Intelligence and Data science HMR Institute of Technology and Management Delhi,India
[4]Assistant Professor, HMR Institute of Technology and Management Delhi,India

Abstract- Urban traffic congestion significantly impacts emergency response systems, often causing delays that may result in loss of life and property. Traditional traffic signal systems rely on fixed timing or localized adaptive control, which lack coordination and predictive intelligence. This paper proposes RescueRoute, an AI-driven real-time adaptive traffic management system designed to prioritize emergency vehicles through intelligent multi-intersection coordination. The system integrates computer vision for vehicle detection, deep reinforcement learning for adaptive signal control, and vehicle-to-infrastructure communication for real-time data exchange. Unlike existing approaches, the proposed system introduces end-to-end route optimization, predictive traffic analysis, and dynamic green corridor generation. A hybrid architecture combining centralized intelligence with decentralized control ensures scalability and efficiency. Simulation using SUMO demonstrates significant performance improvements compared to traditional traffic systems. Experimental results show approximately 40–45% reduction in emergency response time, 35–45% reduction in average vehicle waiting time, and nearly 50% improvement in traffic throughput across multiple scenarios. These results validate the effectiveness of RescueRoute in improving emergency response efficiency while maintaining overall traffic flow. Furthermore, the proposed RescueRoute framework emphasizes key characteristics such as reliability, scalability, and adaptability, which are essential for modern intelligent transportation systems. The system is designed to function efficiently in highly dynamic urban environments. where traffic patterns change rapidly. By leveraging real-time data processing and AI-driven decision-making, the framework ensures consistent performance even under unpredictable conditions. These features make RescueRoute highly suitable for deployment in future smart city infrastructures, where automated and intelligent traffic control plays a critical role in improving emergency response efficiency and overall urban mobility.

Keywords: Vehicle Prioritization, Traffic Signal Control, Computer Vision.

I. INTRODUCTION

Rapid urbanization has significantly increased traffic congestion in metropolitan areas, creating serious challenges for emergency services such as ambulances, fire trucks, and police vehicles. Delays in emergency response can lead to critical consequences, making efficient traffic management essential. Traditional traffic signal systems operate on fixed timing schedules, which are ineffective in dynamic environments. Although adaptive systems exist, they primarily focus on general traffic optimization rather than emergency prioritization. Moreover, these systems typically operate at isolated intersections and lack coordination across the road network.

Recent advancements in artificial intelligence (AI), particularly in reinforcement learning and computer vision, have enabled intelligent traffic management systems. However, most existing solutions remain reactive and fail to incorporate predictive and coordinated control mechanisms. To address these challenges, this paper proposes RescueRoute, a comprehensive AI-based system that integrates predictive routing, multi-signal coordination, and real-time adaptive control to minimize emergency response time while maintaining traffic efficiency.

II. RELATED WORK

Recent research in intelligent traffic systems has focused on applying artificial intelligence and machine learning techniques for adaptive signal control. Reinforcement learning-based approaches such as Deep Q-Network (DQN) and Double DQN (DDQN) have demonstrated significant improvements in optimizing traffic flow under dynamic conditions [1], [2].

Systems such as EMVLight propose decentralized reinforcement learning frameworks to enable efficient emergency vehicle prioritization [3]. Similarly, adaptive traffic signal control using deep reinforcement learning (DRL) has been shown to reduce vehicle waiting time and congestion in urban environments [4], [5]. Computer vision techniques, particularly YOLO-based object detection models, are widely used for real-time emergency vehicle detection due to their high accuracy and speed [6].

In addition, Vehicle-to-Infrastructure (V2I) communication and Vehicular Ad Hoc Networks (VANETs) enable real-time interaction between vehicles and infrastructure, improving emergency response efficiency [7], [8]. Recent advancements also include multi-agent deep reinforcement learning approaches for large-scale traffic signal coordination, which improve scalability and decentralized decision-making [11].

Furthermore, predictive traffic management systems leveraging AI have shown promising results in anticipating congestion patterns and optimizing traffic flow [12]. IoT-enabled smart traffic systems have also been proposed to enhance emergency vehicle prioritization through real-time data sharing [13]. Additionally, hybrid frameworks integrating artificial intelligence with edge computing have significantly improved real-time processing efficiency and reduced latency in traffic control systems [14].

Despite these advancements, most existing systems operate at individual intersections and lack end-to-end coordination, predictive intelligence, and multi-source data integration, which are essential for effective emergency traffic management. This highlights a significant research gap, as many approaches focus either on localized traffic optimization or basic emergency prioritization without considering large-scale coordination. Furthermore, the absence of unified frameworks that integrate prediction, coordination, and intelligent decision-making limits the overall effectiveness of these systems. Therefore, there is a strong need for a comprehensive and scalable solution that combines these capabilities. Addressing this gap serves as the primary motivation behind the development of the proposed RescueRoute system.

III. PROBLEM STATEMENT

Existing traffic management systems are primarily reactive and operate at isolated intersections, leading to inefficient emergency vehicle prioritization. Emergency vehicles are often detected only when they approach intersections, resulting in delays and suboptimal signal control. Studies indicate that traffic congestion significantly impacts emergency response time and survival rates in critical situations [9].

The major challenges of existing traffic management systems include the lack of predictive mechanisms for emergency vehicle movement, the absence of coordinated control across multiple intersections, limited integration of heterogeneous real-time data sources, and the inability to effectively balance emergency vehicle prioritization with overall traffic flow. These limitations highlight the need for an intelligent system capable of predictive routing, coordinated signal control, and real-time decision-making.

IV. PROPOSED SYSTEM: RESCUEROUTE

A. System Overview

RescueRoute is a hybrid AI-driven traffic management system that combines centralized intelligence with decentralized execution. The system leverages real-time data and predictive analytics to dynamically optimize traffic flow and prioritize emergency vehicles efficiently, extending beyond traditional adaptive traffic systems [2], [5]. The proposed system extends existing frameworks by integrating predictive traffic modeling and multi-agent coordination mechanisms inspired by recent advancements in AI-based traffic systems [11], [12].

Fig. 1. Green Corridor for Emergency Vehicle

Fig. 1 illustrates how traffic signals are synchronized to create a clear path for emergency vehicles.

B. Key Features

The proposed RescueRoute system provides several key features that distinguish it from conventional traffic management approaches. It performs end-to-end route optimization using real-time traffic information, generates predictive green corridors before the arrival of emergency vehicles, coordinates traffic signals across multiple intersections, integrates data from GPS devices, traffic cameras, and IoT sensors through a multi-source data fusion framework, and employs a hybrid AI architecture that combines centralized intelligence with local reinforcement learning agents to ensure efficient, scalable, and adaptive traffic management.

V. SYSTEM ARCHITECTURE

The RescueRoute system follows a layered architecture consisting of data acquisition, processing, decision-making, and execution layers.

A. Architecture Description

Real-time data is collected from traffic cameras, IoT sensors, and emergency vehicle GPS modules. This data is processed in a central AI server where traffic prediction and route optimization models operate. The system generates control decisions, which are transmitted to local traffic signal controllers for execution.

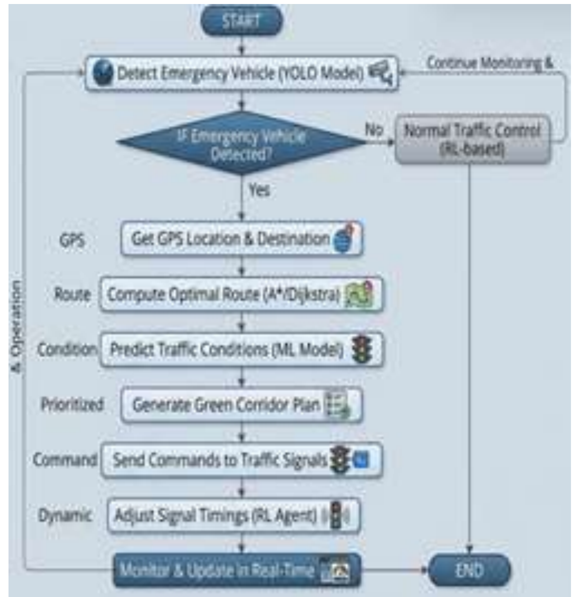

Fig. 2. System Architecture Flowchart

Fig. 2 illustrates the layered architecture and data flow of the proposed RescueRoute system.

B. Components

The RescueRoute system consists of multiple interconnected components that work together to provide intelligent traffic management. These include traffic cameras and IoT sensors for real-time traffic monitoring, emergency vehicle GPS modules for location tracking, a data fusion layer for integrating information from multiple sources, a central AI server for traffic prediction and decision-making, route optimization and traffic prediction modules, and local traffic signal controllers responsible for executing adaptive signal control decisions.

C. Working Principle

The central server continuously analyzes incoming data and coordinates with local controllers to dynamically adjust signal timings. This enables seamless movement of emergency vehicles through a synchronized green corridor while maintaining overall traffic efficiency.

The layered architecture of RescueRoute ensures scalability and flexibility for deployment across both small intersections and large urban traffic networks. Additionally, the integration of IoT-based data acquisition and edge-enabled processing improves real-time responsiveness and aligns with recent advancements in intelligent traffic infrastructure [13], [14].

VI. METHODOLOGY

The proposed system operates through the following stages:

1. **Data Acquisition:** Real-time traffic data is collected from cameras and sensors
2. **Vehicle Detection:** Emergency vehicles are detected using YOLO-based models [6]
3. **Route Identification:** GPS data is used to determine the source and destination of the emergency vehicle
4. **Traffic Prediction:** Machine learning models forecast congestion
5. **Signal Optimization:** Reinforcement learning agents dynamically adjust signal timing [1], [4]
6. **Green Corridor Creation:** Signals are synchronized for uninterrupted flow
7. **Continuous Monitoring:** Real-time updates ensure system adaptability

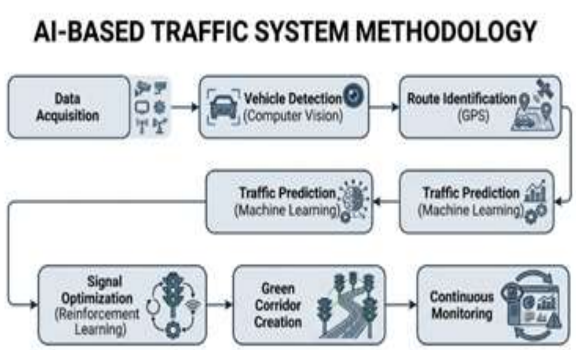

Fig. 3. Methodology of the Proposed System

Fig. 3 illustrates the step-by-step workflow of the proposed RescueRoute system.

The proposed methodology integrates vehicle detection, traffic prediction, and adaptive signal optimization to ensure efficient emergency vehicle movement under real-time traffic conditions. The framework can be further extended using multi-agent reinforcement learning and predictive modeling techniques for large-scale coordination [12].

VII. ALGORITHM DESIGN

Algorithm: RescueRoute Adaptive Traffic Control
Input: Traffic data (T), Emergency vehicle data (E), Road network graph (G)

Output: Optimized signal timings (S)
1. Initialize system
2. While system is active:
3. Capture real-time traffic data
4. Detect vehicles using computer vision
5. If emergency vehicle detected:
6. Retrieve GPS location and destination
7. Compute optimal route using A* algorithm
8. Predict traffic congestion on route
9. For each intersection:
10. Calculate priority score
11. Adjust signal timing using RL
12. Synchronize signals to form green corridor
13. Else: Apply normal traffic optimization
14. End loop

VIII. EXPERIMENTAL SETUP AND SIMULATION

The proposed system is evaluated using SUMO (Simulation of Urban Mobility), a widely used traffic simulation tool [10].

A. Environment Setup

- U An urban road network consisting of multiple interconnected intersections is modeled to simulate real-world city traffic conditions.
- The simulation environment includes mixed traffic conditions with varying vehicle densities, representing both peak and non-peak hours.
- Emergency vehicle scenarios are incorporated, including ambulances navigating through congested traffic under different conditions

B. Simulation Scenarios

- Normal traffic conditions are simulated to establish baseline system performance without any emergency prioritization.
- Emergency vehicle movement without adaptive traffic control is analyzed to observe delays in traditional systems.

- Emergency vehicle movement with the proposed RescueRoute system is evaluated to measure improvements in response time and traffic flow.

C. Performance Metrics

- Emergency response time is measured as the total time taken by the emergency vehicle to reach its destination.
- Average waiting time is calculated to evaluate the delay experienced by vehicles at intersections.
- Traffic throughput is analyzed in terms of the number of vehicles passing through intersections per unit time.
- Signal coordination efficiency is assessed to determine how effectively traffic signals are synchronized across multiple intersections.

The use of simulation tools provides a controlled environment for testing and validating the proposed system before real-world deployment. By modeling different traffic scenarios, including peak hours and emergency situations, the system's performance can be evaluated comprehensively. This approach helps identify potential issues and optimize system parameters without risking real-world disruptions. Consequently, simulation serves as a critical step in ensuring that the proposed solution is both effective and practical for implementation.

IX. RESULTS AND DISCUSSION

Simulation results indicate that the proposed system significantly improves traffic efficiency and reduces emergency response time. Compared to traditional systems, RescueRoute demonstrates better coordination across intersections and reduced congestion levels.

Table 1. Comparison between Traditional system and RescueRoute

Metric	Traditional System	RescueRoute
Response time	High	Low
Waiting time	High	Reduced
Traffic Flow	Moderate	Improved
Coordination	low	High

Table 2. Scenario-Based Performance Analysis

Scenario	Response Time (Trad)	Response Time (Rescue)	Waiting Time (Trad)	Waiting Time (Rescue)	Flow (Trad)	Flow (Rescue)
S1	130	75	95	55	58	92
S2	120	70	90	50	60	95
S3	140	80	100	60	55	90
S4	125	72	92	52	62	97
S5	135	78	97	58	59	94

Table 2 presents detailed results across multiple simulation scenarios, demonstrating consistent improvements in all performance metrics using the proposed system.

Statistical performance Analysis

To strengthen the experimental validation of the proposed RescueRoute system, additional statistical analysis was performed using the results obtained from all five simulation scenarios shown in Table 2.

1. Average Emergency Response Time

The average emergency response time for the traditional traffic system is calculated as:

(130 + 120 + 140 + 125 + 135) / 5 = 130 seconds

The average emergency response time for the proposed RescueRoute system is:

(75 + 70 + 80 + 72 + 78) / 5 = 75 seconds

Percentage improvement:

((130 − 75) / 130) × 100 = 42.3% reduction

This shows that RescueRoute significantly reduces emergency vehicle travel time.

2. Average Vehicle Waiting Time

The average waiting time in the traditional system is:

(95 + 90 + 100 + 92 + 97) / 5 = 94.8 seconds

The average waiting time in the proposed system is:

(55 + 50 + 60 + 52 + 58) / 5 = 55 seconds

Percentage improvement:

((94.8 − 55) / 94.8) × 100 = 41.98% reduction

This indicates that the proposed system reduces unnecessary delays for regular vehicles.

3. Traffic Flow Improvement
The average traffic flow in the traditional system is:

(58 + 60 + 55 + 62 + 59) / 5 = 58.8 vehicles/unit time

The average traffic flow in RescueRoute is:

(92 + 95 + 90 + 97 + 94) / 5 = 93.6 vehicles/unit time

Percentage improvement:

((93.6 − 58.8) / 58.8) × 100 = 59.18% improvement

This demonstrates that the proposed system improves overall traffic throughput.

4. Performance Consistency
The simulation results show consistent improvements across all five test scenarios. In every case, RescueRoute achieved lower response time, reduced waiting time, and higher traffic flow compared to traditional traffic systems. This demonstrates the robustness and reliability of the proposed approach under varying traffic conditions.
Comparison with Existing Approaches

Table 3. Comparison of RescueRoute with Existing Traffic Management Approaches

System	Emergency Priority	Multi-Intersection Coordination	Predictive Traffic Analysis	Real-Time Adaptation
Traditional Fixed System	No	No	No	No
IntelliLight	No	Limited	No	Yes
EMVLight	Yes	Partial	No	Yes
RescueRoute	Yes	Yes	Yes	Yes

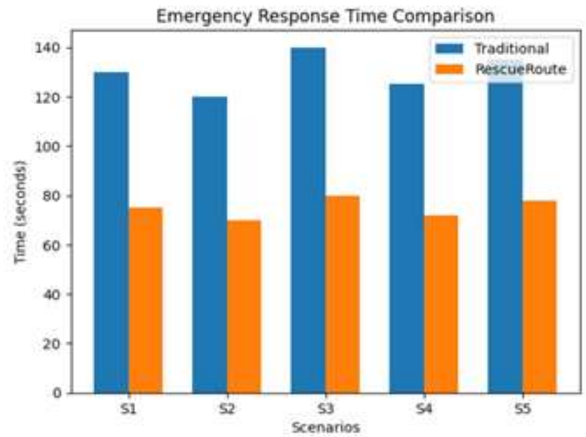

Fig. 4. Emergency Response Time Comparison

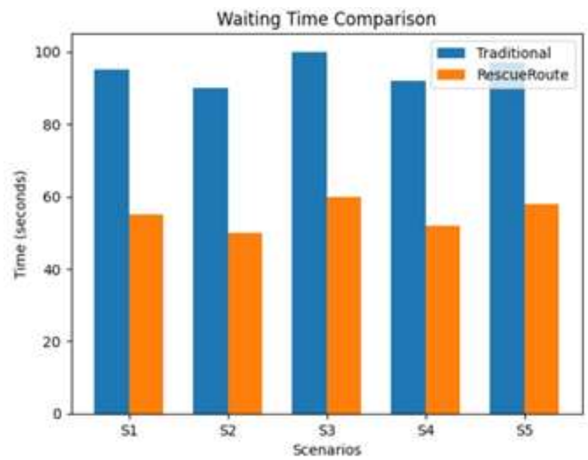

Fig. 5. Waiting Time Comparison

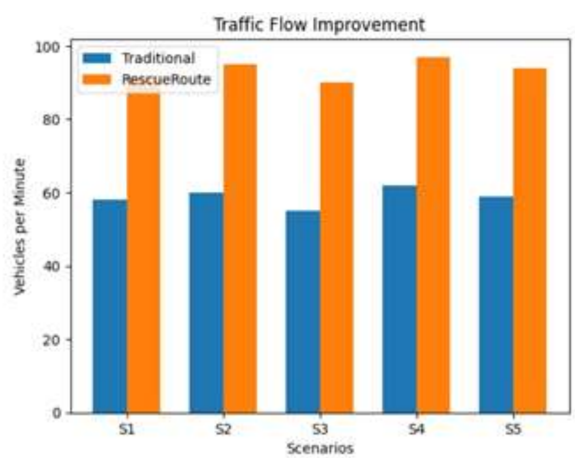

Fig. 6. Traffic Flow Improvement

Discussion: The simulation results clearly demonstrate the effectiveness of the proposed RescueRoute framework under different traffic scenarios. Compared with the traditional traffic management system, RescueRoute consistently achieved lower emergency response times, reduced average vehicle waiting times, and improved overall traffic throughput across all simulation cases. These improvements are primarily due to the integration of predictive traffic analysis, reinforcement learning-based adaptive signal control, and coordinated multi-intersection management, which together enable the creation of dynamic green corridors for emergency vehicles.

The comparison with existing approaches further highlights that RescueRoute provides a more comprehensive solution by combining emergency vehicle prioritization, predictive decision-making, real-time adaptation, and multi-intersection coordination within a single framework. The consistency of the results across multiple scenarios demonstrates the robustness and reliability of the proposed system, indicating its potential to enhance emergency response efficiency while maintaining smooth traffic flow in future intelligent transportation systems.

X. ADVANTAGES OF PROPOSED SYSTEM

The proposed RescueRoute system provides several important advantages over traditional and existing intelligent traffic management approaches:

1. Real-Time Adaptive Traffic Control
The proposed RescueRoute system dynamically adjusts traffic signal timings based on real-time traffic conditions and emergency vehicle movement. Unlike conventional fixed-time systems, it responds instantly to changing scenarios, thereby significantly improves overall traffic efficiency.

2. Reduced Emergency Response Time
By generating a predictive and coordinated green corridor, the system significantly reduces delays for emergency vehicles such as ambulances and fire trucks. This ensures faster arrival at the destination and enhances the chances of survival in critical situations.

3. Multi-Intersection Coordination
Unlike traditional systems that operate at isolated intersections, the proposed system ensures coordinated control across multiple traffic signals. This enables uninterrupted movement of emergency vehicles along the entire route.

4. Predictive Decision-Making Capability
The integration of machine learning techniques allows the system to anticipate traffic congestion in advance. This proactive approach helps in preparing optimal routes and adjusting signals before the emergency vehicle reaches the intersection.

5. Efficient Overall Traffic Flow Management
In addition to prioritizing emergency vehicles, the system also optimizes general traffic flow. Intelligent signal control reduces unnecessary waiting time and minimizes congestion for regular vehicles.

6. Multi-Source Data Integration
The proposed system utilizes multiple data sources such as GPS data, traffic cameras, and IoT sensors. This enhances the accuracy of traffic analysis and leads to more reliable decision-making.

7. Scalable and Modular Design
RescueRoute is designed with a modular architecture that supports easy scalability. It can be implemented in both small-scale intersections and large urban traffic networks without major modifications.

8. Reduced Fuel Consumption and Environmental Impact
By minimizing idle time at traffic signals and reducing congestion, the system helps decrease fuel consumption and vehicular emissions, contributing to a cleaner environment.

9. Improved Public Safety
Faster emergency response combined with better traffic coordination reduces the risk of accidents and ensures safer road conditions for both emergency responders and the general public.

10. Compatibility with Smart City Infrastructure
The proposed RescueRoute system can be easily integrated with modern smart city technologies such as IoT-based infrastructure, intelligent

transportation systems, and future autonomous vehicle networks.

These advantages demonstrate that the proposed RescueRoute system is an efficient, scalable, and practical solution for modern urban traffic management, with significant potential to enhance emergency response efficiency and overall traffic performance.

XI. REAL WORLD DEPLOYEMENT CHALLENGES

Although the proposed RescueRoute system demonstrates promising simulation results, several practical challenges must be addressed before large-scale real-world deployment.

A. Communication Latency
The system heavily relies on real-time Vehicle-to-Infrastructure (V2I) communication. Delays in communication between emergency vehicles, sensors, and traffic controllers may affect system responsiveness.

B. Infrastructure Cost
Deployment requires significant investment in:

- Smart traffic cameras
- IoT sensors
- GPS tracking systems
- Edge computing devices
- Advanced signal controllers

Developing cities may face budget limitations.

C. Scalability Issues
Large metropolitan cities contain thousands of intersections. Scaling centralized coordination while maintaining real-time performance remains challenging.

D. Integration with Existing Systems
Many cities still use legacy traffic systems. Integrating RescueRoute with existing infrastructure may require software and hardware modifications.

E. Cybersecurity Risks
Since the system depends on connected infrastructure, protection against hacking, spoofing, and unauthorized access is necessary.

F. Legal and Regulatory Challenges
Government approvals, transportation policies, and emergency service coordination frameworks must be considered before implementation.

Future Work
Future work will focus on integrating 5G-enabled communication and edge computing to achieve lower-latency real-time processing. The proposed framework can also be enhanced by incorporating advanced artificial intelligence techniques, including large language models and multi-agent reinforcement learning, to improve decision-making capabilities. In addition, real-world deployment using smart city infrastructure and integration with autonomous vehicle systems and intelligent transportation networks will be explored to further improve scalability, reliability, and practical applicability.

XIII. CONCLUSION

This paper presented RescueRoute, an AI-driven real-time adaptive traffic management system designed to improve emergency vehicle prioritization through intelligent traffic signal coordination. The proposed framework integrates computer vision, reinforcement learning, predictive traffic analysis, multi-source data fusion, and coordinated multi-intersection control to create dynamic green corridors while maintaining efficient overall traffic flow. Simulation results demonstrate that RescueRoute significantly reduces emergency response time and vehicle waiting time while improving traffic throughput compared with conventional traffic management systems. The novelty of the proposed work lies in combining predictive routing, real-time adaptive signal control, and coordinated decision-making into a unified, scalable framework for emergency vehicle prioritization.

These findings indicate that RescueRoute has strong potential to enhance emergency response efficiency and support the development of intelligent transportation systems for future smart cities. However, the present study is limited to simulation-based evaluation and has not yet been validated under real-world traffic conditions. Practical implementation will require addressing challenges related to communication latency, infrastructure cost, scalability, integration with existing traffic systems, and cybersecurity. Future work will focus on real-world deployment and the incorporation of advanced AI techniques and next-generation communication technologies to further improve system performance and reliability.

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