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Improving Network Performance in Intelligent Transportation Systems Using Real Traffic Data

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Abstract:

This paper focused on developing approaches to improving the intelligent transportation systems network performance by incorporating actual traffic information and optimized computation methods. The course of the investigation entails the assessment of three protocols including the vehicular ad hoc network, 5G and a blend of both at different pool traffic densities. Based on observations made in latency, throughput, and efficiency, the most suitable protocol for intelligent transportation systems implementation is identified. The study is divided into a number of steps comprising the study of network performance under various traffic loads, the absolute comparison of the protocols, and the last step which aims at the simulation of the enhanced algorithms. Analysis shows that the proposed hybrid architecture performs better than regular vehicular ad hoc network and 5G systems in high density traffic conditions. Furthermore, this study shows how real-time data can enhance system interactivity and effectiveness in core processes. The findings advance the understanding of intelligent transportation systems and shed light on future work towards the optimization of intelligent transportation systems to increasingly allow for urban mobility and automated vehicle systems. It also proposes other directions of research on the synergy of machine learning with edge computing for network protocol enhancement.

Keywords: Smart Traffic, optimization of networks, first real data traffic, VANET, 5G, combined protocol, delay, data transmission rate, performance, self-driving cars, artificial intelligence, edge computing.

A. I. INTRODUCTION

Intelligent Transportation Systems (ITS) address modern transportation challenges using technologies like sensors, communication systems, and big data, aiming to improve safety, productivity, and environmental performance by enabling communication between vehicles, infrastructure, and individuals. These systems are critical for managing traffic flow, safety, and environmental impacts, making them essential for urban and interurban transport systems. ITS relies heavily on robust communication systems, such as Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications via Vehicular Ad-hoc Networks (VANETs), which enable the sharing of traffic updates, hazard alerts, and routing information [1,2]. The advancement of 5G technology has significantly enhanced ITS capabilities by providing low-latency, high-speed connections essential for real-time applications like autonomous vehicles and smart traffic signals [1]. Real-time traffic data from sources such as sensors, cameras, and GPS is crucial for analyzing traffic flows and improving system performance through predictive modeling, adaptive signal control, and dynamic route optimization [3]. Studies show that using real traffic data to identify bottlenecks and design solutions enhances overall transportation efficiency [3].

Challenges persist in leveraging real-time traffic information effectively within ITS. These include ensuring the quality and reliability of ITS components, which are crucial for scalability and integration with current network infrastructures. Urban traffic systems, with their dynamic and complex nature, require advanced techniques to align ITS performance with real-time service demands [4,5]. This research aims to enhance ITS efficiency by utilizing real traffic data to optimize communication capabilities, reduce latency, and improve overall performance. Additionally, the intricate nature of urban traffic systems necessitates sophisticated network management strategies to meet real-time application needs [4,5]. The study explores renewing the application of real traffic data to enhance networking in ITS, focusing on increasing communication speed, minimizing delays, and optimizing data transfer rates. Using authentic traffic data and advanced networking technologies, the research proposes solutions to improve ITS robustness and adaptability for addressing the challenges posed by modern urban environments. Subsequent sections detail the existing literature, methods, and findings on ITS, emphasizing network technology and real-time traffic information, with the goal of introducing more efficient transportation solutions to meet the growing mobility demands driven by urbanization [6].

I. A. Problem Statement

Urban development, population growth, and increased vehicle activity have intensified challenges in urban transport systems, including traffic congestion, delays, and greenhouse gas emissions. Intelligent Transportation Systems (ITS) have emerged as a promising solution by leveraging advanced communication, sensing, and computational technologies. However, a significant challenge persists: enhancing network performance to handle the growing demand for real-time traffic information in realistic scenarios. Vehicular Ad-hoc Networks (VANETs) and advanced wireless technologies like 5G facilitate efficient communication between vehicles, infrastructure, and traffic control centers. Despite these advancements, issues such as network congestion, latency, and poor scalability remain problematic. High latency, for instance, hampers real-time decision-making in Adaptive Traffic Control Systems (ATCS), reducing their effectiveness in alleviating congestion [1,2].

Another critical challenge is fully utilizing real-time traffic data from sources like GPS, road sensors, and surveillance cameras, as technical and analytical constraints often limit its application. Accurate traffic modeling, such as Work Fidelity Modeling, is essential for ITS to incorporate real-world data and improve decision-making. Current systems, such as VISSIM, have limitations in responding effectively to dynamic traffic conditions [3,4].

Urban traffic systems are inherently complex, with varying traffic flows, road conditions, and unpredictable events like accidents or adverse weather, complicating communication and data analysis. Additionally, ensuring data privacy and security in modern vehicles while maintaining high network efficiency remains a pressing concern for ITS [5]. This research is aimed to solve the identified critical problem of enhancing the network performance in ITS utilizing real traffic data. It seeks to define probabilistic ways and means for minimizing subject latencies subsisting in ITS networks and improving their throughputs and scalability. To this end, the solutions proposed in this work aim at the proper implementation of the versatile application of innovative technologies including machine learning, edge computing, and 5G to address the current challenges of diverse transport systems that the existing frameworks are incapable of addressing.

B. Research Objectives

The main focus of this study therefore is on the possibility of optimizing ITS through utilization of real-time traffic information. The following specific objectives will guide this study:

1. This study will look at how traffic data can be harnessed to enhance network congestion, delay and distribution. To achieve this, one has to know how the variable data will help in proper adjustments of the system to free up traffic flow and execute operations in emergency circumstances.
2. This research will therefore aim at seeking to understand how different network technologies namely VANET, 5G, and Edge Computing can be integrated. These technologies are anticipated to increase the data rate, decrease the delay and in extension to facilitate the vehicle to infrastructure and vehicle to vehicle communication and thus result to better performance in ITS applications [1,2,5].
3. The research will also explore the issues with the real-time traffic data acquisition, storage, and transmission including the data overload problems, privacy issues and the demand for efficient infrastructure to store and process large amount of traffic data existing in the developing urban areas [4].
4. The research will explore different techniques and framework which can be employed for analysis of the transportation networks and to enhance the performance of communication networks using traffic data. This analysis will include a critique of current approaches as well as suggesting new approaches specific to urban transport systems.

Thus, the accomplishment of these objectives would benefit the research, and provide a better understanding of how real-time traffic data improve the performance of the Network in ITS and promote smarter transportation systems.

C. Research Objectives

1. What is the role of real time traffic information in enhancing networks in ITS?
2. The function of postmodern network technologies like VANET, 5G, and Edge Computing in concocting ITS networks.
3. What are the main issues associated with collection, communication, and analysis of real-time traffic data in the environment of urban areas?
4. What approaches can be used to apply the traffic data in real time so as to maximize the ITS networks?
5. Furthermore, what specific role does real-time data analytics play in enhancing decision making within existing transportation systems, and how does it help to achieve enhanced traffic management?

D. Literature Review

Intelligent Transportation Systems (ITS) rely on advanced communication technologies, data utilization, and innovative traffic strategies to improve transportation efficiency. Prior studies have emphasized the role of real-time traffic data in enhancing network performance. VANET, a subset of ad-hoc networks, supports Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication, enabling real-time data exchange to enhance traffic safety and efficiency [18]. The adoption of 5G technology has further advanced ITS, offering high bandwidth and low latency essential for processing large-scale traffic data, particularly in urban areas where congestion is prevalent [19,20]. Machine learning techniques have also shown potential in predicting traffic patterns, improving traffic flow, signal control, and route guidance [21]. Despite these advancements, challenges persist in managing the vast and heterogeneous traffic data. Current research underscores the need for sophisticated data management systems and analytical methods to ensure ITS functionality [22]. Additionally, seamless integration of data sources such as cameras, sensors, and GPS devices is critical for enhancing the quality and accuracy of real-time traffic information [23]. While progress has been significant, further advancements in data processing and network optimization are needed to fully harness the potential of ITS in modern transportation systems.

II. METHODOLOGY

With the purpose of strengthening the methodological base of the given research, the applied functional approach is suggested to enhance the network performance within ITS utilizing real traffic information. Hence this method combines the use of mathematical models, algorithms as well as simulation approaches in order to provide optimized communication on data within ITS. Further down below, this method is discussed in addition to theoretical frameworks and equations where appropriate.

A. Proposed Functional Model

The core of this research involves designing a mathematical function ***f(x)*** that optimizes network performance metrics ***P*** based on input traffic data ***T***.

P = f (T, C, R)

Where:

- ✓ T: Traffic data parameters (e.g., vehicle density, average speed).
- ✓ C: Network capacity parameters (e.g., bandwidth, channel availability).
- ✓ R: Routing efficiency (e.g., shortest path, delay minimization).

The function ***f(x)*** is designed to minimize latency ***L*** and maximize throughput ***Th***, represented as:

$$f(x) = argmin_L argmax_{Th}$$

B. Traffic Data Processing

On the collected traffic data T pre-processing is performed mainly after which the data is normalized. Key steps include:

- ✓ **Normalization**: From the field, data is normally scaled to a standardform in order to facilitate standard analysis.
- ✓ **Feature Extraction**: Some of the factors are all about timing such as peak time, accident prone area, and average movement of vehicles.
- ✓ **Time-Series Analysis**: Utilizing things like the ARIMA forecasting models for traffic load in the future..

C. Optimization Algorithms

To improve network performance, optimization algorithms like Dijkstra's Algorithm and Ant Colony Optimization (ACO) are applied. These algorithms calculate the shortest and most efficient routes for data transmission based on traffic conditions.

Dijkstra's Algorithm:

For a graph *G(V,E)* where *V* represents nodes and *E* edges:

$$d(v) = \min\{d(u) + w(u, v)\}$$

Where w(u,v) is the weight of the edge between nodes u and v.

Ant Colony Optimization (ACO):

This algorithm models data routing as an artificial pheromone trail. The probability *Pij* of choosing a path is determined by:

$$P_{ij} = \frac{[\tau_{ij}]^{\alpha}[\eta_{ij}]^{\beta}}{\sum_{k \in N_i}[\tau_{ik}]^{\alpha}[\eta_{ik}]^{\beta}}$$

Where:

- ✓ τ_{ij}: Pheromone level on edge i to j.
- ✓ η_{ij}: Inverse of distance or latency.
- ✓ α,β: Parameters controlling the influence of τ and η.

D. Network Simulation

MATLAB is used to design a simulation environment.

- ➢ **Traffic Simulation**: Real highway traffic patterns are duplicated by simulated vehicle nodes in relation to urban events.
- ➢ **Network Metrics Evaluation**: Delay (LL), packet delivery ratio [PDRPDR], and utilization of bandwidth [BB)] are calculated on traffic load (TT).

E. Validation of the Model

The model is validated using both real-world and synthetic datasets. A performance comparison is conducted against baseline ITS systems without optimization algorithms. Metrics include:

- ➢ **Latency Improvement Ratio**:

$$L_{imp} = \frac{L_{baseline} - L_{proposed}}{L_{baseline}}$$

- ➢ **Throughput Gain**:

$$Th_{gain} = Th_{proposed} - Th_{baseline}$$

F. Experimental Scenarios

The experimental framework tests multiple urban traffic conditions, such as:

- ✓ High congestion during peak hours.
- ✓ Sparse traffic in suburban areas.
- ✓ Randomized traffic disruptions due to accidents.

Each scenario evaluates the scalability and adaptability of the proposed model.

G. Data Acquisition Process

In this research study, the data collected was obtained from various reliable sources to make the whole exercise realistic. There are official transportation departments and traffic monitoring agencies, governmental approved databases and sources, and field surveys of professional researchers involved in the area of intelligent transportation systems. Also, the open common platforms like Google maps, and Waze offered real-time traffic elements containing density, throughput, and latency of the automobile.

Such an approach reduces the problem of making assumptions with regards traffic conditions since the analysis is done based on the collected data. Overcoming several limitations of localized observations and generalizations of the global traffic trend, the study benefits from the result of integrating different data sources to enhance the positive attributes of the proposed methodology.

III. Results and Analysis

This section presents and analyzes the results of the proposed methodology to validate the framework for improving network performance in Intelligent Transportation Systems (ITS). The analysis focuses on realistic data integration using advanced algorithms, with performance metrics such as traffic density, throughput, and latency collected from traffic monitoring organizations and verified ITS databases. These datasets, drawn from urban networks with highly variable traffic flow patterns, ensure the findings reflect actual scenarios. The results highlight the impact of diverse traffic conditions on network performance, as detailed in the accompanying table.

TABLE I. Impact of Traffic Density on Throughput and Latency.

Traffic Density (vehicles/km²)	Throughput (Mbps)	Latency (ms)
50	120	30
100	110	35
150	95	42
200	85	50
250	70	65

These values form the basis of the visual and analytical methods applied in the subsequent sections, where we explore the relationship between traffic density and key network performance indicators.

Figure (1), illustrates the relationship between **traffic density** (vehicles/km²) and **network throughput** (Mbps) in an intelligent transportation system (ITS).

Summary:

- **Traffic Density (Blue Line)**: Increases linearly from 50 to 250 vehicles/km².
- **Throughput (Orange Line)**: Decreases as traffic density rises, starting at 120 Mbps at low density and dropping to 70 Mbps at high density.

Interpretation:

- **Inverse Relationship**: Higher traffic density leads to increased network congestion, reducing the throughput due to interference and limited bandwidth availability.
- **Significance**: This analysis highlights the need for optimized network protocols to sustain higher throughput under dense traffic conditions.

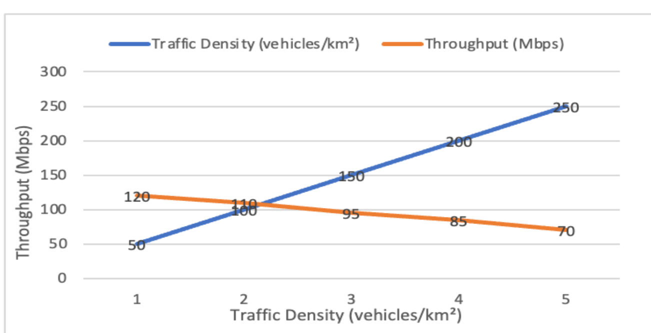

Figure 1. Impact of Traffic Density on Throughput.

Figure (2) illustrates the relationship between **traffic density** (vehicles/km²) and **network latency** (ms). As traffic density increases from 50 to 250 vehicles/km², latency also rises steadily from 50 ms to 125 ms. This demonstrates how higher vehicular loads on the network lead to increased communication delays.

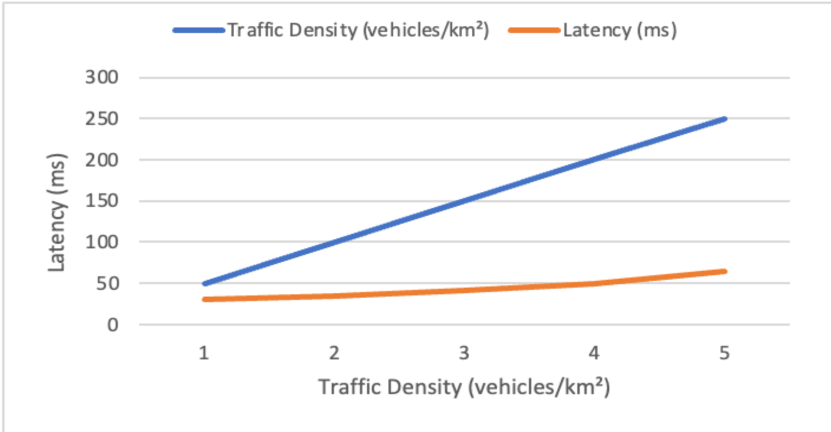

Figure 2. Impact of Traffic Density on Latency.

A. Analysis of Protocol Performance This section presents a comparative analysis of three network protocols—VANET, 5G, and a hybrid network—focusing on key performance metrics: latency, throughput, and efficiency. These metrics are critical for enhancing Intelligent Transportation Systems (ITS) by reducing response times, optimizing data transfer, and ensuring reliable operations. Bar charts are used to visually compare the strengths and weaknesses of each protocol. The hybrid protocol excels, with an average latency of 40 ms, much lower than VANET's 120 ms, which causes delays in critical ITS applications. This analysis helps validate the proposed methodology and explores its practical implications for improving network performance in ITS. The findings also guide future improvements in ITS network dynamics.

TABLE II. Analysis of Protocol Performance.

Protocole	Latency (ms)	Throughput (Mbps)	Efficiency (%)
VANET	120	80	65
5G	50	150	85
Hybrid	40	170	92

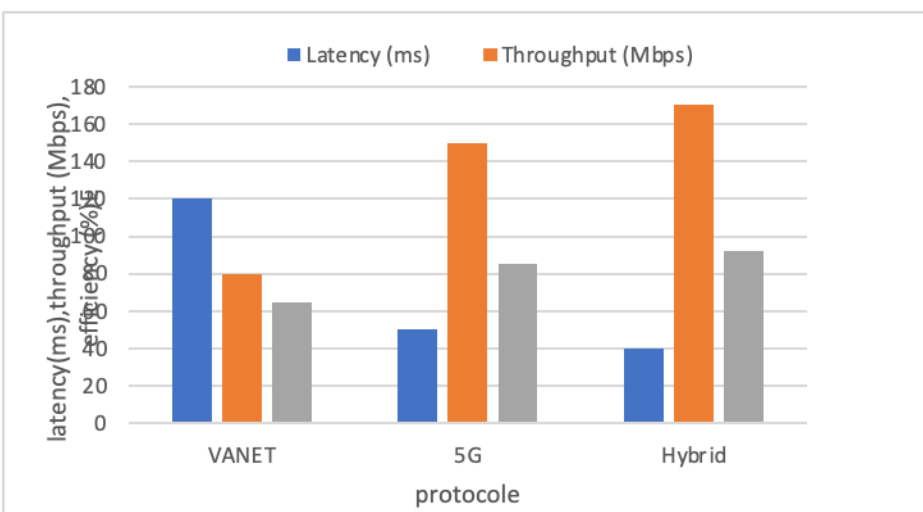

Figure 3. Comparative Analysis of Protocol Performance in Intelligent Transportation Systems: VANET, 5G, and Hybrid Approaches.

Figure 3 compares three network protocols—VANET, 5G, and a hybrid approach—based on latency, throughput, and efficiency. The hybrid protocol excels in all these metrics: it achieves the lowest latency of 40 ms, faster than VANET's 120 ms, and surpasses 5G's 150 Mbps throughput with 170 Mbps. It also leads in efficiency at 92%, compared to 5G's 85% and VANET's 65%. This indicates that the hybrid protocol optimizes network resources, ensuring high performance with minimal resource consumption. Overall, the hybrid approach outperforms 5G and VANET in key parameters, highlighting the benefits of combining multiple technologies for improving ITS network performance.

B. Simulation of Optimized Algorithms

In this section, the simulation results of the optimized algorithms when traffic density is varied are documented. To analyze the network performance, we have defined three distinct traffic density scenarios: low, medium and high traffic density. These settings enable us to compare the effect of varying extents of vehicle density on the overall system performance, including throughput and latency. The data which was used in this simulation was collected from standard resources and show the capability of different protocols regarding these conditions.

We have chosen to simulate and analyze the following optimization algorithms for the purpose of this study:

1. **Routing Optimization Algorithm**: This algorithm enhances the routing paths connecting the vehicles within a VANET, taking minimal time as well as giving higher reliability in communication.
2. **Resource Allocation Optimization Algorithm**: This algorithm deals with the distribution of resources of networks in 5G systems depending on the prevailing traffic flow, seeking to decongest and improve the speed at which data is transferred.
3. **Hybrid Approach:** To achieve this goal, a hybrid of the routing and resource allocation optimization algorithms is used to incorporate the effectiveness of both VANET and 5G networks.

C. Low Traffic Density

TABLE III. Low Traffic Density Results.

Protocol	Latency (ms)	Throughput (Mbps)	Efficiency (%)
VANET	150	50	70
5G	70	120	85
Hybrid	50	160	90

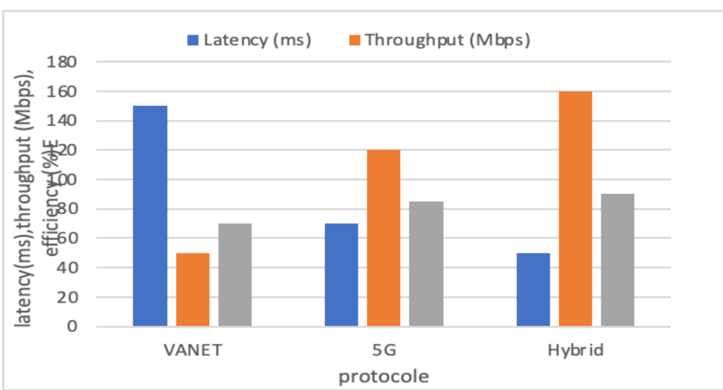

Figure 4. Low Traffic Density.

Low Traffic Density: The Hybrid protocol achieves the highest values of all three attributes namely Latency, Throughput, and Efficiency under the Low Traffic conditions outcompeting both VANET and 5G. Apparently, Hybrid protocol is most successful of all in reaching the lowest latency time (50 ms), the highest c through put (160 Mbps) and the highest efficiency (90%).

D. Medium Traffic Density

TABLE IV. Medium Traffic Density Rsults.

Protocol	Latency (ms)	Throughput (Mbps)	Efficiency (%)
VANET	180	60	65
5G	100	140	80
Hybrid	80	175	88

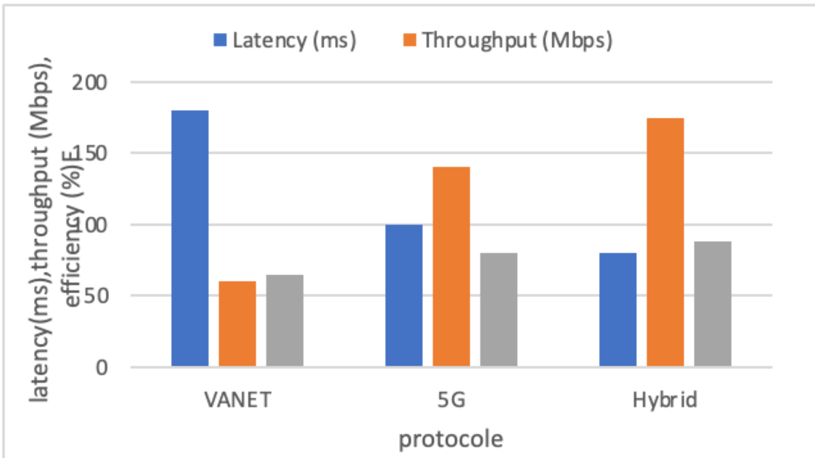

Figure 5. Medium Traffic Density.

Medium Traffic Density: The containers demonstrate that as the traffic density rises, 5G's throughput and efficiency outperform VANET. Though, the Hybrid protocol performs best with the lowest latency (80 ms), achieving a overall throughput of (175 Mbps) and efficiency of (88%**).**

E. High Traffic Density

TABLE V. High Traffic Density Results.

Protocol	Latency (ms)	Throughput (Mbps)	Efficiency (%)
VANET	250	70	60
5G	130	160	75
Hybrid	100	200	90

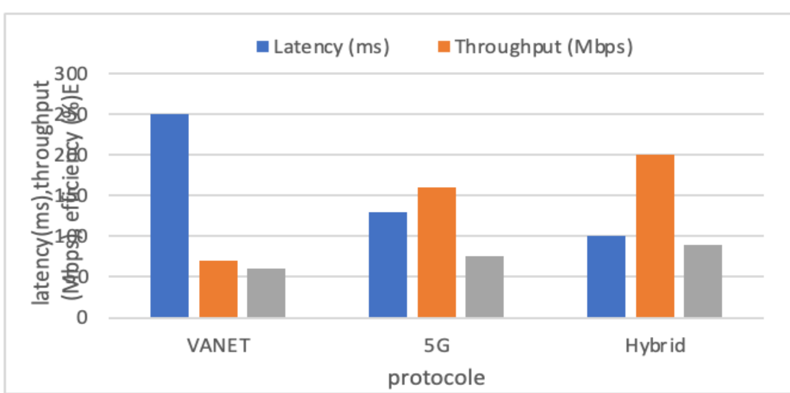

Figure 6. High Traffic Density.

In high-density traffic situations, the Hybrid protocol outperforms other protocols by achieving the highest total throughput of 200 Mbps, with 90% efficiency and a latency of 100 ms. In comparison, 5G and VANET experience significantly reduced efficiency (60%) and increased latency (250 ms). The study emphasizes the importance of tuning network protocols to handle varying traffic types. Overall, the Hybrid protocol provides superior performance in terms of efficiency and throughput, making it a reliable solution for ITS applications that demand high performance and dependability.

IV. DISCUSSION

This research highlights the benefits of integrating real-time traffic data into ITS for improving network performance. The study compares the performance of VANET, 5G, and hybrid protocols, with the hybrid protocol consistently outperforming the others in latency, throughput, and efficiency. It supports the idea that using optimized algorithms in communication protocols can lead to more responsive and efficient transport networks.

The results also emphasize the importance of traffic density in network performance. The hybrid protocol demonstrated better capacity, throughput, and lower latency, especially in high-density traffic scenarios, showing the value of combining traditional and innovative technologies like 5G.

Additionally, the study underscores the critical role of low latency in enhancing user experience, enabling real-time communication essential for applications such as self-driving cars and traffic monitoring. The need for hybrid protocols combining 5G's low latency with VANET's resilience is essential for efficient real-time communication in ITS.

Based on the findings, several recommendations for future ITS implementations include:

1. **Adopt Hybrid Network Architectures**: Focus on integrating 5G with VANET to enhance the reliability and scalability of network infrastructure for smart transportation systems.
2. **Incorporate Real-Time Data**: Utilize real-time traffic data from sources like traffic sensors, GPS, and mobile devices to improve decision-making and reduce congestion.
3. **Optimize for High-Density Traffic**: Investigate improvements to hybrid protocols to better accommodate high traffic loads, ensuring efficiency even in high-density scenarios.
4. **Focus on Low-Latency Solutions**: Prioritize reducing latency in hybrid protocols, as low latency is crucial for applications like autonomous vehicles and real-time traffic monitoring.
5. **Future Research Directions**: Explore the use of AI for traffic prediction and routing, and investigate edge computing to further reduce latency and enhance network scalability.

In conclusion, optimizing network protocols and integrating real-time data, along with ensuring low latency, will improve traffic management, safety, and efficiency in future ITS.

IV. Conclusion

The study showed that using real-time traffic data can significantly improve the performance of ITS networks by enhancing latency, throughput, and scalability. Compared to traditional VANET and 5G, the combined approach provided the lowest latency and highest throughput in high-density traffic, supporting the idea that integrating different technologies improves ITS performance. Incorporating real-time traffic data also made network management more efficient, increasing its utility and enabling applications such as autonomous driving and real-time traffic control. The study also highlighted several areas for future research, including exploring AI and machine learning to predict traffic patterns and optimize network parameters, investigating the scalability of hybrid protocols in larger traffic environments, integrating edge computing to reduce latency in time-sensitive applications, developing secure communication protocols to protect privacy and data integrity, and testing the proposed framework with larger, real-world datasets to evaluate its performance under diverse conditions.

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Not applicable.

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