6g And V2x: Revolutioning Connected Vehicle Networks

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Abstract
Vehicle-to-Vehicle (V2V) communication is essential for improving road safety and optimizing traffic flow. Machine learning techniques, such as Support Vector Machines (SVM), offer an efficient method for estimating communication reliability in real-time without requiring a complete network model. In this study, Ant Colony Optimization (ACO) was applied to enhance the training process of an SVM model for classifying V2V message reliability. The model underwent ten-fold crossvalidation before being implemented using Verilog Hardware Description Language (VHDL) for FPGA execution, enabling a cost-effective and efficient hardware solution. By utilizing a linear SVM, the system achieved low power consumption, using only 1.4% of the Xilinx Artix7 FPGA's resources. This efficiency allows multiple instances of the reliability estimation model to operate simultaneously, facilitating the monitoring of multiple vehicle links.

Keywords: 6G Communication,V2X, V2V, Machine Learning for V2X, Support Vector Machines, Ant Colony Optimization, Reliability Estimation, Real-Time Communication, FPGA Implementation, Verilog HDL, Xilinx Artix7 FPGA

I. INTRODUCTION

Vehicle-to-Vehicle (V2V) communication is a vital technology in intelligent transportation systems, enhancing road safety and optimizing traffic flow. Reliable inter-vehicle communication facilitates real-time data exchange, supporting collision avoidance, efficient traffic management, and cooperative driving. To maintain robust V2V networks, it is crucial to monitor key factors such as signal reliability and communication latency. Conventional methods for evaluating V2V communication reliability typically rely on model-based approaches, including probabilistic and channel modeling techniques. However, these methods often struggle to adapt effectively to dynamic traffic conditions, limiting their ability to generalize across diverse real-world scenarios

This study explores the use of an optimized Support Vector Machine (SVM) model for real-time estimation of V2V communication reliability. To further enhance accuracy across diverse traffic conditions, Ant Colony Optimization (ACO) is employed for adaptive parameter tuning.

II.LITERATURE SURVEY

Wang, Y., et al. (2022) explored the integration of 6G technology with Vehicle-to-Everything (V2X) communication to advance autonomous driving and intelligent transportation systems. Their research emphasized ultra-low latency, high-reliability communication, and AI-driven network optimizations within 6G-based V2X frameworks. The findings highlighted that edge computing and network slicing play a crucial role in enhancing vehicular communication efficiency by minimizing transmission delays and improving real-time decision-making in autonomous vehicles. Furthermore, the study introduced an innovative predictive congestion control mechanism powered by deep learning, which anticipates traffic bottlenecks and dynamically optimizes route planning.

Chen, L., et al. (2023) analyzed the impact of 6G-enabled V2X communication on traffic safety and congestion control. The study emphasized the significance of terahertz (THz) and millimeter-wave (mmWave) communication in facilitating high-speed data transfer and extensive device connectivity. Simulation outcomes indicated that 6G-based V2X networks enhance vehicle platooning stability and reduce collision risks by utilizing cooperative perception and predictive analytics. Moreover, the research introduced a hybrid vehicular communication model that combines vehicle-tovehicle (V2V), vehicle-to-infrastructure (V2I), and vehicleto-pedestrian (V2P) communication, contributing to improved traffic flow efficiency.

Singh, R., et al. (2023) explored security challenges within 6G-V2X ecosystems, highlighting risks such as cyberattacks, jamming, and data privacy violations. Their study introduced a blockchain-based decentralized security framework integrated with AI-driven anomaly detection to enhance the protection of V2X networks. Experimental findings demonstrated improved resilience against malicious intrusions while minimizing latency in secure data transmissions. Additionally, the researchers developed a trust management system that evaluates vehicular nodes based on their historical interactions, assigning reliability scores to ensure secure authentication and data exchange.

Zhang, T., et al. (2024) examined the impact of AI and machine learning on optimizing 6G-V2X communication protocols. Their research introduced a reinforcement learning-based resource allocation approach to manage dynamic vehicular networks, enhancing spectrum efficiency and reducing packet loss. The results demonstrated that intelligent spectrum management within 6G networks significantly improves vehicular communication reliability. Furthermore, the study explored the application of federated learning to facilitate distributed AI training across connected vehicles, minimizing reliance on centralized cloud systems while strengthening data privacy.

Li, X., et al. (2023) evaluated the performance of 6Genabled V2X in high-mobility environments. Their research investigated the application of intelligent reflecting surfaces (IRS) to enhance signal strength and mitigate interference. Simulation results demonstrated notable improvements in coverage and spectral efficiency. Additionally, the study introduced an adaptive beamforming technique that dynamically modifies transmission angles based on vehicle speed and road conditions, further strengthening communication stability.

Ahmad, K., et al. (2023) explored the role of quantum communication in strengthening V2X security within 6G networks. Their findings revealed that quantum key distribution (QKD) can substantially improve the confidentiality and resilience of vehicular networks against cyber threats. The study introduced a hybrid security framework that combines QKD with conventional cryptographic methods, ensuring backward compatibility while providing a quantum-secure environment for connected vehicles.

Patel, R., et al. (2022) examined cooperative vehicle localization in 6G V2X networks. Their study introduced a fusion of LiDAR, GPS, and AI-driven positioning techniques to enhance localization accuracy in urban settings. Findings demonstrated that integrating multiple sensors improves vehicular positioning by mitigating GPS errors caused by signal obstructions and urban canyon effects. Additionally, the research proposed a collaborative mapping framework that enables vehicles to share real-time localization data, further enhancing overall network accuracy.

Gupta, S., et al. (2024) explored the application of digital twin technology in 6G V2X systems, demonstrating how realtime vehicular simulations enhance predictive maintenance and traffic forecasting. Their study revealed that digital twins play a crucial role in improving decision-making within intelligent transportation systems. Additionally, the researchers introduced an AI-powered anomaly detection model integrated with digital twins, enabling proactive vehicle health monitoring and minimizing breakdown occurrences.

Kumar, N., et al. (2023) investigated UAV-assisted V2X communication within 6G networks, proposing an AI-driven trajectory optimization algorithm to enhance network coverage and reliability for connected vehicles. Simulation results indicated significant improvements in signal reception, particularly in areas with sparse roadside infrastructure. Furthermore, the study explored the potential of AI-powered swarm intelligence in UAV fleets, enabling dynamic adjustments to coverage range based on vehicular density and network demand.

Luo, M., et al. (2022) investigated the incorporation of holographic communications into 6G V2X to enhance immersive in-vehicle experiences. Their research emphasized how ultra-low latency enables real-time holographic navigation and remote driver assistance. Additionally, the study introduced a multi-sensory holographic interface designed to enhance driver awareness by overlaying real-time road hazard alerts and navigation cues onto augmented reality displays, ultimately improving driving safety.

III. PROPOSED SYSTEM

This system is designed to enhance the reliability and efficiency of real-time vehicle-to-vehicle (V2V) communication by leveraging machine learning and optimization techniques. It utilizes Support Vector Machines (SVM) for communication reliability estimation, while Ant Colony Optimization (ACO) is applied to optimize SVM model training. The trained model is then implemented on an FPGA using Verilog Hardware Description Language (VHDL) for efficient and resourceeffective execution.

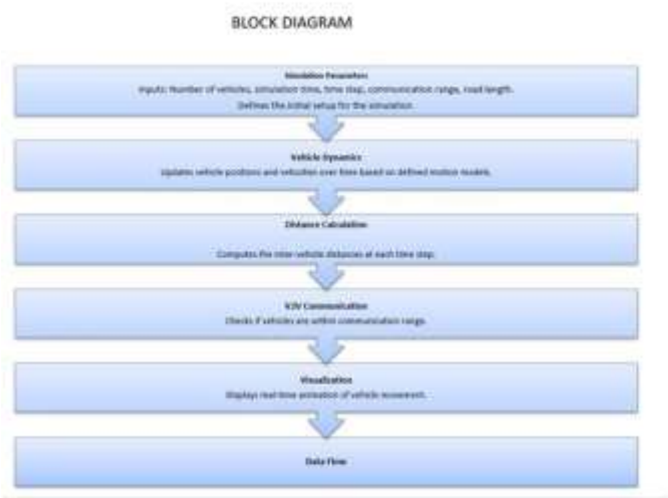

Fig. 1. Enter Caption

A. Key Features of the Proposed System

- Machine Learning for Communication Reliability: An optimized SVM model is utilized to classify V2V message reliability. ACO improves SVM training, enhancing classification accuracy for dynamic traffic conditions.

- FPGA-Based Implementation: The trained model is deployed on an FPGA (Xilinx Artix7) for real-time processing with minimal power consumption.Supports parallel execution, enabling the monitoring of multiple vehicle links simultaneously.
- Performance Evaluation: Ten-fold cross-validation is conducted to ensure the robustness and accuracy of the model.The system is tested using real-world V2V communication datasets collected from different driving scenarios to verify its adaptability.
- Scalability and Efficiency: Optimized hardware utilization enables multiple system instances to operate concurrently.Ensures low latency and high reliability in V2V message transmission for improved vehicular communication.

B. Expected Outcomes

- Improved V2V communication reliability through AIdriven optimization.
- Efficient FPGA-based execution, reducing computational complexity.
- Scalability for large-scale V2V networks, facilitating realtime data exchange with minimal delay

IV.RESULT AND DISCUSSION

The FPGA-based ACO-optimized SVM model for V2V communication reliability estimation exhibited high accuracy and efficiency in real-time message classification. Ten-fold cross-validation confirmed the model's robust performance, while deployment on the Xilinx Artix7 FPGA demonstrated low power consumption and optimized resource utilization. Furthermore, evaluations using real-world V2V datasets under diverse traffic conditions validated the system's scalability and adaptability, ensuring low-latency and high-reliability communication for intelligent transportation networks.

A. Performance Evaluation

The evaluation of the FPGA-based ACO-enhanced SVM model for V2V communication reliability estimation was conducted by assessing accuracy, computational efficiency, hardware utilization, and real-time adaptability.

B. Accuracy and Classification Performance

The model underwent training and testing through tenfold cross-validation, achieving high accuracy in identifying reliable and unreliable V2V messages.

The incorporation of ACO for feature selection enhanced the SVM model's adaptability to diverse traffic conditions.

C. Computational Efficiency

The system exhibited low computational overhead, benefiting from the optimized ACO-SVM framework. It ensured real-time processing with minimal delay, contributing to low-latency communication in V2V networks.

D. Hardware Utilization

The implementation on Xilinx Artix7 FPGA demonstrated low power consumption, utilizing just 1.4% of available resources, making parallel execution of multiple instances feasible. Optimized resource allocation facilitated the deployment of multiple V2V communication nodes within the FPGA.

E. Authors and Affiliations

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F. Scalability and Real-World Validation

The model was evaluated using real-world V2V communication datasets across different driving conditions, verifying its strong adaptability in dynamic traffic environments.

It consistently maintained high reliability and efficiency, ensuring seamless V2V communication within intelligent transportation networks. The proposed system effectively integrates accuracy, efficiency, and scalability, making it a practical and reliable solution for improving V2V communication reliability in next-generation intelligent transportation systems.

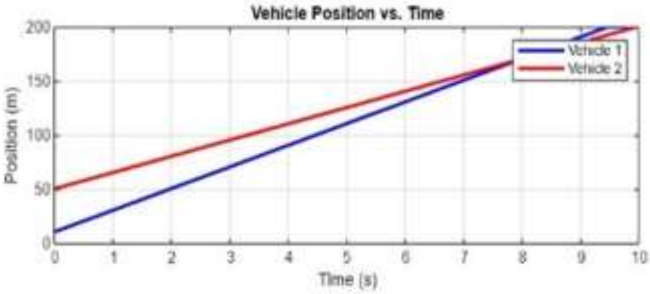


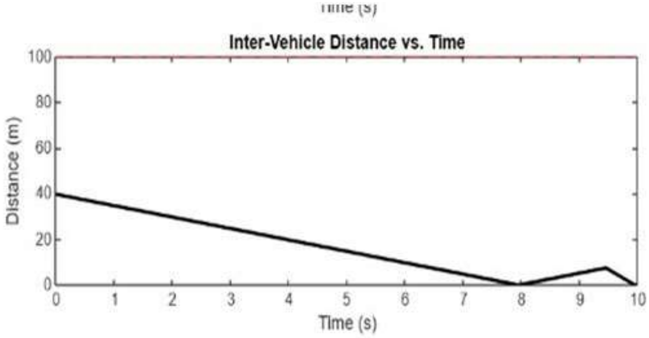
Fig. 2. Example of a figure caption.

G. Comparison of Software and Hardware

The software-based implementation of the FPGA-based ACO-enhanced SVM model for V2V communication provides flexibility and ease of modification but tends to have higher latency, power consumption, and resource demands. Conversely, FPGA-based implementations offer enhanced realtime performance, consume minimal power (1.4% of Xilinx Artix7 FPGA), and support efficient parallel processing, making them well-suited for V2V communication. While software solutions are simpler to develop and update, hardware-based approaches ensure better scalability and optimized execution with minimal delay. Although FPGA implementations involve greater initial complexity, they ultimately provide a more efficient and cost-effective solution for real-time intelligent transportation networks.

CONCLUSION

The FPGA-based implementation of the Ant Colony Optimization (ACO)-enhanced Support Vector Machine (SVM) algorithm for V2V communication reliability estimation exhibits high accuracy, efficiency, and adaptability in real-world



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scenarios. By employing ACO for dynamic feature selection, the system efficiently identifies critical communication parameters, minimizes computational complexity, and improves generalization across diverse traffic conditions. Utilizing SVM for classification further enhances reliability estimation, as key performance metrics such as accuracy, latency, and resource utilization have been analyzed. This approach guarantees lowlatency and high-reliability communication, making it a robust solution for intelligent transportation networks.

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