**Abstract**

Non-Line-of-Sight (NLOS) vehicle localization is a major challenge in Vehicular Ad Hoc Networks (VANETs), affecting node positioning and emergency message dissemination. Traditional methods struggle with dynamic obstacles, high mobility, and signal interference, leading to delays and reduced packet delivery. This research proposes a hybrid metaheuristic approach integrating Ant Colony Optimization (ACO) and Simulated Annealing (SA) to enhance NLOS localization accuracy. ACO efficiently explores optimal node positions but risks premature convergence to suboptimal solutions. SA refines these solutions using probabilistic perturbations, improving global optimization. This hybrid approach enhances localization precision, reduces message delays, and improves packet delivery rates, ensuring reliable communication in urban VANETs. Extensive simulations show that ACO-SA outperforms standalone ACO, SA, and conventional techniques in accuracy, scalability, and efficiency. By optimizing node placement and message routing, this system supports intelligent transportation and emergency response, advancing next-generation VANET applications in smart cities.

**Keywords:** *NLOS localization, Vehicular Ad Hoc Networks (VANETs), Ant Colony Optimization (ACO), Simulated Annealing (SA), intelligent transportation systems.*

**Introduction**

Vehicular Ad Hoc Networks (VANETs) play a crucial role in intelligent transportation systems, enabling seamless communication among vehicles, infrastructure, and pedestrians. One of the significant challenges in VANETs is the rapid and reliable dissemination of emergency messages, especially under Non-Line-of-Sight (NLOS) conditions. Various optimization algorithms have been employed to enhance node localization, routing, and data dissemination in VANETs. A hybrid approach combining Ant Colony Optimization (ACO) and Simulated Annealing (SA) has shown promise in optimizing node localization and minimizing transmission delays, thereby improving emergency message propagation. ACO, inspired by the pheromone-based foraging behavior of ants, has been extensively utilized in VANETs for efficient routing and clustering. Studies such as [2, 5, 8] demonstrate its effectiveness in optimizing network performance and data transmission. Meanwhile, SA, a probabilistic technique that simulates the annealing process of metals, helps escape local optima to find global solutions. Research in [7, 24, 29] highlights SA’s potential in solving complex optimization problems, making it a valuable addition to VANETs. Additionally, integrating these techniques with machine learning and reinforcement learning approaches can further improve network efficiency and adaptability in real-time scenarios.

Hybrid optimization techniques integrating ACO with other metaheuristic algorithms have been explored to enhance VANET efficiency. The study in [9] introduces CACONET, an ACO-based clustering algorithm that improves network performance, while [1] proposes a Spotted Hyena Optimization and SA-based NLOS localization scheme that enhances node localization accuracy. Other bio-inspired algorithms such as Particle Swarm Optimization (PSO) [6], Gray Wolf Optimization [12], and hybrid Crow Search-Gray Wolf Optimization [13] have been applied to improve localization accuracy, further optimizing vehicle positioning for better emergency message propagation. Additionally, emerging technologies such as 5G-based cooperative localization methods in [18, 19, 20] offer precise vehicle positioning for reliable data dissemination. These studies highlight the importance of integrating multiple optimization techniques to ensure robust and scalable solutions in VANETs. Moreover, the inclusion of blockchain-based security mechanisms can enhance data integrity and prevent malicious attacks, strengthening the overall reliability of VANET communication.

A hybrid ACO-SA approach presents a promising solution for optimizing emergency message dissemination in VANETs. By leveraging ACO’s dynamic path optimization and SA’s ability to escape local optima, this method enhances message reliability, reduces transmission delays, and optimizes network resource utilization under NLOS conditions. Studies such as [25, 28, 30] further validate the effectiveness of this hybrid approach in solving complex network routing and scheduling problems. The integration of ACO and SA not only improves VANET performance but also paves the way for future advancements in intelligent transportation systems, ensuring efficient and timely emergency communication. Furthermore, the combination of deep learning techniques with ACO and SA can refine decision-making processes in vehicular networks, enabling predictive analytics for congestion control, accident prevention, and traffic flow optimization. As VANETs continue to evolve, hybrid models incorporating optimization algorithms, AI-driven methodologies, and emerging wireless communication technologies will be pivotal in shaping next-generation intelligent transportation systems.