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VULTURE OPTIMIZATION ALGORITHM BASED HIERARCHICAL ROUTING STRATEGY (VOA-HRS) FOR VEHICULAR AD HOC NETWORKS

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Abstract

Vehicle surroundings are dynamic and movable, which poses special problems for Vehicular Ad Hoc Networks (VANETs). For the provision of different services, traffic control, and road safety, effective vehicle-to-vehicle communication is essential. The Vulture Optimization Algorithm based Hierarchical Routing Strategy (VOA-HRS), a revolutionary approach created especially to handle the complexities of routing in VANETs, is introduced in this study. To improve the efficiency and dependability of data transfer in automotive networks, VOA-HRS establishes a hierarchical routing system based on the concepts of the Vulture Optimization Algorithm. Because of the hierarchical architecture, communication within clusters may be effectively organized and managed by designating cluster heads according to predetermined criteria. The architecture, design, and implementation of VOA-HRS are covered in this research work, along with performance assessments utilizing important metrics such routing overhead, packet delivery ratio, and end-to-end delay. The simulation findings show encouraging gains in network performance and routing efficiency, proving the practicality and efficacy of VOA-HRS in resolving routing issues in VANETs.

Keywords: Vehicular Ad hoc Network, Routing, Vulture Optimization Algorithm, Throughput, Delay, Overhead, Simulation.

1. Introduction

Specialized Mobile Ad Hoc Networks (MANETs) designed specifically to facilitate smooth vehicle-to-vehicle communication are known as Vehicular Ad Hoc Networks (VANETs). Vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) communications are made possible by VANETs, which use wireless communication technologies to build dynamic networks. This turns conventional automobiles into intelligent beings operating in a networked environment. In Fig. 1, an illustrative VANET environment is shown.

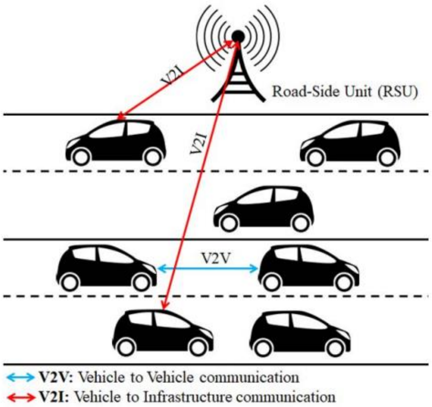

Fig. 1. Structure of VANET

1.1. Applications of VANETs:

VANETs have a wide range of applications that affect several aspects of road safety and contemporary transportation systems. Enabling the real-time transmission of vital information among vehicles to prevent accidents and alleviate traffic congestion is one of the main applications for improving road safety. Additionally, VANETs are essential for streamlining traffic, offering clever routing and navigation, assisting with emergency vehicle prioritizing, and supplying passengers with infotainment and entertainment.

1.2. Characteristics of VANETs:

Because vehicular surroundings are dynamic and movable, VANETs have various unique properties. These include different vehicle densities, fast-changing network topologies, sporadic connectivity, high mobility, and strict latency requirements for safety applications that depend on reaction times. Furthermore, due to the highly decentralized character of VANETs, effective and dependable communication is maintained despite the network's dynamic nature by depending on the collaboration and prompt decision-making abilities of the vehicles. Essentially, the convergence of wireless communication technologies with automotive systems has led to the development of VANETs, which are transforming transportation networks through the promotion of connection, safety, and intelligent services on roads.

1.3. Motivation and Problem Statement

The purpose of VOA-HRS is to rectify the deficiencies of traditional routing protocols on VANETs. The dynamic nature of automotive networks is often too much for the protocols that are in place, which can result in problems including packet loss, increased latency, poor route selection, and scalability limitations. The VOA-HRS is a novel approach that specifically establishes a hierarchical routing strategy for VANETs by utilizing the Vulture Optimization Algorithm. The main objective is to provide a novel architecture that maximizes communication channels, reduces latency, boosts dependability, and boosts network efficiency in automotive settings.

The main issue facing vehicle ad hoc networks (VANETs) is the inadequacies and constraints of current routing protocols in handling the complex and dynamic nature of automotive surroundings. Because VANETs are characterized by high mobility, intermittent connectivity, and rapid changes in network topologies, conventional routing algorithms have difficulty keeping up. The smooth transfer of vital information between vehicles is hampered as a result of reduced communication efficiency, higher latency, packet loss, and poor route choices.

The requirement for an enhanced routing method designed especially for VANETs is the issue that VOA-HRS attempts to solve. Creating a hierarchical routing architecture that maximizes communication channels, reduces latency, boosts dependability, and boosts network performance overall is the goal. By introducing a novel hierarchical structure enabled by the Vulture Optimization Algorithm, VOA-HRS seeks to overcome the drawbacks of conventional protocols. Its ultimate goal is to revolutionize routing strategies in VANETs and guarantee effective, dependable, and timely information exchange among vehicles.

1.4. Objectives

Creating and implementing a unique Hierarchical Routing Strategy (VOA-HRS) specifically designed for VANETs is the main objective. This entails creating a hierarchical structure inside the network, appointing cluster leaders, and clustering automobiles according to predetermined standards. The goal is to maximize packet loss, minimize delays, and improve overall communication efficiency by optimizing routing choices and communication channels among vehicles by utilizing the concepts of the Vulture Optimization Algorithm

(VOA). This research uses simulations and performance evaluations in realistic vehicular scenarios to test and assess the efficacy, scalability, and dependability of VOA-HRS.

Furthermore, a comparison analysis highlighting the advantages and enhancements of VOA-HRS will be carried out to evaluate it against traditional routing protocols in VANETs. In the end, these goals seek to expand VANET routing techniques by presenting a novel framework that tackles the difficulties present in vehicular contexts and improves the dependability and efficiency of vehicle-to-vehicle communication networks.

1.5. Organization of the Paper

The paper is organized as follows. Section – 2 emphasizes on related works. Section – 3 presents the proposed routing strategy. Section – 4 elaborates on the simulation environment. Section – 5 displays the performance metrics for evaluating the efficacy of the proposed routing strategy. Section – 6 showcases results and discussions on it. Section 7 gives concluding remarks.

2. Related Works

This section presents various related works for the problem statement and objectives as discussed in the previous section.

2.1. TAD-HOC Routing Protocol for VANETs ([1])

The TAD-HOC routing protocol was developed by Sadakale, Ramesh, and Patil as a creative solution designed specifically for infrastructure-oriented communication networks and vehicular ad hoc networks (VANETs). Their protocol aims to maximize communication robustness and efficiency while addressing the difficulties present in extremely dynamic vehicle situations. The TAD-HOC protocol most likely uses dynamic route selection methods that adjust to shifting network conditions by utilizing adaptive strategies, guaranteeing dependable and effective data sharing between cars. The focus on infrastructure-oriented communication points to a strategy that makes effective use of the infrastructure support that is already in place to increase network connectivity and stability, which may improve communication performance in mobile situations.

2. 2. Simulation-Based Analysis of Routing Protocols ([2])

An extensive simulation-based study on ad hoc routing protocols in urban and highway VANET situations was carried out by Singh, Lego, and Tuithung. They examined a wide range of routing systems in detail, perhaps taking into account measures like packet delivery ratio, end-to-end latency, and routing overhead. The investigation most likely offered insightful information about how various protocols function in a range of mobility patterns and surroundings by simulating a variety of traffic and environmental scenarios. This comparison analysis probably helped determine the advantages and disadvantages of each protocol, which helped choose appropriate routing techniques depending on particular VANET scenarios.

2. 3. GBSR-B Routing Protocol Enhancement ([3])

The GBSR-B protocol was first presented by Barba, Aguiar, and Igartua as an improved variant of GPSR (Greedy Perimeter Stateless Routing) designed specifically for VANETs. Their improvement of the protocol most likely aims to increase routing efficiency by tackling the particular problems that come with metropolitan contexts. GBSR-B has the ability to apply optimizations to route selection algorithms by utilizing geographic data and adjusting to different vehicle movement patterns that are frequently seen in urban settings. This improvement most likely attempts to address issues with dynamic topology changes and sporadic connectivity by customizing GPSR for VANETs, which will lead to more dependable and effective routing in urban vehicular contexts.

2. 4. Analysis of Routing Protocols in Urban Scenarios ([4])

The study by Ferronato and Trentin examines the performance of three well-known routing protocols—OLSR, AODV, and ZRP—in real-world urban vehicular settings. Evaluating important performance indicators including packet delivery, delay, scalability, and overhead was probably part of this in-depth investigation. Through simulations in dynamic urban environments with varying density of nodes, the study probably offered a thorough understanding of how these protocols handle changing urban scenarios. This comparison analysis probably helps determine the efficacy and adaptability of each protocol, which helps choose appropriate routing techniques designed for urban VANET environments.

2. 5. Optimization Techniques: Genetic Algorithms and Firefly Optimization ([5]-[7])

A genetic algorithm-based optimization technique was used by Jafer et al. ([5]) to improve broadcasting strategies in VANETs. Their efforts probably concentrated on optimizing broadcasting tactics to increase the effectiveness of information dissemination among vehicles. An intelligent firefly-based multicast routing algorithm was presented by Elhoseny ([6]), which may help with effective multicast communication in vehicle networks. In the meantime, with the goal of improving routing efficiency through optimized clustering algorithms, Joshua et al. ([7]) suggested a reputation-based weighted clustering protocol employing a firefly optimization approach. By utilizing intelligent optimization paradigms, this research make use of swarm and evolutionary intelligence methodologies, which are predicted to improve the efficiency of routing and information dissemination in VANETs.

2. 6. Other Optimization Approaches and Protocols ([8]-[11])

Citations [8] through [11] offer a wide range of protocols and optimization strategies tailored for VANETs. One of the optimal routing algorithms ([8]) used in these investigations addresses the particular difficulties presented by car ad hoc networks. Moreover, the goals of hybrid genetic firefly algorithms ([11]), meta-heuristic-based optimal path determination ([10]), and grey wolf optimization for clustering ([9]) are to improve the routing, clustering, and data distribution of VANETs. This research probably offers creative fixes that make use of optimization paradigms, improving several facets of VANET efficiency and performance.

3. Proposed Work

An optimization algorithm influenced by biology, the Vulture Optimization Algorithm (VOA) simulates vulture hunting behavior. It is employed in a variety of optimization scenarios and has demonstrated the ability to effectively solve challenging issues. The goal of the VOA-HRS (Vulture Optimization Algorithm based Hierarchical Routing Strategy) is to optimize data packet routing within a vehicular network when it comes to Vehicular Ad Hoc Networks (VANETs). This approach makes use of the Vulture Optimization Algorithm's concepts to improve the effectiveness and performance of communication within VANETs.

The implementation of VOA-HRS is as follows.

3.1. Hierarchical Structure Establishment:

Initialization: Every vehicle in the VANET sets up its properties, such as its computational power, available resources, and connectivity state.

Cluster Head Selection: If a vehicle satisfies specific requirements, it may elect itself as a candidate for cluster head (such as improved connection or an abundance of resources). The predetermined criteria are used to pick the cluster heads.

Cluster Formation: By requesting other vehicles to join their cluster, a few designated cluster heads form clusters around themselves.

Cluster heads are responsible for overseeing and arranging communication within their respective clusters. This entails managing coordination, routing, and ongoing network condition monitoring.

Pseudocode for Hierarchical Structure Establishment

```
Procedure VOA_HRS_Hierarchical_Structure_Establishment ():
  Initialize vehicles in the VANET with their parameters
  Repeat until convergence or specific conditions are met:
    For each vehicle v in the VANET:
      If v meets criteria to become a cluster head:
        Become a candidate for a cluster head
      else:
        Continue as a regular node
    Determine criteria for selecting cluster heads (e.g., strongest connectivity, most available resources)
    Select cluster heads based on the determined criteria
    Form clusters around selected cluster heads
    Organize communication and management within clusters
    For each cluster head:
      Establish and maintain communication with cluster members
      Handle routing and coordination within the cluster
      Continuously monitor network conditions and adapt as needed
```

3.2. VOA-based Routing Optimization in VANETs:

Initialization: Set up the routing tables for every VANET vehicle.

Fitness Function Calculation: Based on certain parameters related to routing optimization, like distance, available bandwidth, traffic circumstances, or connection reliability, determine the fitness function value for each vehicle. One important tool for assessing the value or appropriateness of possible routes between cars is the fitness function. This function uses a number of variables related to routing optimization in VANETs to quantify a route's desirability or efficiency. As was previously indicated, the fitness function in this case might take into account a number of variables, including the distance, the bandwidth that is available, the volume of traffic, and the dependability of the connections between the vehicles.

Below is a mathematical representation of a fitness function that combines these parameters into a composite fitness value for a specific route between two vehicles V_{source} and $V_{destination}$ in a VANET:

Let's denote the fitness function as F, which is a function of various parameters:

$F(V_{source}, V_{destination} = w_1 * \text{Distance} + w2 * \text{Bandwidthx} + w_3 * \text{Traffic Conditions} + w_4 * \text{Connection Reliability}$

Where:

Distance represents the geographical distance between the source and destination vehicles.

Bandwidth indicates the available bandwidth along the route.

Traffic Conditions signify the current traffic density or congestion on the route.

Connection Reliability denotes the reliability or stability of the communication link between the vehicles.

The w_1, w_2, w_3, and w_4 are weight factors that determine the importance or priority given to each parameter in the fitness function. The fitness function aggregates multiple parameters, each weighted according to its significance in route evaluation. As mentioned earlier, the aim is to optimize the routing by identifying routes with lower distance, higher available bandwidth, favorable traffic conditions, and more reliable connections.

VOA Optimization Process: Based on the fitness value, each vehicle, which in the VOA metaphor represents a vulture, modifies its position (route) and velocity (information exchange). This stage simulates the motion of vultures searching for the best places within the algorithm.

Information Exchange for Routing:

Neighboring vehicles communicate with one another via routing information, keeping each other informed about the most recent routes and optimizations.

Route Adjustment: Each vehicle modifies its route based on the information shared, taking into account both received and local updates.

Iterations: To continuously improve the routing decisions based on VOA optimization and information exchange, the process iterates for a predetermined number of iterations or until convergence.

An example of how VOA could optimize routing in a VANET setting is shown in the following pseudocode. This pseudocode omits some of the more complex aspects of the VOA algorithm and assumes a simple representation.

Pseudocode for VOA_Route_Optimization

```
Procedure VOA_Routing_Optimization():
  Initialize routing table for each vehicle
  Repeat for a specified number of iterations or until convergence:
    For each vehicle v in the VANET:
      Determine neighboring vehicles within communication range
      Calculate fitness function value based on specific parameters (e.g., distance, available bandwidth, traffic conditions)
      Apply VOA optimization process to update routing:
      Repeat until convergence or specified iterations:
        Update position (route) of vulture (vehicle) based on fitness value
        Update velocity (information exchange) of vulture (vehicle)
    Share routing information among neighboring vehicles:
    For each pair of neighboring vehicles:
      Exchange routing information and update routing tables
    Update routing decisions based on received information:
```

```
    For each vehicle v in the VANET:
        Adjust routes based on exchanged information and local updates
Return optimized routing tables
```

3.3. Efficient Data Transmission

The goal of VOA-HRS is to improve the efficiency of data transmission within the VANET by utilizing VOA principles in route optimization. This entails determining the best routes for data packet routing, which ultimately results in:

Delays are Reduced: VOA-HRS-determined optimized routes reduce latency in the data transfer between cars. Faster data delivery is ensured by efficient pathways, which enhances network responsiveness overall.

Minimized Packet Loss: Better routing pathways make it less likely that packets will be lost during transmission, which increases the dependability of data transmission between cars.

Improved Network Performance: By obtaining optimized routing paths through VOA-HRS, the VANET's vehicles are able to exchange data more smoothly and effectively, leading to an overall improvement in network performance.

3.4. Enhanced Network Lifetime:

By using a variety of parameters that affect network resources and energy usage in its intelligent routing decisions, VOA-HRS helps to extend the life and sustainability of the VANET.

Preservation of Energy and Resources: The routing choices made by the algorithm consider things like the best routes in terms of energy consumption and the most effective use of the resources that are available (bandwidth, processing capability). In doing so, VOA-HRS contributes to the network's energy and resource conservation, enabling sustainable operation and an extended network lifetime.

Long-Term Operational Sustainability: VOA-HRS helps to maintain the VANET's long-term operational sustainability by means of its astute routing optimizations. The algorithm makes sure that the network can run effectively for longer periods of time without experiencing resource depletion or noticeable performance deterioration by conserving energy and resources.

Through the application of VOA-based routing optimizations, VOA-HRS greatly enhances the sustainability and lifespan of VANET operations by lowering latency and packet loss and increasing data transmission efficiency. Simulator settings are explained in detail in the next section.

4. Simulation Settings

Vehicles can communicate more effectively thanks to the dual antenna design used in this VANET simulation setting. Effective data exchange is possible within this radius because the communication range is set to 250 meters. Effective communication methods are used, with a data transmitting rate of 1.8 Mbps and the IEEE 802.11 MAC protocol with a speed of 10 Mbps. A hybrid mobility model is integrated into the simulation, taking into account different movement patterns inside the network. Nodes can be anywhere from 10 and 50, and each one can send up to 25 512-byte data packets. The propagation model that is employed is called Vehicle-to-Vehicle (V2V), and it emphasizes direct contact between cars. The UDP/CBR routing agent is used to make data transfer easier.

The simulation, which lasts for 3000 seconds, provides a thorough understanding of network behavior throughout time. Adaptive spectrum usage is made possible by cognitive radios, which solve spectrum shortage issues. Realistic mobility scenarios are ensured by the vehicle range speed variation between 10 and 80 kmph, and the vehicle density is kept at 30 nodes per kilometer to reflect the density of vehicular traffic in the simulated region. Table 1 also displays the simulation settings.

Table – 1: Simulation Settings

Parameters	Value
Antenna	Dual
Communication Range	250 meters
Data Sending Rate	1.8 Mbps
Jam Density (Blocked Traffic)	50 nodes / km
MAC	IEEE 802.11 (10 Mbps)
Maximum Speed	55 kmph
Minimum Speed	15 kmph
Mobility Model	Hybrid
Nodes	10, 20, 30, 40, 50
Number of Data Packets	25
Packet Size	512 bytes
Pair	20 (default)
Propagation Model	Vehicle-to-Vehicle (V2V)
Routing Agent	UDP / CBR
Simulation Time	3000 seconds
Spectrum Scarcity	Cognitive Radios
Vehicle Density	30 nodes / km
Vehicular Range Speed	10 – 80 kmph

5. Performance Metrics

Packet Delivery Ratio (PDR): This metric presents the proportion of successfully delivered data packets to all packets sent. It shows how consistently data is transmitted throughout the network.

End-to-End Delay: This metric is used to evaluate the time it takes for a packet to move from its source to its destination node. It assesses network responsiveness and data transfer efficiency.

Routing Overhead: This metric shows the extra control packets produced as a result of routing operations, demonstrating how well the routing protocol manages network resources.

Throughput: This metric presents the quantity of data that is successfully transferred over a network in a given amount of time is measured by throughput. It assesses the network's data transmission efficiency and capacity.

Average Energy Consumption: This metric determines how much energy each node used on average while the simulation was running. It is essential for evaluating the VANET's energy efficiency and network longevity.

Packet Loss: This metric reflects the packets that were dropped during transmission. Assesses how well routing techniques and the network operate to prevent packet loss.

Overhead of Control Packets: This metric determines how many control packets are utilized for administration and routing in relation to all data packets that are sent. It shows how effectively the protocol manages network resources.

6. Results and Discussions

In Vehicular Ad Hoc Networks (VANETs) with different node densities, the analysis contrasts two routing strategies: HGFA [11] and VOA-HRS (Vulture Optimization Algorithm based Hierarchical Routing Strategy). In numerous criteria, VOA-HRS regularly performs better than HGFA. When it comes to Packet Delivery Ratio (PDR), HGFA begins at 0.91 and drops to 0.87, whereas VOA-HRS maintains higher rates, beginning at 0.95 at 10 nodes and continuing at 0.91 even at 50 nodes. Fig. 2 displays the graphical result of the simulation. HGFA records end-to-end delays of 1484.80 whereas VOA-HRS records 1125.97 at 50 nodes, indicating reduced delays. Fig. 3 displays the graphical result of the simulation.

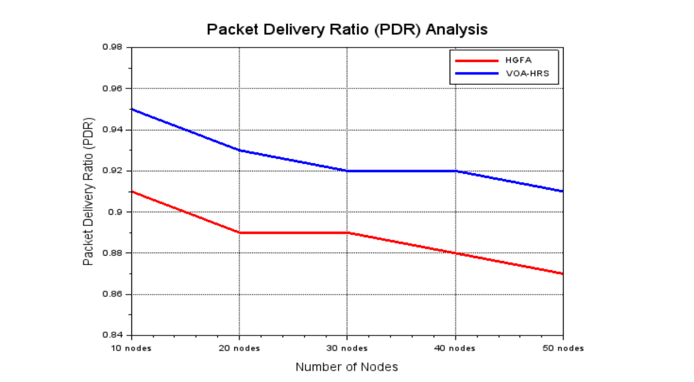

Fig. 2. Packet Delivery Ratio Analysis

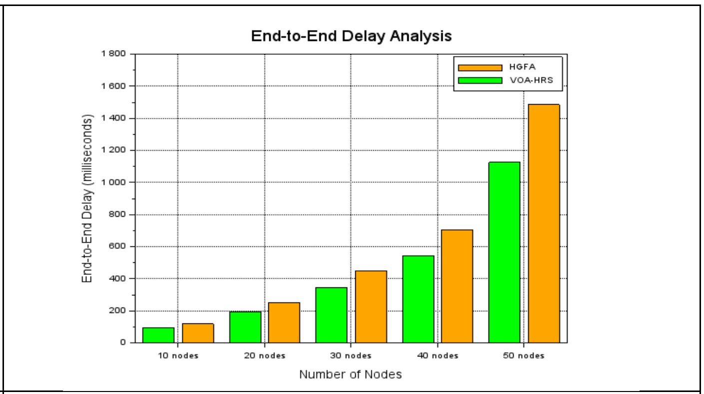

Fig. 3. End-to-End Delay Analysis

Routing overheads in HGFA range from 12 to 55 at 10 to 50 nodes, but VOA-HRS has significantly reduced routing overheads, ranging from 8 to 14. Fig. 4 displays the graphical result of the simulation. Furthermore, compared to HGFA, which averages 4659 to 22272, VOA-HRS shows superior throughput, averaging 4864 to 23296. Fig. 5 displays the graphical result of the simulation.

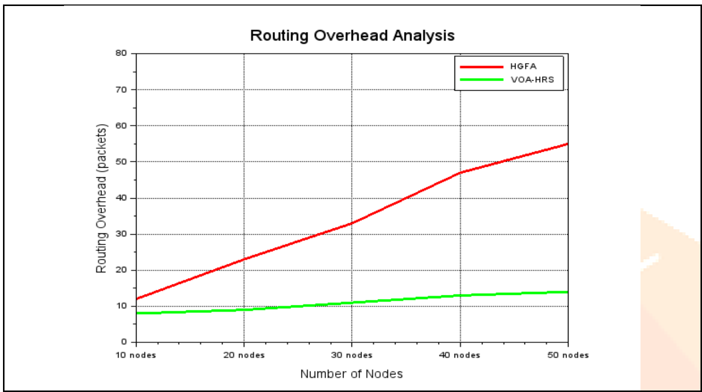

Fig. 4. Routing Overhead Analysis

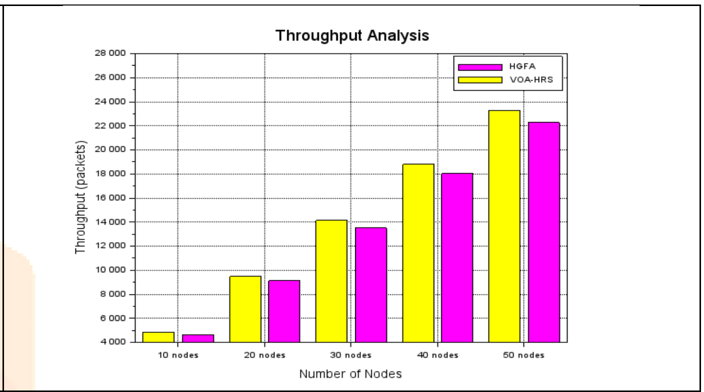

Fig. 5. Throughput Analysis

Furthermore, VOA-HRS emphasizes its effectiveness and superiority over HGFA in handling communication and routing difficulties within VANETs by maintaining lower energy consumption, packet loss rates, and control packet overheads. Figures 6, 7, and 8 display the graphical output of the simulation, accordingly. Table 2 presents the comprehensive numerical results.

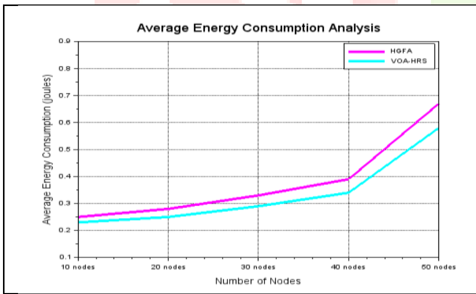

Fig. 6. Average Energy Consumption Analysis

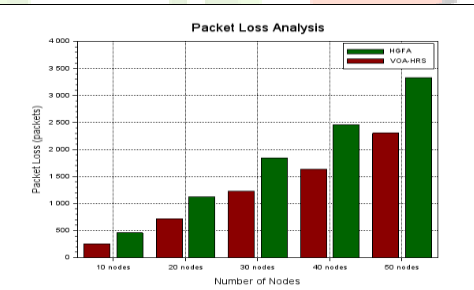

Fig. 7. Packet Loss Analysis

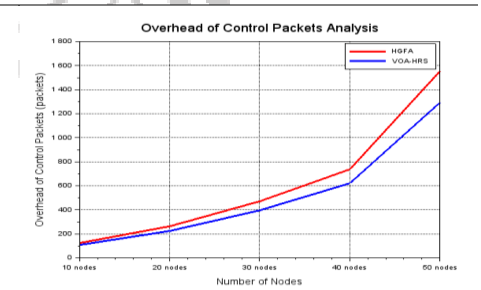

Fig. 8. Overhead of Control Packet Analysis

Table – 2: Simulation Results

Number of Nodes	Packet Delivery Ratio (PDR)		End-to-End Delay		Routing Overhead		Throughput		Average Energy Consumption		Packet Loss		Overhead of Control Packets	
	HGFA	VOA-HRS	HGFA	VOA-HRS	HGFA	VOA-HRS	HGFA	VOA-HRS	HGFA	VOA-HRS	HGFA	VOA -HRS	HGFA	VOA-HRS
10	0.91	0.95	118.60	93.89	12	8	4659	4864	0.25	0.23	461	256	124	108
20	0.89	0.93	252.08	195.36	23	9	9114	9523	0.28	0.25	1126	717	263	224
30	0.88	0.92	450.56	345.43	33	11	13517	14131	0.33	0.29	1843	1229	471	396
40	0.88	0.92	705.22	540.67	47	13	18022	18842	0.39	0.34	2458	1638	737	621
50	0.87	0.91	1484.8 0	1125.97	55	14	22272	23296	0.67	0.58	3328	2304	1553	1292

7. Conclusion

To sum up, this research proposes an innovative and efficient Hierarchical Routing Strategy (VOA-HRS) based on the Vulture Optimization Algorithm, which is specifically designed to handle the complexities of Vehicular Ad Hoc Networks (VANETs). Utilizing the Vulture Optimization Algorithm's (VOA) flexibility, the hierarchical routing framework improves the network's stability, scalability, and performance when managing the dynamic nature of vehicular situations. This research makes a substantial contribution to tackling the concerns related to high mobility, inconsistent connectivity, and scalability that are inherent in VANETs through the use of the VOA-HRS. The suggested approach shows promising results in routing path optimization, congestion reduction, network lifetime extension, and overall vehicular node communication efficiency by integrating the VOA's intelligence. Essentially, the VOA-HRS framework provides a viable path toward improving the effectiveness and dependability of communication in VANETs, providing a basis for future developments in routing algorithms specifically designed for the complex dynamics of vehicle networks.

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