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RESEARCH ARTICLE

Minimizing Energy Consumption in Vehicular Sensor Networks Using Relentless Particle Swarm Optimization Routing

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Abstract – Increasing traffic issues, particularly in highly populated nations, have prompted recent interest in Vehicular Sensor Networks (VSNETs) from academics in several fields. Accident rates continue to rise, highlighting the need for a highly functional Smart Transport System (STS). Improvements to the STS should not be spread thin across the board but should concentrate on improving traffic flow, maintaining system reliability, and decreasing vehicle carbon dioxide and methane emissions. Current routing protocols for VSNETs consider various scenarios and approaches to provide safe and effective vehicle-to-infrastructure communication. The reliability of vehicle connections during data transmission has not been well explored. This paper proposes a Relentless Particle Swarm Optimization based Routing Protocol (RPSORP) for VSNET to use vehicle kinematics and mobility to identify vehicle location, send routing information packets to road-side devices, and choose the most reliable path for travel. RPSORP optimizes local and global search to minimize energy consumption in VSNET. The RPSORP is evaluated in the GNS3 simulator using Throughput, Packet Delivery, Delay, and Energy Consumption metrics. RPSORP has superior performance than state-of-the-art routing protocols.

Index Terms – VSNET, Routing, Swarming, PSO, Local-Search, Global-Search.

1. INTRODUCTION

Over the last decade, advancements in mobile communication have entirely revolutionized the automobile industry by allowing for seamless, anywhere-and-at-any-time data sharing between vehicles and other devices [1]. Because of this streamlined interaction, valuable data may be transferred across devices while users are on the go. A new standard has emerged for efficient data transfer in real time. Similarly, the development of communication and information technology has facilitated mobile devices' communication with one another [2]. The Vehicular Sensor Networks (VSNET) introduction is particularly notable among these developments, which has provided novel opportunities to take advantage of safety-related applications. Sensor networks, or VSNETs, are formed when mobile nodes, such as computers and mobile phones or vehicles, come close to one another through wireless communication to share and exchange data [3]. In that instant, automobiles and gadgets act as nodes in a tiny network. Each node shares whatever data it has with every other node in the network. As soon as one node broadcasts its data, the other nodes get it simultaneously. After gathering this information, nodes work hard to draw conclusions and relay them to other gadgets. In an open network, nodes may join or leave the network at will and can exchange data with any other node. Newer cars have built-in sensors that make it easy to connect them to a VSNET and start enjoying the benefits right away [4].

1.1. Characteristics of VSNET

Significant characteristics of sensor networks are [5] :

- Heterogeneity: Each node in a VSNET network has its skills and abilities. Example: Vehicles are mobile nodes with varying ranges of data classifications, sensors, and connectivity. RSUs, on the other hand, are fixed nodes strategically deployed and outfitted with fully ad hoc capabilities [6].
- Traffic Density: Heavy traffic density occurs in metropolitan areas, whereas low density occurs in rural areas and on highways. High traffic occurs during rush hours, while off-peak hours see lower traffic densities. Creating effective VSNET communication protocols is made more difficult by the increasing complexity of networks as traffic volumes rise. Data distribution protocols need to address the possibility of network disconnection, which might occur in rural regions with a low volume of daily Internet users. However, in the event of extremely high traffic density, notably in metropolitan areas during rush hours, it is recommended to employ sophisticated data transmission systems to avoid the well-known broadcast storm problem [7].
- Pattern of Vehicle Movements: There is a distinction between VSNETs and Mobile Ad-hoc Networks regarding how nodes travel within the network (MANETs). In reality, MANETs allow mobile nodes to roam freely. Contrarily, vehicles in a VSNET adhere to the road network topology of their locations. The city, the country, and the highway are three typical settings. A greater variety of vehicles and a higher traffic density may be found in metropolitan areas as opposed to their more rural counterparts. Even more so, there are more roadblocks, traffic lights, and RSUs than in a typical rural region or highway. The latter has traffic flowing in a single direction over a wide roadway. There is a correlation between the road system's geographical characteristics and the resulting communication's efficacy and efficiency [8].
- Mobility: The primary components of VSNETs are stationary Road-Side Units (RSU) and mobile devices. The wide range of vehicle speeds creates novel difficulties in maintaining contact. In congested regions, drivers have more time to communicate since their vehicles are either halted or going at a snail's pace. However, because of the high density of vehicles, they suffer significant difficulties, such as interference concerns, message loss, channel fading, and data collision. The high speeds attained by vehicles in low-traffic regions (such as on a highway) provide additional communication difficulties, such as a narrow communication window, connection failures, and significant end-to-end latency [9].

1.2. Problem Statement

VSNETs share multiple pieces of information with ad-hoc wireless and wired systems. Likewise, it shared various unique attributes which can set it apart from previous systems. These remarkable qualities convey great concentration on routing protocol design that can go beyond the regular wired and wireless ad-hoc appointed systems. While meeting the plan necessities exhibits a particular and unique difficulty. The difficulties can be credited to various components, including extreme energy utilization, low-level computing, and the progressively changing condition inside sensors that will make communication. VSNET nodes work with restricted computing, memory, and communication capability under extreme energy consumption. Because of the enormous number of possible sensor applications, the density of VSNET may shift broadly, extending from a deficient level to a very high level. Besides, in numerous applications, VSNET nodes are unlimited in number with network coverage areas, where VSNET nodes are deployed in an ad-hoc and unsupervised manner. The communication of VSNET nodes is dynamic and adaptive. The nodes need to self-organize and conserve energy, which forces the VSNET node to alter their conduct continually because of their present movement or the deficiency in energy utilization. Moreover, VSNET nodes might be required to alter their conduct because of wireless networks' changeable and capricious conducts to counteract extreme execution degradation.

1.3. Objective

The primary goal of this research is to solve the problems of latency and energy consumption in VSNET by developing an optimization-based routing protocol that takes its inspiration from the behavior of birds.

1.4. Organization of the Paper

This paper is organized as follows: Section 1 introduces Virtual Sensor Networks (VSNET) and highlights their characteristics. Then the problem statement is presented, and the objective of this study. Section 2 comprehensively reviews the relevant literature on routing protocols and energy efficiency in VSNET. Section 3 details the proposed routing protocol based on Relentless Particle Swarm Optimization (RPSO). We discuss various aspects of the protocol, including efficient energy consumption, reliability,

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energy consumption framework, optimization-based routing, loop avoidance using Dijkstra's algorithm, and calculation of average energy consumption. Section 4 presents the results of the simulations and analysis, including throughput analysis, packet delivery analysis, delay, and energy consumption analysis. Section 5 summarizes the findings, highlights the research's contributions, and provides suggestions for future research.

2. LITERATURE REVIEW

"Novel algorithm for routing for wireless-sensor-network" was structured [10] for virtual communications to promote the network sink position. Many sinks of mobile from the network were also supported, wherein simulation results show the energy consumption and delay decreased. The existence of the network was also increased than the existing algorithms. "Secure routing and tracking protocol" was presented [11] for multi-variant tuples with TF symmetric key model for evolving and avoiding the rivals in the sensor network. The authentication and Encryption model was used to structure the model with the eligibility weight function. Multipath OLSR and AOMDV protocols were inherited, and the implemented result proves to have a higher level of tracking nodes, and it also proves to have multipath delivery. "Innovative Technique" for transmitting the data [12] was proposed to handle the delay in delivering sensitive data. An energy delay for a balanced path from the source and the sink was also handled to facilitate faster data delivery with the help of a competent energy hop. The implemented results increase the received data packets percentage in thick and network along with aggregation of data. A proper balancing of the load was also given for any network.

"QWR Protocol" [13] on query-driven circumstances. An innovative packet forwarding process was also developed to increase the data delivery performance. The evaluation of its performance demonstrates the decrease in energy usage by maintaining the increased data delivery ratio and decreased delay. "Hierarchical Clustering-Based Routing Scheme" was employed [14] with the LO algorithm. All the nodes in the cluster were made active for transmitting the data. The packet delivery rate, network lifetime, energy usage, and average latency were analyzed, and the proposed result was tested with other processes. It shows the increased quality of services for the network. "Secured Routing Protocol with multi–Objective Routing" was developed [15] for wireless sensor networks. The evaluation model for trusting the node was also innovated with efficient D-S evidence theory. Pareto Optimal solution mechanism was extracted with the archived method and the criterion for crowding distance. The simulation results show the desired performance besides the wireless sensor network's black hole attack for routing. A "Traffic-differentiated routing algorithm" was proposed for each cluster [16] to handle the delay-sensitivity and reliability-based services. A transmission reliability prediction model was also developed to consider the availability of the link and forwarding facility of the node. The final implemented results with the simulation show the higher end-end delay handling performance rate and the proposed technique's pack-dropping ratio.

"Cognitive routing protocol" [17] was proposed for large-scale networks to manage disasters and was implemented for wireless sensors handling in traffic infrastructures of the city. The whole network energy for routing the packets in the wireless sensor network was also considered. The limitations of the resource for counting the hop and the energy level were considered. The results of the proposed study were also compared with other routing protocols in the existing literature. "Opportunistic power controlled routing protocol" was proposed for IoUTs [18]. For selecting the level for power transmission for every sensor node, factors, namely, energy waste, packet advancement, distance, quality of the link, and neighborhood density, were considered. Every node of the neighborhood is considered for forwarding the packets. The proposed results proved to be the best performance in data delivery, and the energy cost was maintained at all system levels. "FPT-Approximation Algorithm" was developed to solve the load balancing [19] problem. A routing algorithm was also implemented, which uses virtual grid infrastructure for the network. The simulation result of the proposed study proves to be applied for handling large-scale WSNs to ensure a higher performance rate than the existing methods. The "Efficient Stream Region Sink Position Analysis Model" [20] is proposed as an effective algorithm for detecting attacks in MANET. Complete information about the mobile nodes for analyzing the sink position was performed, and a group of actions was traced. The implemented algorithm decreases the routing overhead by comparing it with other processes like LFR-TA, G-Hazard, and FBRD.

"Link quality and energy utilization" [21] proposed to acquire the next hop. The quality of the sensor nodes was evaluated along with the level of energy, the quality of the link, and the transmission of the data was also enhanced. Different simulations were carried out to evaluate the proposed protocol, and the implemented results proved to be a good solution for decreasing the energy of the nodes. "Privacy-Preserving History-based Routing" was developed [22] to track historical locations. A history table was used to prevent data leakage and maintain privacy and integrity. OppNet node was also taken as the data communication node, and the location of each programmed node was considered for interactions. Along with that, the optimized node route is defined by validating the history table. "CAPTAIN" was developed [23] for executing the collection and aggregation of data. The algorithm segregates the network into clusters, constructs the tree for routing, and delivers the collected data

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to the sink node. The results of the implemented study were compared with the shortest path algorithm and showed that the proposed result achieves decreased latency in the clustered network. Optimization [24], [25] plays a vital role in all kinds of networks for minimizing energy and enhancing the network performance

"Centralized Wireless Routing Process (CWRP)" proposed [26] to detect the optimal path and validate the average number of links' transmission time. The energy consumption of the data was also at a minimum rate. The outcome of the proposed work ensures that detecting the sensor network's state and the mode of attack are differentiated. The result also proves to consume less transmission of data and lesser consumption of energy. "Dynamic Ring-Based Routing (DRBR)" was proposed [27] in which the source node was selected to send the data packet to the mixing ring. The ring nodes at the mixing ring will group the packets and are passed on to the node at the sink. Finally, the result shows that the proposed model achieves the highest swapping of packets from energy consumption and between its privacy.

Table 1 Comparison of Related Literature

Related Literature	Merits	Demerits
Novel algorithm for routing for wireless-sensor-network	• Uses mobile sink and virtual infrastructure for efficient routing in wireless sensor networks • Reduces delay and prolongs the network lifetime	• Increased network complexity • Not effective in larger or more complex networks
Secure routing and tracking protocol	• Provides both secure routing and monitoring in IoT-based wireless sensor networks • Uses a hybrid approach for improved performance	• Increased overhead and latency in the network • Limited applicability outside of IoT-based networks
Innovative Technique	• Prioritizes energy efficiency and reliability for improved routing in heterogeneous mobile sink wireless sensor networks • Delays aware of optimizing the data transmission	• Increased computational requirements • Not effective in other types of networks
QWR Protocol	• Uses query-driven virtual wheel routing for efficient routing in wireless sensor networks with mobile sink • Provides efficient routing with the improved query success rate	• Increased network complexity • Not effective in larger or more complex networks
Hierarchical Clustering-Based Routing Scheme	• Uses a software-defined networking approach and Lion Optimization algorithm for efficient routing in multi-hop and relay surveillance • Improves routing efficiency in multi-hop and relay surveillance	• Increased computational requirements • Not effective in other types of networks
Secured Routing Protocol with multi–Objective routing	• Provides secure routing for wireless sensor networks using multi-objective optimization • Adapts to changing network conditions for improved performance	• Require high computational resources for large networks • Increased overhead and latency in the network

Traffic-differentiated routing algorithm	• Prioritizes traffic in Flying Ad Hoc Sensor Networks for better performance • Uses SDN cluster controllers for improved routing	• Increased network complexity and require specialized hardware or software
Cognitive routing protocol	• Adapts to network conditions in real time for optimal performance • Provides efficient routing in disaster-inspired IoT networks	• Not suitable for large-scale IoT networks • Increased overhead and latency in the network
Opportunistic power-controlled routing protocol	• Efficiently routes data in underwater networks while improving power efficiency • Adapts to changing network conditions for improved performance • It may not be suitable for other types of networks	• Have limited applicability outside of underwater networks
FPT-Approximation Algorithm	• Provides load-balanced clustering and routing in WSNs with improved performance • Uses a grid structure for improved routing • Offers an FPT-approximation algorithm for efficient clustering and routing	• Not be as efficient for very large networks • Increased overhead and latency in the network
efficient stream region sink position analysis model	• Provides efficient detection of routing attacks in mobile ad hoc networks • Uses stream region sink position analysis for improved routing attack detection	• Increased computational requirements • Not effective in large or complex networks
Link quality and energy utilization	• Prioritizes link quality and energy utilization for improved routing in wireless body area networks • Selects the most preferable next hop for efficient routing	• Not effective in larger networks or different types of networks • Increased network complexity
Privacy-preserving history-based routing	• Protects user privacy in opportunistic networks • Uses history-based routing for improved performance	• Increase overhead and latency in the network • Limited applicability outside of opportunistic networks
CAPTAIN	• Efficiently collects data in underwater optical-acoustic sensor networks • Adapts to changing network conditions for improved performance	• Limited applicability outside of underwater optical-acoustic sensor networks • Increased latency in the network

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Centralized Wireless Routing Process	• Adapts to changing network conditions for improved performance • Efficiently routes data	• Increased overhead and latency in the network • Not suitable for other types of networks
Dynamic Ring-Based Routing	• Provides improved source location privacy in wireless sensor networks • Uses a dynamic ring-based routing scheme for efficient routing	• Increased network complexity • Increased overhead and latency in the network

3. RELENTLESS PARTICLE SWARM OPTIMIZATION-BASED ROUTING PROTOCOL

The Relentless Particle Swarm Optimization Based Routing Protocol (RPSORP) is a method that utilizes clustering to determine the optimal number of clusters for routing packets to the sink while minimizing energy consumption. This approach also ensures reliability by finding the best Pareto solution through weight assignment to each constraint.

A computation process is performed to identify the Head of the Cluster (HOC) and its neighbors, and neighbor nodes are assigned a unique metric based on their energy balance and distance from the current node. The HOC collects data based on the remaining energy of the nodes, and the two functions of energy capability and reliability are measured.

Various algorithms, such as swarm intelligence, differential evaluation, artificial immune system, and genetic algorithms, are used to solve optimization problems with multiple objectives. Among these algorithms, Particle Swarm Optimization (PSO) is known for finding a single solution for a given problem, with each swarm member working towards the ideal solution.

PSO is being developed further to solve MO optimization problems and is a popular metaheuristic approach due to its ease of implementation. During the initial stage, PSO randomly determines particle positions and speeds and then updates their values using Eq.(1) and Eq.(2) in subsequent rounds. PSO is a productive optimization algorithm that effectively addresses live optimization problems.

$$\frac{l-1}{j,\sum c^u} = xu\frac{l}{j,\sum c^u} - \sum_0^u \left(d^{j+1}q^{i+1}\left\{W^i, c^u, oa - W\frac{l}{j,\sum c^u}\right\}\right) \quad (1)$$

$$W\frac{l-1}{j,\sum c^u} = \prod W\frac{l}{j,\sum c^u} - \sum u\frac{l-1}{j,\sum c^u} \quad (2)$$

Eq.(1) and Eq.(2) indicate the speed and position j^{th} particle in k^{th} iteration in an individual manner, where $c^u = 1,2,\dots,c^{um}; j = 1,2,\dots,M^o$, and M^q is the population size, c^u signifies the dimension count, x indicates the weight of disinterest in the population, d^{j+1} and d^{j+1} denotes the public and subjective knowledge rate; q^{j+1} and q^{j+2} indicate two numbers that are selected randomly with the range [0,1]. $W^{i,oa}$ is considered as the best position separately at any point, and it is established by the j^{th} particle and W^{ha} is found in the finest position among all the particles.

Commonly, the estimations of d^{j+1} and d^{j+2} is always 4. To obtain the optimal solution through fine-tuning particles in further generations, a few particles are selected randomly using deterministic and homogeneous distribution concepts based on the Hammersley sequencing sampling method.

Transformative methods have gained significant attention in VSNETs due to their potential for addressing various issues. Among them, the RPSORP approach effectively optimizes load balancing and clustering in routing, which are critical factors in achieving energy-efficient and reliable data transmission. By grouping nodes based on MO clustering, RPSORP can achieve a balance between reliable data transmission and energy consumption. This approach is effective in various applications, making it a promising solution for WSN optimization.

3.1. Efficient Energy Consumption

RPSORP utilizes a method to determine energy consumption efficiency by calculating the total remaining energy of the HOCs. The method's efficiency is determined based on whether the cumulative balance energy of the HOCs increases or the total energy of the HOCs decreases. To select the HOC node for each iteration, the node with the highest balance energy is chosen.

3.2. Reliability

The term “reliability” refers to the level of trust in data transmission. Energy consumption during data transfer should be minimized to enhance reliability because WSN nodes operate on battery power. Thus, reducing energy consumption at the nodes can increase the network’s lifespan and lower the cost of communication outside the cluster. The global cost of communication outside the cluster is the total cost between HOCs.

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3.3. Energy Consumption Framework

The framework for energy consumption is designed to transmit data in the form of bits. It incorporates energy loss computations at each node for various network operations that involve communication with other nodes. The method of dual-channel broadcasting evaluates energy usage during data transmission, while the octal-channel broadcasting technique estimates energy loss during multi-hop data transmission. The mathematical representation of this framework is given by Eq.(3).

$$F^{SW}\{k,c\} = \prod \begin{pmatrix} kF^{sel} - kF^{et}c^{i+2}, & (c-1) \leftarrow c^{i} \\ kF^{sel} - kF^{no}c^{i+4}, & (c+1) \rightarrow c^{i} \end{pmatrix} \quad (3)$$

Where F^{et} is the loss of energy at the single hop, F^{no} is the loss of energy at multi-hop. F^{sel} is the electrical energy which incorporates numerous variables like signalling, digital modulation, computerized coding, sorting, etc. c is the distance that exists between the sender node and receiver node and c^{o} is the hybrid separation and mathematically expressed as Eq.(4):

$$c^{o} = \int \frac{F^{et}}{F^{no}} \times \sum F^{SW}\left\{k, \sum c\right\} \quad (4)$$

The energy consumed by the vehicular sensor devices to receive the message F^{QW} is mathematically expressed as Eq.(5).

$$F^{QW}(k) = e^{\sum c} kF^{sel} + \bigvee \frac{F^{et}}{F^{no}} \quad (5)$$

Hence, the energy consumed for (i) transmitting and (ii) receiving the messages is structured in the physical and medium access control layer of WSN.

3.4. Optimization-Based Routing

The present research proposes dividing the entire VSNET area into smaller units, with each unit having its own base station (BS). Nodes within a given unit communicate with their respective BS, while communication between different BSs is called inter-unit communication. To facilitate this, the proposed methodology assigns each node to its respective BS and each BS to its next hop. In the research's first phase, the WSN is divided into cardinal clusters during network segregation.

3.4.1. WSN Segregation Phase

At the outset of the study, the locations of the nodes are collected and mapped. Using this information, each node is assigned to one of the eight cardinals (QD1 to QD8) created in the WSN to satisfy the MO. The allocation of nodes to cardinals is done haphazardly. The entire WSN can be represented as the summation of all the cardinals, which is mathematically expressed as Equation (6):

$$T = \sum_{d=d1}^{d8} qd \quad (6)$$

WSNs rely on dynamic clustering to effectively manage the network, but this can consume a lot of energy and harm performance if not done correctly. The RPSORP approach divides the WSN into “cardinals” and creates clusters within each cardinal to address this issue. These clusters are inherently stable and have a coverage area of 2000m x 2000m. The goal of creating cardinals and mapping nodes to them is to reduce the energy needed for nodes to communicate with their base station. The system employs two types of base stations: primary base stations (PBS) and secondary base stations (SBS). Nodes communicate with their SBS, which then communicates with PBS. All activities within the cardinal are considered optional by the base stations. The RPSORP approach is designed to operate in all cardinals via base stations, allowing nodes to use energy effectively. Secondary base stations transmit collected data to the appropriate base station. Overall, RPSORP offers an effective solution for managing WSNs and optimizing energy consumption while maintaining stable cluster formation and reducing the risk of performance degradation.

3.4.2. Node Initialization

RPSORP employs a routing mechanism where each node represents a route of base stations and forwards data to both PBS and SBS. The number of nodes in the WSN region is assumed to be the same as the node dimension. To estimate the number of nodes in an SBS, RPSORP uses Eq.(7).

$$SBS\ capacity = \sum Current\ Node\ location \times \prod Neighbor\ Node\ Count \quad (7)$$

Once the cardinals are formed in RPSORP, the base stations (BSs) play a critical role in consolidating the data received from each node within each cardinal and passing it to the next level. However, since the energy consumed by the BSs is limited, ensuring that the data consolidation process is efficient and does not consume excessive energy is crucial. To achieve this, RPSORP employs a strategy where the data consolidation level varies for each node and each secondary base station (SBS), depending on the energy balance. Specifically, suppose the balance energy of a node is high. In that case, the data receiving and consolidation level will be high, and if the balance energy is low, the data consolidation level will also be low. This ensures that the data is consolidated efficiently while minimizing the energy consumption of the BSs. Since the energy of the BSs is limited, it is necessary to calculate the energy level at the SBS and primary base station (PBS) levels rather than at the node level. To calculate the energy level, RPSORP uses Eq.(8),

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which considers the energy consumed by the nodes and the BSs. By using this approach, RPSORP can optimize the energy consumption of the WSN while ensuring that the data consolidation process is efficient and effective.

$$Energy\ level\ of\ BS = \sum_{i=n} \frac{messages\ sent}{balance\ energy} - Threshold\ Energy \quad (8)$$

In RPSORP, each higher-order cluster (HOC) is connected to the subsequent HOC for the iteration. However, there is a risk of a loop between the clusters, which can harm the overall network performance. To avoid this, the base stations utilize an unbiased function that prevents the formation of loops. To establish connectivity between the base stations and all HOCs, the sink node creates an adjacency matrix that determines the shortest route (SR) between them using Dijkstra's algorithm.

The number of HOCs is then calculated based on the nodes available for transmission. Finally, a random number is generated and assigned to each HOC from the available neighbor nodes to ensure that the HOCs are evenly distributed across the WSN. Using this approach, RPSORP can effectively establish connectivity between the base stations and HOCs, without creating loops or biases that could degrade the network performance.

3.4.3. Data Aggregation Function of HOC

After the clusters are formed, each higher-order cluster (HOC) aims to collect data from all the members of its corresponding cluster and send it to the next node on its path. In RPSORP, the amount of data a HOC gathers varies depending on its balance energy. If a HOC has high balance energy, the amount of data gathering is minimized to ensure it is processed with increased accuracy.

The estimated cost of data gathering is mathematically expressed in Equation (9), which considers various factors such as the number of nodes in the cluster, the energy consumed by each node, and the distance between the nodes and the base stations. By using this approach, RPSORP can optimize the data-gathering process while minimizing the energy consumption of the HOCs.

$$\text{cst} = \bigvee_{j \sim o^{set}} x^j + \sum \left\{ \frac{b^j + a^j}{max^t} \right\} \quad (9)$$

The amount of data gathering is maximum when the balance energy is at its minimum level. The nodes' total energy consumption is considered to determine the Energy Window ($E_{ng}W_{in}$) for a particular quantity. To optimize the data-gathering process, a decision-making scheme is proposed in RPSORP. This scheme considers the cost of gathering data and selects two nodes to combine their data, thereby reducing the overall packet size. This approach also identifies and eliminates inconsistencies, resulting in more accurate data. In RPSORP, the amount of data gathered by each HOC is determined by the energy balance at the HOC. This approach ensures that the data gathering rate is optimized while considering the energy balance of the HOCs.

3.4.4. Threshold Weight Assignment

After the data is consolidated, it is sent to the neighboring SBS to be forwarded to the PBS for processing. To reduce energy consumption, the data is only forwarded through the BSs, eliminating the need for each node to find the path toward the destination. In RPSORP, SBSs follow one of the three modes below for forwarding the consolidated data to PBS.

- ✓ Beginning: All SBSs are assigned predefined values.
- ✓ Information Sharing: Identified routing is shared with SBSs.
- ✓ Route Generation: New routing paths are created with the help of neighbor SBSs to make the consolidated data reach PBSs.

In the second and third modes, the RPSORP algorithm prioritizes using loops to conserve energy. To achieve this, the algorithm identifies and avoids looping paths and instead focuses on paths that lead directly to the PBS. At the beginning of the process, the algorithm assigns weights to the BSs based on their distance from the nodes and the energy available. This is expressed mathematically in Eq.(10). By considering the weight of each BS, and the RPSORP algorithm can select the most efficient path for data transmission and minimize the overall energy consumption of the WSN. This approach not only ensures the reliable delivery of data but also increases the lifetime of the WSN.

$$Weight = \prod \left\{ \frac{distance}{energy} \right\} + \sum Time\ Concumption \quad (10)$$

The neighbor information of the nodes is updated in each iteration based on the assigned weights. The node with the highest weight value is selected as HOC, and a random selection is made if there are multiple nodes with the same weight. The communication outside the cluster is transmitted between HOC and the base station.

A multi-hop method is used to create a network by utilizing the nodes in each HOC, and each node is assigned a HOC from the neighbor nodes. Only the nodes with a minimum balance of energy ($f^i > f^{threshold}$) are allotted weights, and the HOC selection process is limited to nodes that meet the

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necessary conditions. The cluster count changes based on the number of nodes in the WSN.

3.5. Loop Avoidance Using Dijkstra's Algorithm

RPSORP uses the Dijkstra algorithm to build a routing tree free from loops, which connects the base station and HOC. The network is modeled as a directed graph H = {U, F}, where U represents the set of HOCs and base stations, and F represents the edges between the vertices. The shortest route (SR) between nodes is determined based on distance and link quality. Each node assigns a weight to an edge, represented as (x^{vu}) in Eq.(11), which determines the link quality between node v and node u. The goal is to minimize the sum of weights along the path from the base station to each HOC, achieved using Dijkstra's algorithm.

$$x^f = x^{vu} = \int \begin{matrix} R, if\ u\ is\ neighbor\ of\ v \\ 0, \quad if\ v = u \\ MNV, otherwise \end{matrix} \tag{11}$$

Where R denotes the ratio of delivery of a packet, MNV indicates the minimum negative value, and it is defined as Eq.(12):

$$R = \frac{total\ \ packets\ succesfully\ \ recived}{total\ packets\ sent} \tag{12}$$

Where R is the proportion of the quality of the link, and it has a value between 0 and 1.

In Eq.(13), the connection quality for the route between the HOC and the base station is calculated by taking the product of the weights of the edges along the route. The MNV value of the corresponding column in the adjacency matrix gives the weight of the edge between the HOC and the base station C^s. The MNV value is the most negative in the column, representing the weakest link in the route. Therefore, the quality of the route depends on the strength of the weakest link in the route. By calculating the product of the weights of the edges along the route, Eq.(13) measures the overall quality of the connection between the HOC and the base station.

$$QC^{DG<AT} = \int \begin{matrix} \bigvee_{f \varepsilon Q} x^f, if\ base\ station\ is\ reachable\ from\ HOC \\ \sum MNV\ , otherwise \end{matrix} \tag{13}$$

The connection quality between two nodes can vary in VSNET depending on the transmission direction. For instance, the connection quality of a vehicular sensor from node v to node u may differ from the connection quality between node u and node v. To account for this, the adjacency matrix C^s is generated dynamically at each iteration s by the base station. The Dijkstra algorithm is then used to calculate the shortest path between the base station and the HOC, considering the SR (signal strength ratio) between nodes. This approach helps ensure that the most efficient path is selected for data transmission, leading to better network performance in energy consumption and reliable data delivery.

3.6. Calculation of Average Energy Consumption

The main goal of the optimization process is to minimize the number of active nodes to conserve energy during the iteration. This is achieved by reducing the number of selected HOCs, which L denotes. The head of the selected HOCs is represented by U^j, which is determined by eliminating the duplicate values and decoding K^j. The total number of selected HOCs is calculated using Eq. (14).

$$L^{K^j} = \coprod |U^j| \tag{14}$$

In the RPSORP protocol, the HOC node responsible for collecting and processing data from the cluster nodes is selected based on the node's energy level. The node with the highest energy level is considered the most suitable candidate for the HOC role as it can perform the necessary data gathering and forwarding tasks. The HOC node can utilize its energy in three ways: (i) by improving energy consumption, (ii) by increasing the balance of energy, or (iii) by reducing energy consumption. To determine the optimal HOC node for each cluster, an unbiased function E^j is used. The function is defined as the complement of the balance energy of the HOC node. It can be expressed mathematically as Eq.(15). The balancing energy is the difference between the initial energy level and the energy consumed in each iteration. By selecting the HOC node with the highest unbiased function value, the RPSORP protocol can improve energy utilization, increase the network lifetime, and reduce communication costs.

$$Max(E^j) = FF^{K^j} = \sum \frac{\coprod |U^j|}{\bigvee_{j=0}^{|U^j|} F\{DG^{K^{j,l}}\}} \times \sum L^{K^j} \tag{15}$$

$F\left\{DG^{K^{j,L}}\right\}$ is the rest of the energy (i.e., the balance energy) of HOC number K.

3.6.1. Data Reliability

To improve the throughput and reliable data delivery rate, minimizing the cost of communication within each cluster is important. Their weight determines the link cost between any two nodes, and the average cost of all links in the HOC determines the total cost of communication within the HOC. If a HOC is not connected to any other HOC, a penalty value is assigned to that HOC, which prompts it to seek out and connect with other HOCs. The total cost of communication can be represented mathematically using Eq.(16).

$$\text{Min}\{E^{2i}\} = SD^j = \sum \bigvee_{li=1}^{L} \bigvee_{fi=1}^{F} x^f \tag{16}$$

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Where L represents the HOC count. F denotes the edge count in the selected route li. x^f indicates the edge (i.e., e) weight provided by Eq.(11). The procedure of the $RPSORP$ algorithm is provided in Figure 1.

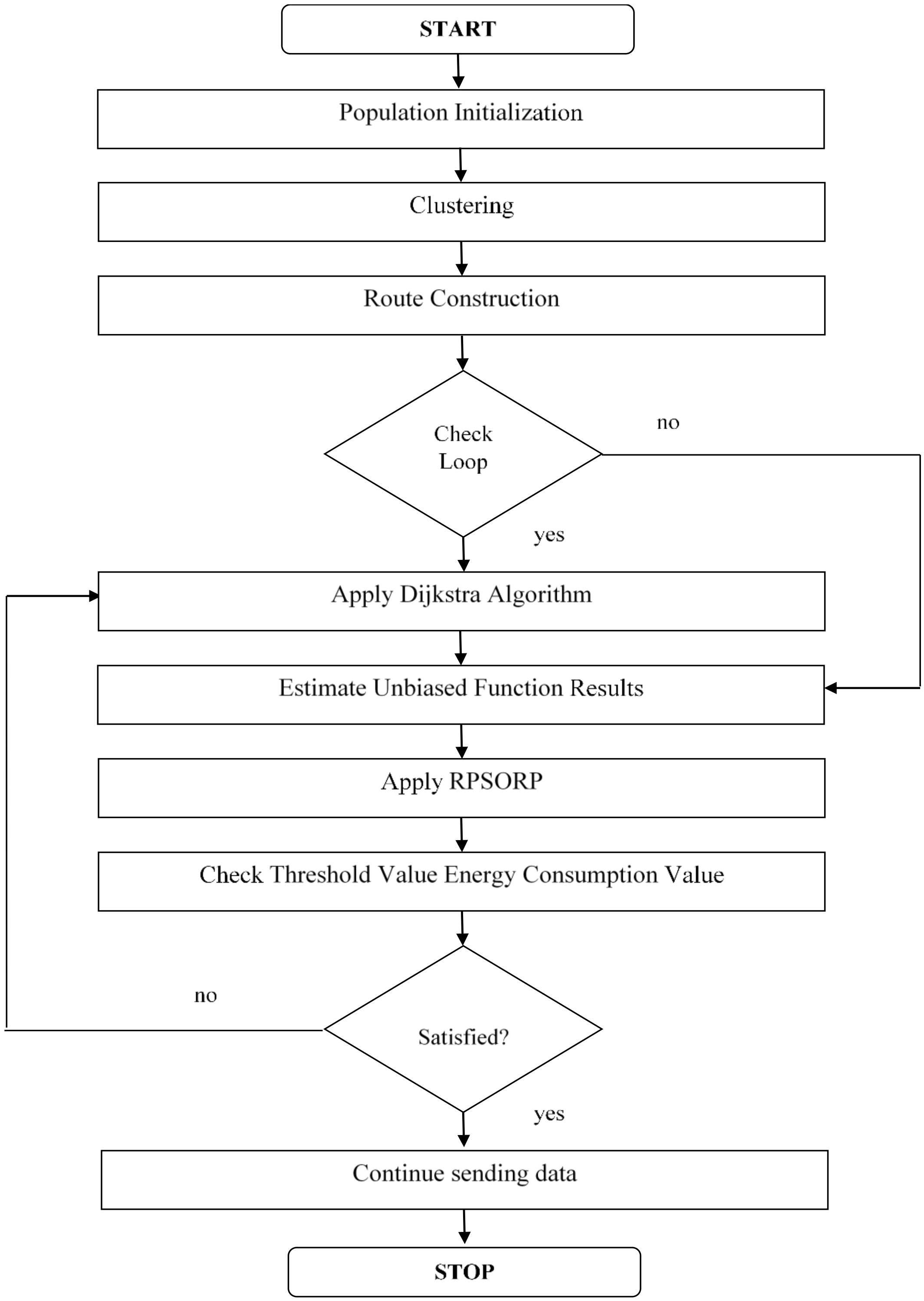

Figure 1 Flowchart of RPSORP

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In the RPSORP algorithm, an unbiased function is used to avoid any loops that may occur between clusters. This function is computed for each solution using the equations involved in the algorithm. A reliable sorting method is employed to determine the best vector among all the HOCs. The algorithm then calculates each particle's speed based on the current and best positions.

The positions are fully utilized to determine the new HOC. The algorithm continues to execute until it reaches the maximum iteration count. This ensures the algorithm performs the necessary iterations to converge toward the optimal solution. Overall, the RPSORP algorithm employs a systematic approach to determine the best HOC for data transmission and ensures no loops between clusters, resulting in a reliable and efficient data transmission process.

3.6.2. Node Evaluation

Routing is a critical aspect of various network systems, including Vehicular Sensor Networks (VSNET). Routing messages in VSNETs is a fascinating and potential research domain in networking due to the unique challenges posed by the lack of centralized communication, the mobility of the nodes, the dynamic nature of the topology, and the need for timely delivery of packets to the destination. The Relentless Particle Swarm Optimization-based Routing Protocol (RPSORP) is a new routing protocol proposed to address issues in VSNET.

The initialization phase of RPSORP involves the creation of units and the allocation of SBSs to each unit to communicate with the PBS. In the second and third modes of the RPSORP approach, loop paths are identified and avoided, and all paths aim to terminate at the PBS. The RPSORP approach assigns weights to BSs based on distance and energy at the starting stage to optimize energy consumption and data transmission. The analysis phase of RPSORP involves the evaluation of the units created during the initialization phase and the routing paths that connect these units. The primary objective of this phase is to identify the most suitable SBSs for data transmission to reduce energy consumption and increase reliable data delivery. To reduce energy consumption, activating only a few nodes in data transmission is essential instead of all nodes.

This approach helps to prolong the lifetime of the WSN by conserving energy. The RPSORP approach increases reliable data delivery by creating different units and allotting SBSs to each unit to communicate with the PBS. This method reduces the network load towards PBS, which results in a higher Packet Delivery Ratio (PDR) for the WSN. By identifying the most suitable SBSs for each unit, the RPSORP approach optimizes energy consumption and data transmission within the WSN. This helps to ensure that the WSN functions optimally while minimizing energy consumption and maximizing the reliability of data delivery. Moreover, the RPSORP approach is inspired by studying ant behavior, which prioritizes sending data along the shortest cum highest-quality link available. By using this approach, RPSORP helps to save time and resources while optimizing energy consumption and data transmission within the WSN.

4. RESULTS AND DISCUSSION

The performance analysis aims to gauge how the proposed protocol does against its competitors. In this research work, the simulation was conducted in GNS3. The physical, data connection, and media access control (MAC) layers of multi-hop wireless networks can all be simulated in GNS3. Results are compared to those attained by CWRP and DRBR. The simulation settings are listed in Table 2.

Table 2 Simulation Setting - Basic Specification

Network Coverage Area	1500 m x 1250 m
Type of deployment	Random
Network architecture	Flat and Homogeneous
Time of Simulation	250 s
Location of sink	(1100,1100)
Node’s initial energy level	15J
Buffer Size	15mb
Radio Frequency Ranges	150 m
Sensing Radius	45 m
Link Layer Transmission Rate	256 Kbps
Transmission Power	7.214e-3 W
Threshold level of receiving signal	$3.59509e^{-10}$ W
Rate of Link Failure	Varying from 0.02 to 0.20
MAC	lEEE 802.11 DCF
Number of nodes	Varying from 50 to 250

4.1. Throughput Analysis

Figure 1 shows a comparison of the throughput attained by different routing strategies. Figure 1 makes it easy to see that the RPSORP outperforms the state-of-the-art routing protocols. While the present routing protocol does not focus on loop avoidance, the suggested routing protocol does. As a result, it achieves greater performance than the state-of-the-art routing methods. RPSORP achieves an average throughput of 53.066%, while CWRP and DRBR attained 35.216% and 43.856%, respectively.

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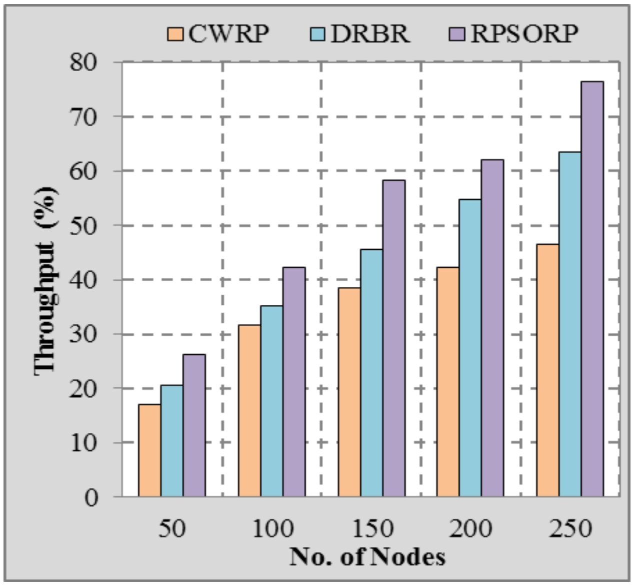

Figure 1 Throughput

4.2. Packet Delivery Analysis

Figure 2 compares the routing protocols' performance in terms of packet delivery. As can be seen in Figure 2, the proposed protocol has significantly increased packet delivery compared to the state-of-art routing protocols. The state-of-art routing protocols don't prioritize route selection properly; instead, they blindly transmit data over any available path, regardless of the route's quality, which might cause packets to be lost or not delivered. RPSORP has obtained the average packet delivery rate of 89.937%, while the CWRP and DRBR have attained 48.862% and 64.333%, respectively.

Figure 2 Packet Delivery

4.3. Delay and Energy Consumption Analysis

Delay and Energy Consumption are always interlinked, i.e., whenever the delay is more than automatic, the energy consumption increases. The energy consumption will be less whenever the delay is less, leading to an increased network lifetime. In Figure 3 and Figure 4, it is shown that the proposed routing protocol has faced low delay compared to the existing routing protocols. Also, the energy consumed by the proposed routing protocol is significantly less. Optimal HOC selection provides a way to achieve minimum delay and energy consumption in the proposed routing protocols. The average delay faced by RPSORP is 4.986%, whereas CWRP and DRBR have faced 7.419% and 9.953%, respectively. The average energy consumed by RPSORP is 44.166%, whereas CWRP and DRBR have faced 60.682% and 61.637%, respectively.

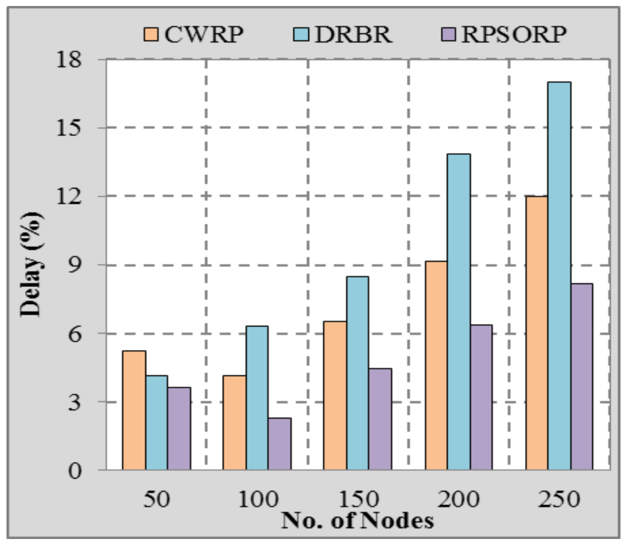

Figure 3 Delay Analysis

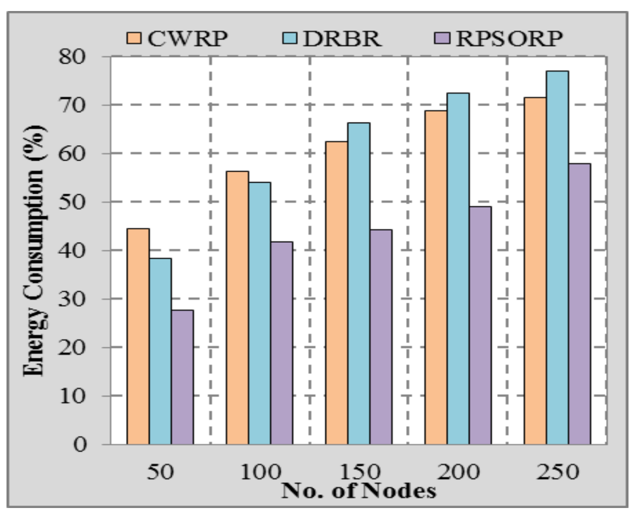

Figure 4 Energy Consumption Analysis

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5. CONCLUSION

Routing plays a crucial role in various types of networks, including Vehicular Sensor Networks (VSNET). Routing messages in VSNETs is a challenging and promising research area in networking due to the absence of centralized communication, node mobility, dynamic topology, and the responsibility of the routing mechanism for timely packet delivery to the destination. This chapter introduces a novel routing protocol called Relentless Particle Swarm Optimization-based Routing Protocol (RPSORP) to address issues in VSNET. The study of ant behavior inspires the design of RPSORP to optimize the use of time and resources by prioritizing data transmission along the shortest and highest-quality link available. RPSORP is evaluated using standard performance metrics in GNS3, and the results demonstrate its superiority over state-of-the-art routing protocols in all aspects.

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