ACO Scheme for Optimistic Routing and Packet Scheduling in Wireless Sensor Networks

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Abstract – More routing protocols have recently been devised for improved data routing in Wireless Sensor Networks (WSN). Link failures do, however, occur in the network as a result of low energy node emergence, poor connectivity across link gaps during routing, low node trust value, etc. Ant Colony Optimization (ACO) one of the bio-inspired algorithms is used in sensor networks to calculate the optimum paths and reduce energy usage. For improved network dependability, an Optimal Routing and Packet Scheduling using ACO scheme is proposed. Using pilot nodes with a high linkage connection factor, the best path is established. To select the best and optimal route the better pilot nodes are elected from the available sub-pilot nodes on basis of node reputation, energy reserve, and distance and bandwidth requirements. The sensed information packets are analyzed by using packet scheduling algorithm and the higher priority packets are forwarded at the earliest through pilot nodes. The presented approach has better delivery rates with a reduced energy consumption rate, according to the performance criteria.

Keywords – Ant Colony Optimization, Bandwidth Coherence, Energy State, Pilot Nodes, Packet Scheduler.

I. INTRODUCTION

The routing technique is typically used to transmit information from one location to the other. Dependable pathways are necessary for reliable packet forwarding. Since it requires strong network qualities like latency, energy efficiency, throughput, connection accessibility, etc., building dependable routes in WSN is not an easy operation. Every node in a network is capable of sensing, processing and transferring the data to other nodes. By reducing the number of hops required to transmit sensed data, shortest path routing [1] significantly enhances network performance. Better rates are obtained when the prices of energy usage and remaining energy levels are linked. Since dependability is regarded as one of the most crucial characteristics for industrial operation and applications, the majority of IoT applications require strict consistency on WSN [2].

Reliability issues cause network disasters and prevent successful network functioning, which has potentially catastrophic implications [3]. A network that performs well in terms of connectivity between sensor nodes and coverage of the intended nodes, such as a Region of Interest (RoI), is referred to as a reliable wireless sensor network. However, because sensor nodes sometimes fail, it is extremely difficult to deploy trustworthy sensor nodes. As a result, the backup sensor nodes should always be accessible.

ACO inspired by swarm intelligence found in nature, was developed to increase the dependability of networks. The network is made more effective through various constraints analysis. By using ACO local and global optimization methods, the nodes situated in the coverage area between them, energy depletion of each node, link gap compatibility among sensor nodes for transmitting data, etc. are investigated.

The rest of this paper is planned as follows: Section 2 specifics the related works that includes the literature survey of Existing methodologies. Section 3 describes the proposed methodology of ACO scheme for optimistic routing and packet scheduling in wireless sensor networks. Section 4 covers the results and discussion, comparing the proposed model with the existing approaches across various evaluation metrics. Finally, the Conclusion section summarizes the findings, emphasizes the framework's impact, and outlines potential areas for further research.

II. RELATED WORKS

The data routing between sensor nodes could be improved using a number of methods. The study of sensor nodes and lowering the cost of finding the nodes in various situations required a significant amount of research. The majority of routing protocols don't meet connectivity standards, which causes a deployment issue with sensor nodes. The following routing protocols were covered in this article: Ant colony optimisation approach [4] is used to extend the network lifetime; in this strategy, path delay, node energy, and velocity of the router node are taken into account to achieve an adaptive and dynamic route discovery. Since there is a difficulty with energy efficiency, Three Pheromones ACO (TPACO) [5] has been offered as a solution for WSN energy-efficient coverage. In this method, active sensor nodes per desired location were identified by using three pheromones, including ‘1’ local and ‘2’ global pheromones. Local pheromones use statistical sensor recognition, whereas global pheromones use a variety of sensors (heterogeneous nodes). Also suggested method named Ant Colony based Scheduling Algorithm (ACSA) [6]. This protocol's probability device recognition approach has been carefully tuned to address Energy Efficiency (EE) issues. The algorithm is used for heterogeneous sensor groups because it was a more practical method of resolving the challenge of energy-efficient coverage.

For reducing the low-graded solutions, ACO with Three Classes of Ant Transitions (ACO-TCAT) [7] had been proposed. Here three classes of ant transitions can be used to solve the connectivity-guaranteed grid coverage problem with this algorithm, which reduces the searching distance. A routing structure based on Swarm Intelligence (SI) has been developed for WSN collision avoidance and link breakdown management [8]. SI techniques such as Particle Swarm Optimization (PSO) and ACO are the most selected models for processing data transmission. SI determines pheromone cost, foraging rate of success, and component location and velocity in PSO and ACO, respectively. The Non-Dominated Quantum Optimization (NDQO) [9] technique was developed whereas when nodes are added; the network size also grows, creating an optimization difficulty. This technique lowers network complexity while also evaluating the acceptable routes using the Pareto optimality method. On the basis of the Maximum Possible Energy Balancing (MPEB) and the Maximum Possible EE (MPEE), an effective transmission strategy should be developed [10].

Utilization of the ACO mechanism forms the basis of an efficient transmission method. Heuristic information is not included in the ant transition probability in this case because the ant only moves one step to accomplish one hop. A node deployment strategy based on ACO was suggested for load balancing [11]. In order to prevent blind connections between nodes, a group-based connection strategy that divides nodes into groups was modelled. This method also reduces deployment costs by assessing actual load transmission for crucial regions. Optimality gain of distance model is taken into consideration when assessing the network lifetime. For mobile-sink based WSN, an effective ACO method [12] was suggested. The generic routing algorithm necessitates route regeneration several times due to mobile sink. Since a single, effective route is generated using heuristic information and the route is thought to be most favourable, regeneration of routes is decreased here by using the ACO process. While establishing the dependable nodes in the network, the NP (Non-polynomial) complete problem is still being addressed. The NP difficulty complete issue was minimised by using the local search heuristic [13]. In order to improve communication, the nodes are positioned at the shortest coverage distance. For obtaining local optimal distance as well as an energy-balancing network system, the Optimal-Distance-based Transmission Approach (ODTA-ACO) was presented [14]. The acquisition of a global optimal distance can reduce the power consumption that sensor networks use for transmission, hence minimising energy depletion.

The Sensor Medium Access Control (SMAC) throughput was used to modify the ACO algorithm, which was then proposed [15]. This system uses trapezoidal membership functions as its input parameters. With less power usage, this fuzzy technique increases system dependability and enhances the quality of data transmission. The energy harvesting in WSN have the capability of saving energy but this process might depend on various kinds of nodes and it may locate at various locations. Therefore, in the consequences the duty cycles and the node wake-up and sleep patterns might change continuously when compared with their existing battery powered nodes [16]. An extended and improved Emergent Broadcast Slot (EBS) model was proposed to facilitate robust and energy efficient communication [17]. Node communication unit stays in sleeping state and activated only when there is any communication message present. This EBS model is fully decentralized and coordinated with their wake-up window in a partially overlapped manner to avoid data collisions in same duty cycle operation [18]. For WSNs, a QoS-aware Energy Balance Secure Routing (QEBSR) algorithm based on ACO was suggested [19]. Here, more accurate approximations are taken into account when determining the routing path's nodes' trust factors and the transmission's end-to-end delay. Among the routing paths constructed by all the ants, the best path which possesses a minimum value of Selectivity value of Node (SVN) is identified and is used to update the pheromone levels on the links between the nodes.

An Opportunistic Packet-forwarding and Energy Harvesting (OPEH) [20] in WSNs was proposed to impact the dynamic duty cycled operation in the heterogeneous WSN. However, in this scheme the relay set and forwarding node selection is not considered. ETC-based Opportunistic Routing (ETCOR) protocol was proposed [21] here ETC properly captures the data transmitting cost in duty-cycled network by estimating both expected communication cost and rendezvous cost. Here the forwarding candidates are selected with the least packet transmission cost for reducing energy utilization of sensors during packet transmission. However, the duty cycle is not dynamically chosen here. A two-way communication model for a Content-Based Adaptable and Dynamic Scheduling Scheme (CADSS) in WSN was proposed. During data aggregation, the CADSS model dynamically changes node states, and each node adopts a new state based on the contents of the sensed data packets. The Base-analyzer Station's module examines the data packets that have been sensed and controls a node's operations by sending control messages backward [22].

Our Contribution

The scheme called Optimal Routing and Packet Scheduling using ACO for Optimal Routing (ORPS_ACO) system is proposed here to maximize the network lifetime, to reduce energy consumption cost, and to attain greatest data transfer rate. The nodes in the network are dispersed at random, and the best routing path from source point to sink point is built through pilot nodes in order to achieve the highest data transfer rate with the least amount of latency and energy consumption. The pilot nodes are chosen using node factors.

III. PROPOSED METHOD

There are many sensor nodes in the network, and it is important to identify an effective path between the source and destination nodes. The protocols typically employ route request messages to find the routes and route reply messages to connect the nodes. However, throughout the data forwarding process, the control messages heavily congest the network. The best path between the source and sink nodes is identified in this case using ACO technique. Pilot nodes are used to choose the prominent path, and these leader nodes are found based on the node's optimality resource restrictions, such as its bandwidth coherence, reputational value, and energy leftover state. Utilizing the ACO approach, the optimum path can be chosen to reduce network congestion. The overall energy utilization of network routing is decreased by utilizing ORPS_ACO to choose the nodes with a good reputation and low amount of energy drain.

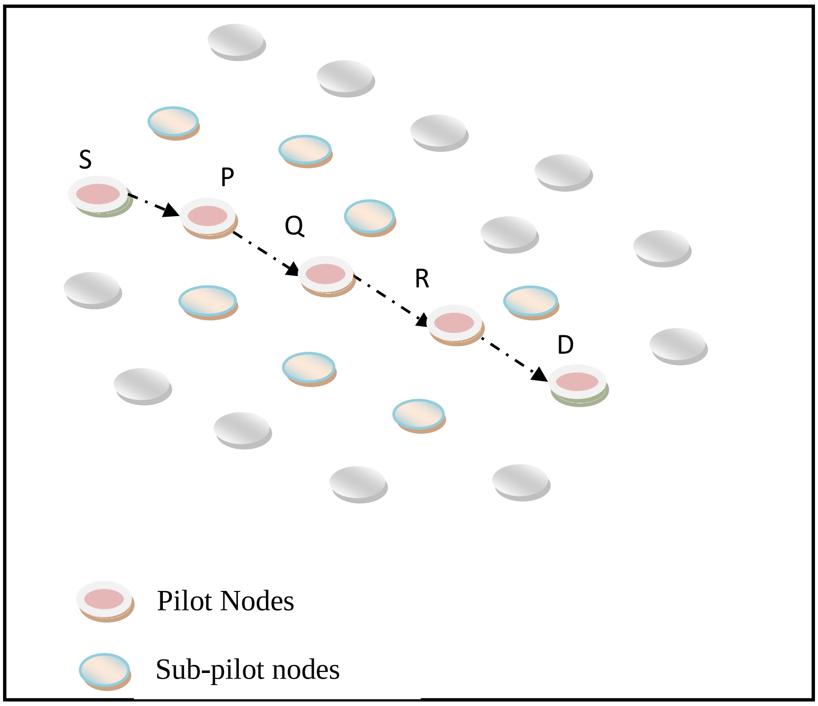

Fig 1. System Architecture of ORPS_ACO Method.

Pilot Nodes (PN) like P, Q, and R, which are depicted in **Fig 1**, are used by source node "S" to deliver data to the intended sink node "D" node. The best ideal pilot node is chosen from among the network's numerous leader nodes using restrictions such node reputational value, residing energy state and available bandwidth. The network may have multiple leader nodes. S-P-Q-R-D is chosen as the best, most optimal path for data transfer in this case.

Pilot Nodes Detection Through ACO

By utilising ACO in the network, a route that is effective for data transmission is found. Route request (R_rq) messages are generated by source node "S" (which serves as the nesting) and disseminated to neighbouring nodes. Neighbouring nodes receive the Route request messages (pheromones) and responding with Route reply (R_rp) if they are destination nodes (food locations), otherwise the RREQ continues until it reaches the destination. Time To Live (TTL) is the amount of time it takes for the pheromones that the ants release to dissipate. TTL period is used to determine the Route request message's signal strength levels. The quantity of RREQ messages can be used to estimate the link's total existing time.

The control messages are used to send information. The signal availability time is used to calculate the link availability. As a result, both the signal level and the distance among nodes are used in the calculation. Equation 1 is used to calculate the link existing period with respect to the dropped route request.

$$L_E = \sum_{i=0}^{t} \varphi_{S,D} + \left(2\pi r_a * I_o^2\right) \quad (1)$$

Where L_E indicates the link existing period between the nodes, $\varphi_{S,D}$ represents the distance among currently selected source node 'S' and the currently acting destination node 'D'; and $2\pi r_S * I^2_o$ denoted for the typical received power from nodes.

Probability of duration of link that exists between the nodes for the selected optimal route of ORPS_ACO is evaluated using equation 2,

$$P_{SA}(n) = \frac{\varphi_{SA}^{\alpha} * \mu_{SA}^{\beta}}{\sum L_E} \quad (2)$$

Where μ_{SA} → represents for successive route request, $\varphi_{SA} \rightarrow (1/d_{SA}) \rightarrow d_{SA}$ (distance between nodes S and A) and 'α' and 'β' denotes for the parameters that determines the TTL.

The probability of a link being present with an optimal route level P_{SA} is '0' if TTL terminate or if there is no link between the nodes. TTL calculations, or the routing channel for data that occurs between nodes for communication by passing control messages, can be used to measure the level of dropped communications. P_{RV} is the minimum threshold or benchmark value for link accessibility. Equation 3 can be used to approximate the reference value,

$$P_{RV} = \sum L_E / Time \quad (3)$$

To transmit data along the best paths, pilot nodes are chosen from the sub-pilot nodes. As a result, PNs are selected upon due deliberation of the node's energy state, bandwidth consistency, and reputational cost.

Data Transmission Stage

For dependable and ideal routing, the network's pilot nodes are chosen. Bandwidth Coherence (BC) and Energy State are two node constraints that are used to choose the pilot nodes and sub-pilot nodes (ES). Pilot node is elected from the number of sub-leader nodes in order to transmit data effectively and reliably with the least amount of processing time. The energy balance left over after nodes in the routing path have used energy for earlier data transmission is taken into account to calculate the node's energy state. Node linkage analysis is used to estimate BC". The term "bandwidth coherence" refers to the higher amount of packets that can be sent through a channel. As a result, the examination of two criteria, such as BC and ES, is used to choose the pilot nodes.

The source of the control message, such as Route request and Route reply, is determined by the NodeID. The energy state describes the node's available energy or remaining energy. Analyzing the quantity of connectivity that is accessible and determining the typical bandwidth usage for a specific data communication are both parts of bandwidth estimate. For fewer packet transmissions, low-level linkage node connectivity is sufficient. Every leading node has a fixed bandwidth reference level and the bandwidth information rate less than the B_{Ref} have been selected for packet forwarding. This improves the network throughput and the estimation is given in equation 4,

$$\beta_{S,D} = \frac{Total\ pkts\ sent}{Time} (bps) \quad (4)$$

The reference value of bandwidth 'B_{REF}' is set through the estimation of typical packet size which is used for node communication. It includes data path rate and control overheads.

$$B_{REF} = \sum BC \quad (5)$$

One of the criteria for choosing the pilot nodes is the node's greater residual energy. Nodes with lesser energy state are kept out of routing in order that an effective communication channel can be established. The node's energy drain rate is measured using their remaining energy to preserve greater quality of link among nodes. The network maintains an energy threshold that is used as a standard for network participation. Rate of energy loss (E_L) is estimated by taking the differences between principal level of energy E_P and present level of energy level P_E with respect to time which is given in equation 6,

$$E_L = \frac{E_P - P_E}{T} \tag{6}$$

The pheromone content or link gap connection between the nodes is selected depending on node parameters BC and ES.

Node Recognition Cost

Through observation of node activities and their response communications in the network, Node Recognition Cost (NRC) is calculated. The NRC is committed to determining if a node is selfish or not. If the NRC value is greater than 25%, a regular node can both transmit and receive the data. Selfish nodes are discovered if the predicted NRC is found to be less than 25%. Utilizing communication control messages, NRC is calculated. It is calculated by subtracting the difference between messages delivered by each individual node as route replies (R rp) and messages sent as route requests (R rq) messages and the equation 7 is used to determine NRC,

$$NRC = \left(\frac{p-q}{p}\right)*100 \tag{7}$$

Where *p* → received R_rq and *q* → unprocessed R_rp

$$q = p - r \tag{8}$$

Where *r* → processed R_rq;

NRC - Algorithm
Set node N_i
Process R_rq to neighbor nodes;
Compute NRC through p, q & r;
If obtained NRV > 75%
N_i → highly reputational node
Else if, 25% < NRV < 75%
N_i → average reputational node
Else NCR < 25%
N_i → selfish node

The node is referred to as having a high reputation or being a trustworthy node if the obtained NRC is greater than 75%. If the NRC is discovered to be lower than 25%, the node is referred to as selfish or poor reputation node. If the value is between 25% and 75%, the node is referred to as medium reputational node.

ORPS_ACO - Algorithm
Step 1: Initialize the network
Step 2: Assign *n* number of nodes;
Step 3: Pick *'S'* as source node & *'D'* as sink node;
Step 4: Generate neighbour node list *(nn)* through *'S'*
Step 5: Check if S≠D;
Step 6: *'S'* broadcasts cntrl_msg (R_rq);
Step 7: Examine P_{SD} for each *nn* & set P_{REF} for reference check;
Step 8: Compare P_{SA} & 'P_{REF}'
Step 9: If {
Step 10: $P_{SA} > P_{REF}$ → Elect as Sub-PN
Step 11: Now only one PN should be chosen from available sub-PN;
Step 12: Check E_L, BC & NRC & Compare with reference level;
Step 13: Select low E_{DR} & high BC → Elect as PN
Step 14: Update 'S' and do repeat step 5 to 13 until reaches D
Step 15: 'D' response with R_rp;
Step 16: PN applies packet scheduler

Step 17: Assign Queue index for data packets
Step 18: Determine Packet weight
Step 19: PN's process data transmission if queue length → $0.7 < Q_{HP} < 1$;
Step 20: Else PN's process Q_{LP}
Step 21: End

Dynamic Packet Scheduling

To make the network more reliable the packet transmission should be more optimal. Hence the packets are transmitted using packet scheduling algorithm.

The classifier uses the queue index value to analyse the packet priority level once it has arrived at the node from the sensing environment. The descending order priority queue is used to find the high priority packet queue. Here, the higher priority number for the higher priority packets is stored in the queue index. The packets are divided into low- and high-priority groups based on their priority. The packet should be dispatched first if the packet queue has a high index value. The packet scheduler assigns the packets to the priority queue in descending order. As a result, the duty cycle is dynamically modified in relation to the queue length and the packet prioritisation process.

The queue length is determined by dividing the active time T_A into equal number of time slots N and it is given in equation 9,

$$T_A = N_{Timeslot} \tag{9}$$

Since there are more timeslots available if the waiting time increases, the waiting time is directly inversely related to the length of the line. In order to calculate the average queue delay for highly priority packets, low pass filter (lpf) is used.

By altering the queue weight in an adaptive manner, the average queue length can be kept to a minimum. As a service rate that is assigned to each queue during transmission, queue weight is referred to in this context. Equation 10 is used to calculate the average queue length, and the lpf parameter is set to 0.01 to reduce the fluctuation of the instant queue length (QL).

$$QL_{Avg} = (1 - lpf) * QL_{Avg} + lpf * QL \tag{10}$$

Maintaining the average QL below the minimal level will reduce queuing latency. This can be done by making the high prioritised packets heavier. However, if QL_{Avg} exceeds TH_{Max}, the high priority class shouldn't go above its upper bound (0.7), as this causes packet clustering.

The packets are transmitted according to the specified time slot on a First In First Out (FIFO) basis if the queue status is available and the weight of the preferred packets is assessed. The Q_{HP} is served on a FIFO basis if the number of high priority packets is less than or equal to the given active timeslot. The Q_{LP} can be handled on a FIFO basis if there are no Q_{HP} packets in the queue at the current state of the queue. If a new Q_{HP} comes in the middle of a Q_{LP} packets queue transfer, then the weight of the new packet is determined. The queue packet is intercepted under Q_{HP} with a weight of $0.7 < Q_{HP} < 1$, after which the pilot nodes processes the queue. Q_{LP} is processed in the leftover time window to prevent low priority packet queue congestion.

IV. RESULTS AND DISCUSSION

A simulated scenario with 250 nodes installed and set up as the underground wireless network with the requirements listed in **Table 1** is used to demonstrate the method suggested here. To locate the various targeted nodes, programming in C++ and the Object-oriented Tool Command Language (OTCL) is used.

In this paper, simulation results are used to examine the proposed ORPS ACO system and compare its performance to that of the existing schemes, CADSS & QEBSR. Simulations are used to compare the packet delivery rate, energy consumption, transmission delay and scheduling overheads in order to examine the performances.

Table 1. Simulation Parameters

Parameter	**Value**
Node Count	250
Protocols for Routing	ORPS_ACO, CADSS & QEBSR
Area of Simulation	1000X1000
Range of Transmission	250mts
Type of Antenna	Omni Antenna
Network Interface Type	WirelessPHY
Type of Channel	Wireless

Packet Rate Delivery

Packet rate delivered (P_{RD}) is defined as the total number of packets that is transmitted from the sender to the receiver successfully. It is measured using the total number of packets delivered for a set of transmission with respect to time. PR_D is measured using equation 11,

$$PR_D = \frac{\sum_0^n Total\ no\ of\ Pkt\_s\ Rcvd}{Time} \tag{11}$$

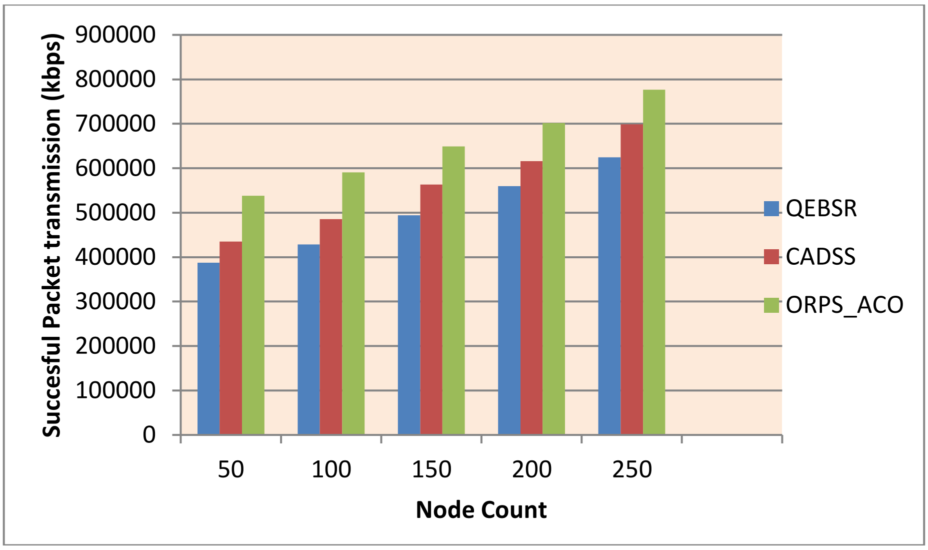

Fig 2. Packet Rate Delivered.

Fig 2 shows packet delivered rate for both the proposed and conventional schemes such as ORPS_ACO, CADSS and QEBSR. This graphical representation clearly shows that the ORPS_ACO scheme has better packet rates delivered at receiver side while comparing with CADSS and QEBSR methods.

Scheduling Overheads

Packet scheduling process is generally used to reduce the data losses during transmission of packets from one node to other. This scheduling process also reduces congestion and unnecessary delays during the packet reception process.

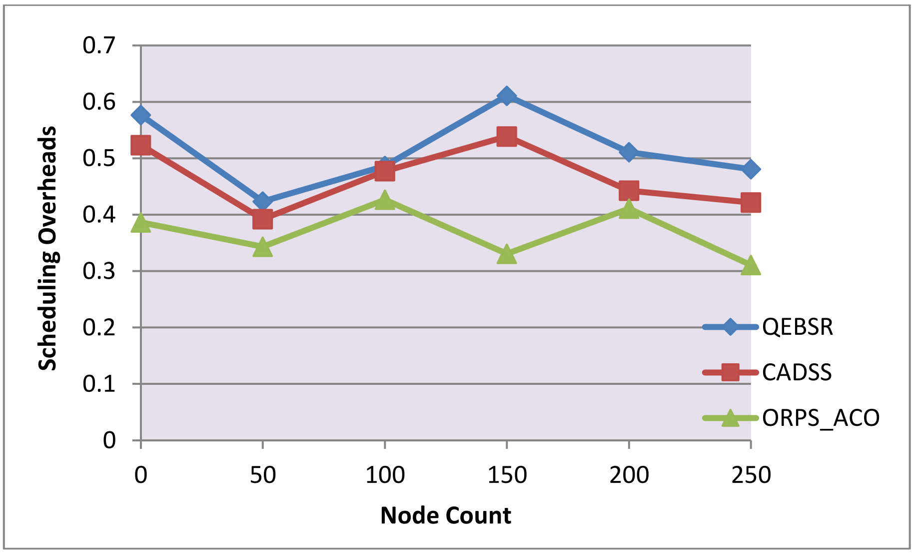

Fig 3. Scheduling Overheads.

By transferring high prioritised packets through the selected pilot nodes with dynamic packet scheduler with respect to the congestion rate. The obtained scheduling costs for the proposed ORPS_ACO method and the existing schemes CADSS and QEBSR is shown in **Fig 3**. Here the proposed scheme ORPS_ACO possess good scheduling cost and proves its efficiency comparatively.

Energy Consumption

The remaining energy present in the node after the transmission of data is defined as residual energy. The proposed system ORPS_ACO utilizes very less energy level for data transmission.

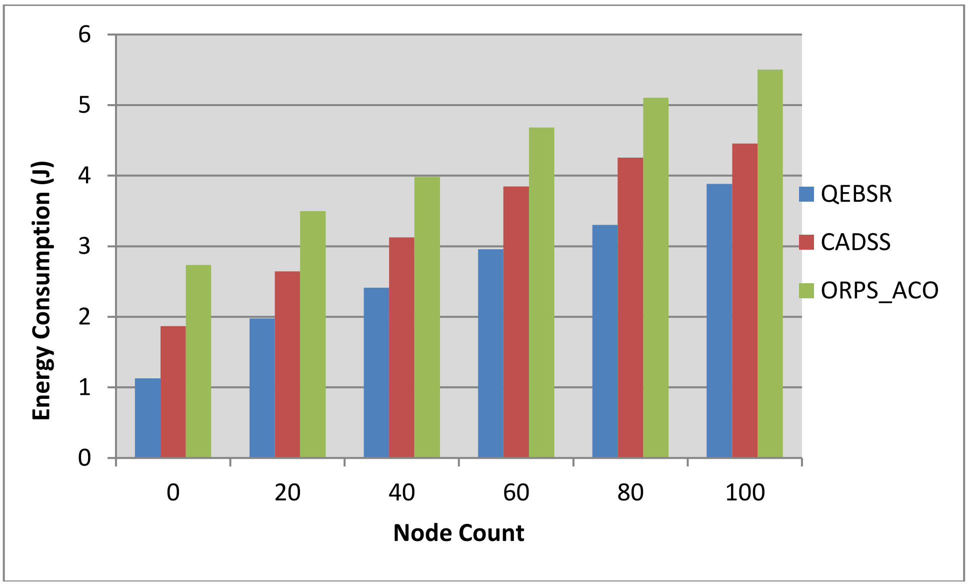

Fig 4. Energy Consumption Cost.

Fig 4 represents the energy consumption cost for both proposed scheme ORPS_ACO and conventional schemes QEBSR and CADSS. Proposed scheme ORPS_ACO has high leftover energy in the nodes since this algorithm selects the DF nodes for routing the packets. Including utilization of dynamic DC adaptation makes the network more energy efficient.

Transmission Delay

The packet transmission delay is measured for evaluating the total time taken for the packet to travel from sending node to the receiving end. It is defined as the time variations calculated from the packets sent from sender and the packet received by the receiver. Transmission delay can be measured using equation 12,

$$Transmission\ Delay = \frac{\sum_0^n Pkt\ Rcvd\ Time - Pkt\ Sent\ Time}{n} \tag{12}$$

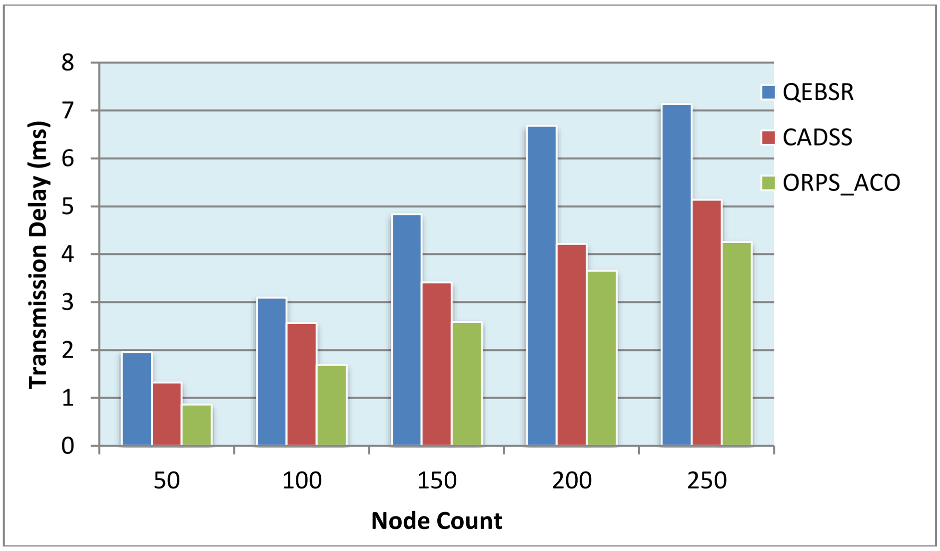

Fig 5. Transmission Delay.

Fig 5 shows the graphical representation for the packet transmission delay of both proposed and conventional schemes. Proposed scheme ORPS_ACO achieves lower transmission delay for transmission of packets from DF nodes to destination. Since adaptive packet scheduling is assigned for higher prioritized packets the data processing delay is minimized for the proposed scheme compared to conventional protocols QEBSR and CADSS. Obtaining lower value of transmission delays signifies that the achievement of higher system throughput.

V. CONCLUSION

The use of an ACO-based optimal routing and packet scheduling system improves the network's properties and capabilities. This strategy has been put forward to decrease link failures that occur in the network as a result of low energy nodes appearing, selfish behaviour, low link gap connection during routing, etc. An ACO mechanism is used in sensor networks to determine computationally intensive routes and to reduce energy usage. The optimal route is determined through the pilot nodes by analysing their energy state, bandwidth coherence and node recognition cost factors. The best pilot nodes are selected and the transmission is done. Dynamic packet scheduler is used to forward the higher priority packets and hence route congestion can be minimized. Compared to the CADSS method, the proposed scheme's efficiency is up to 24% higher.

CRediT Author Statement

The authors confirm contribution to the paper as follows:

Conceptualization: Thirunavukkarasu V, Senthil Kumar A, Saritha K and Lakshmi S; **Methodology:** Thirunavukkarasu V and Senthil Kumar A; **Writing- Original Draft Preparation:** Thirunavukkarasu V, Senthil Kumar A, Saritha K and Lakshmi S; **Visualization:** Saritha K and Lakshmi S; **Investigation:** Thirunavukkarasu V and Senthil Kumar A; **Supervision:** Saritha K and Lakshmi S; **Validation:** Thirunavukkarasu V and Senthil Kumar A; **Writing- Reviewing and Editing:** Thirunavukkarasu V, Senthil Kumar A, Saritha K and Lakshmi S; All authors reviewed the results and approved the final version of the manuscript.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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Competing Interests

There are no competing interests.

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