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Game Theory-Based Multi-Hop Routing Protocol with Metaheuristic Optimization-Based Clustering Process in WSN for Precision Agriculture

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ABSTRACT

In precision agriculture, a wireless sensor network (WSN) is employed to gather data pertaining to atmospheric conditions. WSN consists of sensor nodes installed at multiple points in a greenhouse for monitoring soil properties like moisture, pesticide levels, air temperature, humidity level and so on. Sensor nodes transmit the measured parametric digital information to a sink node. It further transmits the sensed data to a decision support system. The decision system uses a crop development model to effectively manage irrigation, fertilization, and climate control systems in a greenhouse. This allows for exact control over temperature and humidity levels. By using appropriate inputs, crops may be effectively managed, resulting in improved crop health and increased yield. Reliable transmission data is a crucial design objective for WSN in precision agriculture as the presence of foliage in the transmission channel causes significant attenuation of the radiated waves. Additionally, it may cause scattering and diffraction of signals as well. A dynamic data routing protocol selects the optimum data paths for node data transmission in a WSN. This paper presents a novel energy-efficient multi-hop data routing protocol for WSN precision agriculture applications. The proposed method is named Grey Wolf Optimized Coalitional Game Theory-based (GO_CGT) multi-hop routing protocol is adopted for selecting the required features to measure the importance of the corresponding fitness and dilate the feature map containing less information. Moreover, a rapid and highly which achieves 78.2% of PDR, 12% of energy consumption, 34.7% of end-to-end delay, and 247kbps of throughput.

1. INTRODUCTION

Precision agriculture, often known as precision farming, is an interdisciplinary area that utilizes advanced technology to optimize cost management, enhance crop development, and improve output outcomes within agricultural fields [1]. WSN plays a significant role in advancing precision agriculture by facilitating the monitoring of various physical and environmental factors such as humidity, temperature, and illumination. The sensor nodes (SNs) within these networks have the task of gathering data on these conditions and relaying it to the base station (BS) through either single-hop or multichip coordinator nodes [2]. The aforementioned technology exhibits a multitude of advantageous applications in diverse domains such as healthcare, military operations, transportation systems, security measures, and agricultural practices [3].

SNs have been used in healthcare settings to gather physiological or biometric data from patients, including electrocardiogram (ECG) readings, heart rate measurements, and blood pressure data [4]. SNs are strategically installed inside military operations to facilitate the tracking and monitoring of troops on the battlefield. These nodes serve the purpose of locating platoons and safeguarding military personnel. SNs play a crucial role in security by providing vigilant surveillance to detect and monitor hazardous situations, hence maintaining a state of heightened awareness to counteract any terrorist threats [5]. SNs are strategically positioned throughout the field of agriculture to gather data on various environmental factors. Furthermore, the SNs are capable of detecting and monitoring environmental conditions, which may be used for weather forecasting and assessing the likelihood of natural disasters. Within these networks, the SN is classified into two distinct categories: coordinator nodes and normal nodes. The purpose of this categorization is to facilitate the collection of data from the agricultural field [6]. The primary function of the sink node is to gather data from SN and, then, transfer it to the gateway or BS. From there, the data is sent to the central management system, where it is used for decision-making purposes. The sensor nodes are characterized by their compact dimensions, limited processing capabilities, and constrained energy resources [7].

SN is used to observe and assess environmental circumstances, such as crop conditions and several other environmental indicators. The sensor nodes are strategically positioned either on the soil surface or inside the soil. Various technologies and standards have been implemented, taking into consideration factors like as application requirements, data rate, frequency range, power consumption, and transmission distance. Several widely used technologies are Wibree, Wi-Fi, GPRS, WiMAX, Bluetooth, and ZigBee [8]. The data collected from the SN in the field will be monitored and, then, sent wirelessly to the BS for data gathering. The Bachelor of Science degree catalyzes further procedures. The users are provided with crop growth statistics and other relevant data pertaining to drip irrigation. They then undertook further measures to enhance the microenvironment for their agricultural produce [9].

In the field of agriculture, precision control is achieved by the use of SNs that monitor various parameters. The data collected by these sensors is then analyzed to inform decision-making processes and facilitate the implementation of control mechanisms [10, 11]. Numerous initiatives have been undertaken to enhance agricultural cultivation and precision farming, as well as the collection and transmission of monitored data [12, 13]. The collected data pertains to many environmental factors. Additionally, the data includes information on crop identification, leaf area index, leaf moisture content, and the detection of weeds and diseases. Another method used by the SNs is the acquisition of fruit pictures for automated harvesting, as well as the estimation of soil moisture and organic composition [14, 15].

The use of mobile sensor nodes is employed to quantify the biomass of agricultural crops and evaluate the fertilization attributes to optimize productivity. The evaluation of soil strength measurement and prediction-based harvesting time is conducted using specialized sensors [16, 17]. Within a WSN, effective data packet transport to the intended destination necessitates collaborative efforts among the SNs. Each node can serve as a routing node. The design of a safe and energy-efficient routing strategy is crucial in addressing the potential threat posed by a rogue node intentionally dropping packets.

The use of game theory in WSNs has been employed as a means to address the challenges pertaining to energy efficiency and security [18]. Game theory is an academic topic that seeks to model scenarios in which decision-makers are faced with the need to take specified actions that result in mutually contradictory or consequential outcomes. In a previous study [19], a query routing strategy was introduced that demonstrates reliability. The sensors in this scheme are characterized as rational and intelligent agents, working together to create network topologies that optimize their payoffs inside a sensor game. Two economic methodologies have been suggested as countermeasures against Denial of Service (DoS) assaults, namely secure auction-based routing (SAR) and non-cooperative non-zero-sum two-player game [20]. Inside the context of the SAR protocol, nodes are required to engage in a competitive process to determine their eligibility for forwarding incoming packets and, subsequently, establish a favorable reputation inside the network. The competition is grounded on the principles of auction theory.

Several reputation-based approaches have been suggested in the literature to effectively identify and isolate misbehaving nodes in WSNs to enhance their security [21-23]. A novel approach has been introduced to detect malicious nodes, incorporating a zero-sum game strategy and selective node acknowledgments within the forward data channel [24]. In consideration of the above, the current study provides the following contributions:

- The coalitional game model that has been provided may be integrated into an existing wireless routing system, and this study proposes an extension to the LEACH protocol for further refinement.
- In the Reliable Coalition Formation Routing (RCFR) protocol, a node that does not belong to any coalition is excluded from the route. The source node can determine the most efficient route to a destination from a selection of numerous established reliable pathways during the process of route discovery.
- To achieve the most effective selection of Cluster Heads (CHs), this study develops a fitness function that incorporates many requirements. These constraints include energy consumption, limited area coverage by the nodes, the workload of chosen CHs, and low communication delay.

The subsequent chapter is structured as follows: Section 2 provides an overview of previous research studies, Section 3 presents the suggested methodology and techniques, Section 4 showcases the experimental results and subsequent discussion, and lastly, Section 5 concludes with a summary and outlines potential future study directions.

2. RELATED WORKS

In addressing the security concerns associated with WSNs, it is essential to consider the dependability of data creation, the integrity of data transfer, the secrecy of task execution, and the efficacy of data fusion. The security issue of WSNs is widely recognized as a significant factor impeding their progress. The field of game theory is concerned with the analysis of decision-making behavior exhibited by individuals or entities, particularly in situations involving interactions, and the identification of equilibrium states in decision-making processes. Game theory is an academic framework that uses mathematical techniques to analyze the strategic interactions and decision-making dilemmas encountered by several individuals. Within the context of a game scenario, all individuals responsible for making decisions choose the approach that maximizes their anticipated gains. Given the interconnected interests of all parties involved in the game, each decision-making entity needs to take into account the strategic choices made by other players to determine its optimal strategy.

In the study [25], each SN is regarded as an individual participant in the game. The SN can use advantageous strategies based on the duration of idle listening time during the active phase, and then decide on whether or not to enter a resting state. The Multi-Swarm with Energy-Efficient Game Theory on Locust Search (MSGE-LS) algorithm effectively chooses CHs, reduces energy consumption, and enhances network longevity. In the study [26], the Division Non-Cooperative Game LEACH (DivNCGL) routing method is a modified approach that builds upon the Low Energy Adaptive Clustering Hierarchy (LEACH) method. It achieves this by strategically distributing CHs. The clustering technique presented in the study [27] is founded upon the principles of evolutionary game theory (EGT). The formation of the first clusters is accomplished using a straightforward partitioning strategy. Ultimately, the process involves the merging of the original clusters to generate the final clusters. The clusters are formed by the sink node with resourcefulness, and afterward, the CH nodes for each cluster are selected.

Awad et al. [28] used game theory to improve wireless sensor node algorithms, WSN clustering and routing, a remote field farm information monitoring platform, and a comprehensive agricultural information monitoring system. Reddy and Srivathsan [24] proposed a novel methodology that integrates enhanced particle swarm optimization (PSO) and evolutionary game theory (EGT) algorithms to effectively tackle the challenge of optimizing network longevity. The functioning of the WSN is comprised of two distinct phases: initialization and data transmission. During the initialization phase, the use of the enhanced PSO method is employed to build clusters and choose CHs in regions that are beyond the threshold of the BS. In the study [27], a game-theoretic routing protocol (GTRP) for three-dimensional underwater acoustic sensor networks (3-D UASNs) is proposed. The GTRP establishes a forwarding region that prioritizes nodes in closer proximity to the destination for forwarding. Subsequently, it calculates the degree of nodes inside the forwarding region without the need for periodic message broadcasting. Thirdly, the GTRP conceptualizes the process of forwarding as a game.

To achieve a routing system that is both resilient and effective, it is essential to take into account numerous routing metrics. As an example, a routing protocol has the potential to exhibit energy efficiency, although it may also be associated with a diminished packet delivery ratio. Similarly, a protocol might enhance the longevity of a network, albeit at the expense of increased end-to-end latency. Hence, it is essential to take into account the incorporation of cumulative routing metrics. Moreover, it is possible to integrate some QoS measures with the aforementioned routing metrics, including connection quality, route dependability, and packet loss. The protocols examined in this discussion notably lack consideration for the integration of routing metrics and QoS measurements. Some protocols only evaluate a single routing measure. The enhancement of current protocols may be achieved by demonstrating their resilience via a comparative analysis of performance using hybrid and cumulative routing measures.

3. SYSTEM MODEL

SNs are strategically installed in various cultivation areas to effectively monitor a range of environmental characteristics, including air temperature, air humidity, and light intensity, as well as agricultural metrics pertaining to soil conditions, soil moisture levels, pH levels, and so on. Within each geographical area, the sensor node systematically gathers, stores, and transfers data at regular intervals to the management node. Subsequently, the data is forwarded to the control center and ultimately to the server via the use of the Internet. Farmers can make informed decisions on the management of their farm's health to ensure high-quality produce, based on the data that has been acquired. Figure 1 provides an overview of our comprehensive system.

Each SN is equipped with sensors that possess the capability to detect various environmental factors, such as air humidity, temperature, pH levels, light intensity, and other relevant parameters, depending on the specific kind of sensors used. Furthermore, SNs possess the capability to establish communication with other SNs within the designated coverage area, facilitating the wireless transmission of gathered data to the management node.

Management node (MN): The administration of SNs within the coverage area is the primary responsibility of the intermediate node. This node acts as a mediator between the SNs and the control center, facilitating the reception of data from the SNs within its territory and, then, transmitting this data to the control center. Moreover, the management nodes are tasked with the role of receiving and transferring orders from the servers to the SNs to execute activities as requested by the server.

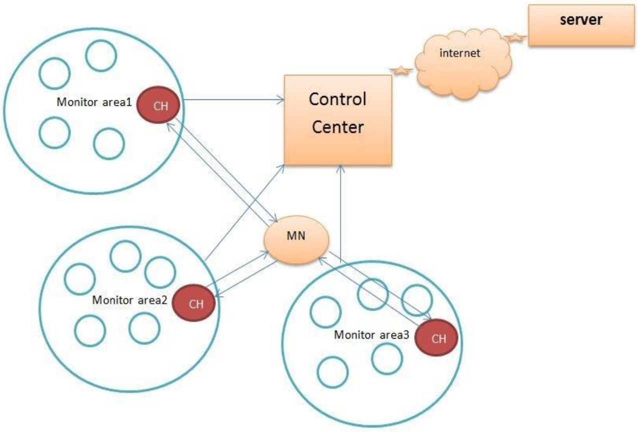

Figure 1. Overall flow diagram between networks

- Before delving into the technical aspects of the suggested Energy-aware IoT Framework for precision agriculture, it is imperative to highlight a number of network assumptions. The hypothesis is presented in a list format, outlined as follows.
- In each network area, there are distributed SNs that are used for real-time monitoring.
- The zones inside the network are circular in size and are dependent on the network coverage provided by the nodes.
- The placement of the nodes and the BS is predetermined and remains unchanged after they are deployed to construct the network.
- All communication channels from the sensors and SNs to the BS exhibit symmetry and provide bidirectional transmission.
- Each network node exhibits variations in terms of the availability of residual energy, such as battery life, processing capability, and accessible memory.
- Nodes are categorized as low, sustainable, or high based on their remaining energy supplies.
- In the network, it is seen that each area is comprised of several clusters, with each cluster including multiple SNs. Inside the SN cluster, there is a unique SN known as the CH, tasked with overseeing the exchange of data.

4. ENERGY CONSUMPTION MODEL

Sensor nodes utilize energy to sense, receive, and transfer data. Sensing energy consumption is constant and independent of the routing technique. The energy use difference between idle and receive modes is small. Gearbox energy consumption is the sole topic of this study. Each sensor may vary gearbox power to control communication range. In the context of data transmission, consider a node that is responsible for transmitting a single bit of data to another node located at a distance denoted as "d". The amount of energy consumed for transmission is represented by an equation:

$$e_{t_x} = E_{e_{lec}} + \varepsilon_{a_{mp}}.d^2 \tag{1}$$

Eq. (1) suggests that the energy consumed during transmission $e_{txcomprises}$ two main components. E_{elec} is the electrical energy consumption, is the energy consumed by the transmission system in the form of electrical power. ε_{amp} is electromagnetic energy dissipation represents the energy lost as electromagnetic waves propagate through space. The factor ε_{amp} is likely related to the efficiency of the amplifier or transmitter, and d is the distance over which the electromagnetic waves propagate. The term d^2 implies that the energy dissipation increases quadratically with distance. This equation provides a useful framework for analyzing the energy efficiency of a transmission system, taking into account both electrical losses within the system and losses due to electromagnetic radiation. The energy dissipation associated with receiving a one-bit packet is shown as,

$$e_{rx} = E_{elec} \tag{2}$$

It is assumed that the amount of energy used in the receiving circuit is equivalent to that of the transmitter circuit is represented by the e_{rx}. While this simplification might be appropriate in some contexts, in real-world scenarios, energy losses often occur during transmission. Factors such as resistance in transmission lines, inefficiencies in the conversion of electrical energy to electromagnetic waves, and environmental factors affecting signal propagation can all contribute to energy loss.

5. CLUSTERING PROCESS USING HYBRID GREY WOLF AND OPPOSITIONAL LEARNING OPTIMIZATION ALGORITHM

The solution representation for the proposed method is denoted as $(CH_1, CH_2, \ldots CH_{N_{CH_J}})$. The variable $CH_{N_{CH_J}}$ denotes the number of CHs, whereas N_{CH_J} represents the overall count of cluster heads. In 2014, Seyedali Mirjalili invented Grey Wolf Optimization (GWO), a metaheuristic algorithm that incorporates the cognitive abilities of grey wolves, namely their effective leadership and hunting strategies. In general, grey wolves engage in group-based hunting strategies, whereby a pack consisting of 5-12 wolves collaboratively pursue and capture prey. The wolf pack operates under a hierarchical structure consisting of four levels of leadership. These levels are designated as follows: the highest-ranking leader is referred to as the alpha (α), the second-ranking leader is indicated as the beta (β), the third-ranking leader is known as the delta (δ), and all other members are classified as omega (ω). The wolves denoted by the symbols α, β, and δ assume major roles within the pack, overseeing the maintenance of safety and cohesion, as represented by the variable ω. The author presented a mathematical formulation of the operational procedures used by grey wolves, which may be categorized into three distinct methods: encircling, hunting, and seeking.

Encircling – Grey wolves use a circling behavior as a first step to ensnare their prey prior to commencing the hunting endeavor. The mathematical expression for the encircling approach is as follows:

$$Y' = \left|C'.P_p'(mx)\right| \tag{3}$$

$$P'(mx+1) = \left|P_p'(mx) - A'.D'\right| \tag{4}$$

In this context, Y' represents the spatial relationship between the wolf and its prey. P' indicates the current position of the wolf after mx generations, whereas P_p' refers to the location of the prey. The coefficient parameters, denoted as A' and C', are calculated using the following procedure:

$$A' = 2a'.Y_1' - a' \tag{5}$$

$$C' = 2.Y_2' \tag{6}$$

The variables Y_1' and Y_2' represent randomly generated values that fall within the range of [0, 1]. These parameters contribute to the random alteration of wolves' circumference concerning their prey. The parameter a' is used to restrict the scope of the approach, which exhibits gradual convergence within the interval of [2, 0].

Hunting – Furthermore, the hunting procedure is gradually launched by the strategic repositioning of all the ω wolves, facilitated by the dominant wolves $\propto$, β, and δ. The location adjustment of dominant wolves was mathematically defined by the author as:

$$\begin{aligned} Y'_{\propto} = |C'_1.P'_{\propto} - P'|,\ Y_\beta = \left|C'_2.P'_\beta - P'\right|,\ Y_\delta \\ = |C'_3.P'_\delta - P'| \end{aligned} \tag{7}$$

$$\begin{aligned} P'_1 = |P'_{\propto} - A'_1.Y'_{\propto}|,\ P'_2 = \left|P'_\beta - A'_2.Y_\beta{}'\right|,\ P'_3 \\ = \left|P'_\beta - A'_3.Y_\beta{}'\right| \end{aligned} \tag{8}$$

Eqs. (7) and (8) may be used to provide a comprehensive update on the positional status of all wolves.

$$P'(k+1) = 0.33 * \sum_{t=1}^{3} P'_i \tag{9}$$

where, P'_i represents the arbitrary location of wolves in relation to the distance between the α, β, and δ wolves.

Searching – Ultimately, the predatory behavior of wolves may be characterized by their assault on prey and subsequent hunting for a new victim within their designated search area. The coefficient parameter A' is responsible for generating a random value that serves to enhance and broaden the search location of grey wolves. Grey wolves exhibit a behavior where they intensify their focus on a particular prey if the absolute value of the prey's attractiveness is denoted as $|A'|<1$. Alternatively, if $|A'|>1$, they engage in searching for a new target or prey. The parameter C' exhibits linear adjustment within the range of [0, 2], hence mitigating the occurrence of internal stagnation in the approach.

Oppositional learning – This approach uses the assessment of the present-day population rather than the alternative population to ascertain a more optimal resolution for a particular issue. Various metaheuristic algorithms have used the OBL approach as a means to enhance the rate at which convergence occurs. The mathematical formulation of the OBL paradigm is presented as follows:

Let $\mu(\mu \in [p,q])$ be a real-valued integer. The formulation of the contradicting integer μ^0 is expressed as follows.

$$\mu^0 = p + q - \mu^0 \tag{10}$$

The paradoxical integer μ^0 is defined for a pursuit space of dimension d.

$$\mu_f^0 = p_f + q_f - \mu_f \tag{11}$$

in which $\mu_1, \mu_2, \ldots, \mu_D$ is a prominent topic in the pursuit space of d dimensions, where $\mu_i \in [p_f, q_f]$ with $f = \{1,2, \ldots . d\}$. The oppositional-based approach is used throughout the setup step and during each generation using the iteration jumping rate J_r. The v parameter is used to investigate the search space and eliminate the occurrence of local optima.

CH selection – The GWO algorithm is a member of the swarm intelligence family designed to emulate the operational principles of grey wolves, particularly their leadership and hunting strategies. The simplicity and user-friendly nature of this method have served as a source of inspiration for several academics since it effectively addresses various intricate optimization challenges. Nevertheless, the traditional approach is plagued by prevalent problems such as the occurrence of local optimum error and premature convergence. The potential consequence of this is a decrease in the accuracy of finding optimum solutions in issues involving multi-model optimization. The OGWO algorithm has been hybridized to address the aforementioned challenges. This study proposes a hybrid algorithm that combines the OBL and GWO algorithms to enhance the search capabilities of the GWO algorithm and improve the convergence in selecting the best CHs within the network. The operational procedure of the OGWO may be described as follows: The population is initialized using the OBL approach, according to the search restrictions specified in the proposed method. Subsequently, the wolves' spatial coordinates are revised via the use of the standard GWO algorithm, while the OBL technique is employed to ascertain the antithetical region of the wolves. Additionally, the method under consideration involves the integration of the most effective OBL and GWO algorithms to update the wolves' position. The algorithm effectively manages the balance between intensification and diversity in its search for the ideal CHs inside the network.

6. GAME THEORY-BASED MULTI-HOP ROUTING

This study examines the WSNs in the context of a coalitional game, as seen in Figure 2. The establishment of a payment allocation technique among coalition members is based on performance measurements, which are used to create a characteristic function.

A rapid coalition-building algorithm has been developed to attain a stable coalition structure. This method may be used in a routing protocol to enhance reliability and reduce costs. The coalition game with transferable utility is represented as $\Delta \leq A, U$, where $A=\{a_1,a_2,\ldots,a_n\}$ denotes the set of players that engage in cooperative routing by forming interacting groups known as coalitions S,S⊆A. The characteristic function U is associated with each non-empty subset S of A. The collection of strategies for the node a_i is denoted as I_{a_i}={join, not join}. In the context of a certain coalition, each node, denoted as a_i, exhibits a preference either to join the coalition or to abstain from doing so. The strategy space of each participant is represented by I, which is equal to the Cartesian product of the individual strategy spaces $I_{a_i} \times I_{a_n}$. In the scope of the proposed coalition building game, it is assumed that time is partitioned into several slots denoted as t_k (k=0,1,…). Within each slot, the performance metrics of the nodes stay constant. The characteristic function of coalition S at the time slot t_k is represented by $U(S^{t_k})$ and computed in the following manner.

$$U(S^{t_k}) = \tau|S| - f_s(PER_i, RCR_i, RER_i) \tag{12}$$

where, $\tau \in (0,1)$ is used for adjustment. The term |S| denotes the cardinality of the current coalition S, whereas f_s represents the cost function. The cost function exhibits a declining trend in relation to the predetermined performance parameters of the nodes within coalition S. The primary factors may be attributed to the following features. There are two main points to consider: (i) the cost of achieving excellent network performance is substantially lower compared to achieving poor performance, and (ii) if a node within a coalition S chooses not to cooperate, it will pay costs as a consequence of its unfavorable conduct.

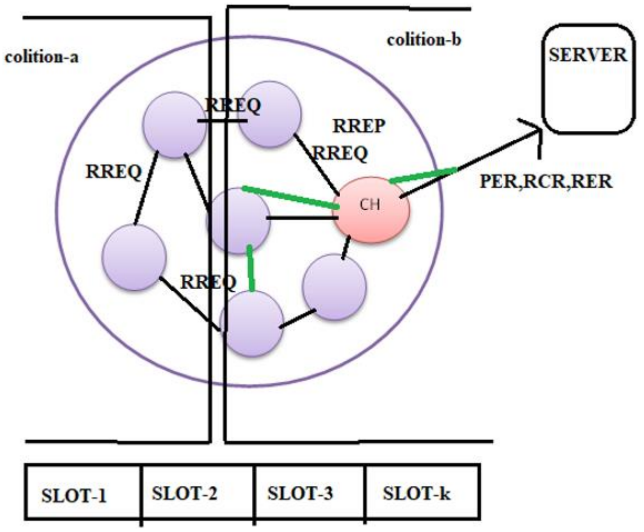

Figure 2. Coalitional game model for the routing process

The pace at which packets are sent is denoted as PER_i. In the context of WSNs, rational nodes may exhibit a reluctance to relay packets received from neighboring nodes as a means to save energy. Each node, denoted as i, keeps track of two records pertaining to its communication behaviors: PR_i, representing the total number of packets received by the node i from its neighboring nodes, and PF_i, representing the total number of packets sent by the node i. The value of PER_i may be determined by using the following calculation method:

$$PER_i = \frac{PF_i}{PR_i} \tag{13}$$

The rate of correctly reporting event RCR_i: Event detection is a prominent area of study within the realm of WSN applications, and the precise characterization of an event is contingent upon the particular application under consideration. To achieve their objectives, malevolent nodes may tend to inaccurately report events. The variables EC_i and ER_i are being referred to. Respectively, the terms "respectively" and "stand for" denote the number of events accurately calculated and recorded by node i and the total number of events reported by node i.

$$RCR_i = \frac{EC_i}{ER_i} \tag{14}$$

The rate of energy RER_i: In the context of WSN, the effective utilization of energy is a critical concern due to the inherent limitation of battery capacity in individual nodes. The notation RER_i is used to denote the residual energy information of the node *i*, whereas IE_i is used to indicate the entire initial energy information of the node i. The equation provided under is used for the computation of the Real Effective Exchange Rate (RER) denoted as RER_i.

$$RER_i = \frac{RE_i}{IE_i} \tag{15}$$

The routing protocol is developed by integrating the suggested coalitional game model with the LEACH protocol. The primary distinctions between LEACH and the proposed coalition-based routing scheme are shown as follows:

- The information on the established coalition partitions and the fields of PER_i, RCR_i, and RER_i are included in the table entry that is managed by each node.
- The route residual energy ratio (E_R) and route cost (f_R) fields are included in the RREP message.
- The ideal path is determined by using the coalitional game model, and the route with the lowest cost is chosen for packet delivery.
- The introduction of the rate of route residual energy is aimed at optimizing the mechanism for maintaining routes.

Route discovery – The route discovery process dynamically determines a potentially optimal path from the source to the destination. Conventional routing protocols like AODV and DSR, as well as energy-efficient, delay-aware, and lifetime-balancing data collection protocols for WSNs (such as EDAL), primarily concentrate on the physical layer and medium access control (MAC) layer within the WSN protocol stack. As a result, route selection primarily considers factors like the number of hops, delay, and overhead. However, the inherent susceptibility of the network layer makes it susceptible to potential attacks from both internal and external sources. Consequently, ensuring the dependability of routes becomes a crucial matter that has to be addressed. Ensuring the dependability of routes necessitates the selection of dependable nodes for packet forwarding. The coalitional game model reveals that nodes within coalitions collaborate to effectively accomplish the objective of dependable supply. To effectively detect and mitigate the presence of nodes engaging in malicious activities, the proposed approach involves excluding nodes that do not belong to any coalition from network topologies and subsequently preventing their participation in routing processes. The coalitional game routing method has three distinct steps in the process of route discovery: the broadcasting of routing request (RREQ) messages, the unicast of RREP messages, and the subsequent route selection.

RREQ broadcast – The RREQ message has many fields. If the source node can successfully transmit packets to the destination node, there is no need for further procedures. When the routing database does not include information on the current route to a destination, the source node will broadcast a Route Request (RREQ) message to its neighboring node to commence the process of discovering a route. When the intermediate node i is a member of any coalition and gets an RREQ message, it handles the packet in the following manner:

- To establish reverse routing, node i initially generates a database entry without assigning a valid sequence number.
- If the node i receives an RREQ message with an identical broadcast ID, it will disregard the message and cease forwarding it. However, if the RREQ message has a different broadcast ID, the node i will update the routing table entry and proceed to the next phase.
- The node i refers to its routing table entry to get information about the destination node as specified in the received RREQ message. Upon discovering a reasonably recent route to the intended destination, the system proceeds to transmit a Route Reply (RREP) message back to the source node, while also appending its remaining energy value (RE_i) as the route's residual energy ratio. Alternatively, if no such route is found, the system proceeds to the subsequent step.
- The node i increments the hop counter by one and disseminates the revised RREQ message to all of its neighboring nodes.

RREP unicast – The RREP message has many essential components, including the address of the source node, the address of the destination node, the sequence number of the destination node, the hop counter, the lifetime, the route residual energy ratio, and the route cost. Upon receipt of an RREQ message from the source, the destination node proceeds to transmit an RREP message using the following sequence of actions:

- Lifetime refers to the duration during which a Route Reply (RREP) message remains active inside the network.
- If the lifespan of the target node has expired, it will reject the subsequent RREP message. Otherwise, it will proceed to perform step (iii).
- If the destination's cache contains fewer than three stored routes, it will incorporate a new path into its cache and proceed to the next step. Conversely, if there are already three or more routes in the cache, it will move on to step (vi).
- The destination node evaluates the residual energy ratio of the newly introduced route in relation to the path currently residing in its cache with the lowest energy. If the former's value is less than or equal to the latter's value, the destination node will decline the incoming RREQ message. Conversely, if the former's value surpasses the latter's, the destination node will advance to the next stage, which entails replacing the old route with the new one and executing the subsequent steps.
- The destination node calculates the route cost, denoted as f_R, and determines the route residual energy ratio, denoted as E_R. It increments the hop counter by one and, thereafter, transmits the RREP message, including f_R and E_R, straight to the intermediate node from where the RREQ message has been first received.

The cost of the route, denoted as f_R, is calculated by the destination node in the following manner.

$$f_R = \sum_{k=1}^{m} \frac{MR}{|S_k|} \times f_{s_k}(PER, RCR, RER) \tag{16}$$

where, m be the quantity of coalitions existing in the given route R, and let MR indicate the number of members belonging to coalition S_k inside route R. Upon receiving an RREP message, the intermediate node proceeds to update the route residual energy ratio, denoted as E_R, in accordance with Eq. (17). Subsequently, the intermediate node sends the RREP message along with the updated value of E_R.

$$E_R = \frac{\sum_{i=1}^{n} RE_i}{\sum_{i=1}^{n} IE_i} \tag{17}$$

where, n is the number of nodes along the route.

During the route selection process, the source node evaluates the RREP message received over the reverse route in response to the RREQ message broadcast. The process involves verifying if the message's lifespan has elapsed and if not, it continues to update the routing table entry it keeps. In an alternative scenario, the source node disregards the second RREP message and opts to select the route with the most economical path from the destination's caches for transmitting packets. The underlying rationale stems from the fact that each coalition S strives to maximize its overall advantages. In this manner, the most cost-effective path is selected from a set of all potential routes.

Route maintenance is a crucial aspect of network management that aims to mitigate the potential risks associated with route failures, such as assaults or the presence of invalid nodes. Its primary objective is to optimize the network's lifespan by implementing strategies that address these challenges effectively. This enhancement addresses the issue of package transmission failure caused by the depletion of energy in nodes.

The achievement of maximal collective benefits in the coalitional game model is facilitated by the suggested routing algorithm, which picks the route with the smallest cost as the best path. The establishment of stability and convergence is ensured within the coalitions formed. Similarly, the issue of node selfishness is recognized, and nodes along the optimal path are imitated by stable coalitions to jointly enhance the transfer of packets. Hence, the chosen path exhibits stability. The stability of the path assignment is contingent upon the allocation of the best path among all potential paths from the source to the destination. The route maintenance mechanism comes into action when either a node failure occurs or a communication connection within the established stable route, as determined by our routing algorithm, is disrupted. In the present time interval, nodes rapidly establish alliances. The process of route discovery is initiated again to identify a stable route, after the establishment of stable coalitions. As a result, our routing protocol can maintain stability in the context of a changing topology.

7. PERFORMANCE ANALYSIS

Experimental setup: The proposed GO_CGT-based CH election and routing approach was simulated in NS-2. The simulation environment of the proposed GO_CGT scheme comprises 500 SNs dispensed at random in the agriculture farm domain of dimension 100×100 square meters. The BS of the system is reputed to be positioned at the corner of the network.

Hardware and software considerations for precision agriculture: Sensors placed in fields which gauge the temperature and moisture content of the soil and the surrounding air are used to gather real-time data. Additionally, satellites and automated drones can give farmers real-time views of specific plants. Drone piloting techniques for assessment, collecting information, and farming GIS-based tools for gathering, displaying, and evaluating land data. Simulation and modeling software allows farmers to simulate different scenarios and assess the potential impact of management decisions on crop yields, resource use, and profitability. These tools can help optimize production systems and mitigate risks associated with climate variability and market fluctuations

In Table 1, the simulation factors employed for the accomplishment of the recommended GO_CGT and the benchmarked MSGE-LS [25], DivNCGL [26], and GTRP [23] approaches are analyzed.

Table 1. Simulation parameters

Parameters	Values
Target area	100×100m^2
Number of sensor nodes	500
Energy of sensor nodes	4 joules
E_{ele}	50nJ/bit
E_{fs}	10pJ/bit/ m^2
E_{amp}	0.0013pJ/bit/ m^4
d_{max}	120m
d_0	57m
Message size	360 bits

7.1 Throughput

It refers to the pace at which data flows through a communication connection. In WSN, the measurement of throughput has a significant importance when considering the scenario when nodes are in motion and no concurrent traffic is present.

$$\text{Throughput}\left(\frac{\text{bits}}{\text{sec}}\right) = \sum \frac{(\text{no. of successful packets}) * (\text{average packet size})}{\text{Total Timetaken by the data}}$$

Table 2 shows the comparative analysis of network throughput between existing MSGE-LS, DivNCGL, GTRP, and the planned GO_CGTas show in Figure 3. The horizontal X-axis denotes the quantity of nodes, while the vertical Y-axis illustrates these values in percentages. When comparing the performance of different techniques, it is seen that the existing methods obtain network throughputs of 168 kbps, 139 kbps, and 201 kbps, respectively. In contrast, the suggested GO_CGT method achieves a network throughput of 247 kbps, which is significantly higher by 79 kbps, 108 kbps, and 46 kbps compared to the existing methods.

Table 2. Analysis of throughput

Number of Nodes	MSGE-LS	DivNCGL	GTRP	GO_CGT
100	167	128	201.4	246
200	166.8	138	179.3	237.3
300	168.1	126.3	187	268
400	165	137.9	189.3	241
500	165.8	125.7	181	240

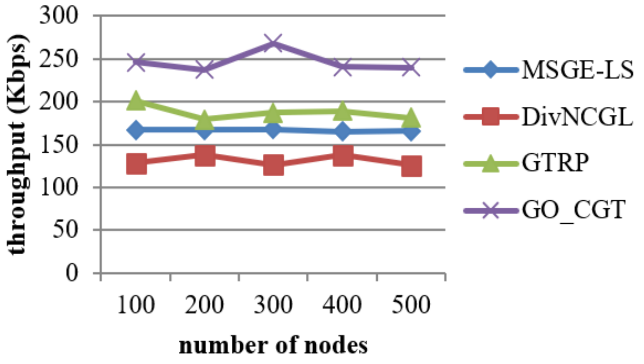

Figure 3. Network throughput

7.2 Packet delivery ratio (PDR)

PDR is the successful transfer percentage of packets from the source node to the target node in the network.

$$PDR = \frac{Number\ of\ packet\ received\ succesfully}{Total\ number\ of\ packets\ forwarded}$$

Table 3 illustrates a comparison of the network PDR between present MSGE-LS, DivNCGL, GTRP, and the planned GO_CGT. In Figure 4, the horizontal X-axis denotes the quantity of nodes, while the vertical Y-axis illustrates these values in percentages. When comparing the performance of the current MSGE-LS, DivNCGL, and GTRP techniques, it is seen that they obtain packet PDRs of 39.18%, 42.55%, and 46.34%, respectively. In contrast, the suggested EBTM-Hyopt approach achieves a much higher PDR of 78.2%. This indicates that the EBTM-Hyopt method outperforms the aforementioned methods by 39.2%, 35.65%, and 31.86%, respectively.

Table 3. Analysis of PDR

Number of Nodes	MSGE-LS	DivNCGL	GTRP	GO_CGT
100	10.2694	12.831	14.3854	71
200	28.1188	30.199	34.2574	76
300	51.9462	54.901	56.2568	75.5
400	65.2473	71.114	78.2522	77
500	79.5436	86.294	94.9474	77.2

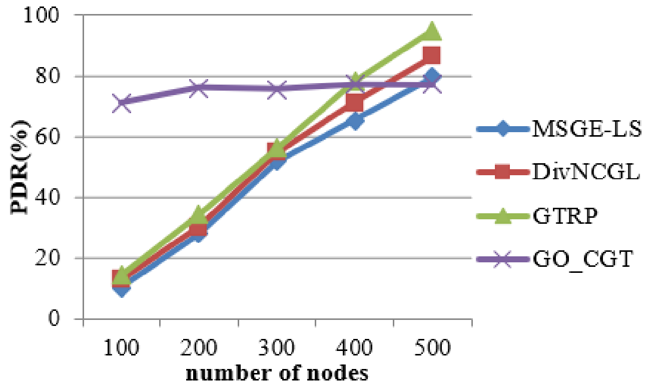

Figure 4. Packet delivery ratio

7.3 Energy consumption

The quantity being evaluated is defined as the aggregate energy of all hops and is calculated as

$$Energy = \frac{1}{p}\sum_{n}^{p} E_n$$

where, p and E_n are hops in multi-hop routing and energy of n^{th} hop.

Figure 5 shows the comparative analysis of energy consumption between existing MSGE-LS, DivNCGL, GTRP, and the planned GO_CGT depending on Table 4. The horizontal X-axis denotes the quantity of nodes, while the vertical Y-axis illustrates these values in percentages. When comparing the energy consumption of existing techniques, it is seen that they reach energy efficiencies of 23%, 32%, and 31%, respectively. In contrast, the suggested approach achieves a much lower energy consumption rate of 12%, which is 11%, 22%, and 21% less than the aforementioned methods.

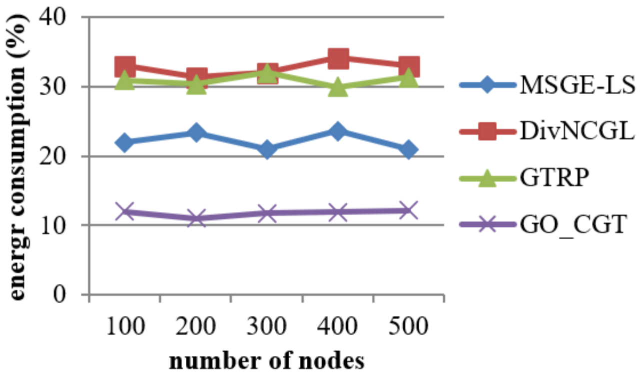

Figure 5. Energy consumption

Table 4. Analysis of energy consumption

Number of Nodes	MSGE-LS	DivNCGL	GTRP	GO_CGT
100	22	33	31	12
200	23.4	31.4	30.4	11
300	21	32	32	11.8
400	23.6	34.2	30	11.9
500	21	33	31.4	12.2

7.4 End-to-end delay

It refers to the total number of hops (p) needed for routing divided by the total number of nodes (tn) in the network.

$$Delay = \frac{p}{tn}$$

Table 5 and Figure 6 illustrate the comparison of packet loss between existing MSGE-LS, DivNCGL, GTRP, and the planned GO_CGT. The horizontal X-axis denotes the quantity of nodes, while the vertical Y-axis illustrates these values in percentages. When comparing the performance of existing techniques, it is seen that they reach 94.55%, 80.4%, and 67.49% of the end-to-end latency. In contrast, the proposed GO_CGT approach achieves a much lower end-to-end delay of 34.7%.

In Table 6 the throughput of WSN is depend on energy consumption of CHs mainly. In the proposed work, fitness function was designed with the consideration of essential parameters that reduces energy consumption of CHs, therefore, better throughput is achieved in the proposed GO_CGT. Limited battery capacity is the biggest challenge of the WSN environment, and the proposed GO_CGT consume very less energy and increases the lifetime of sensors as well. Moreover, the proposed GO_CGT dynamically select the most efficient paths for data transmission based on current network conditions. It can optimize throughput by avoiding congested or unreliable links and by adapting to changes in the network topology. In terms of scalablity and adaptability issues the proposed GO_CGT can handle node failures, communication disruptions, and environmental changes in large-scale WSN deployments. Present results from simulations or real-world experiments demonstrating the protocol's performance under varying network sizes and environmental conditions.

Table 5. Analysis of end-to-end delay

Number of Nodes	MSGE-LS	DivNCGL	GTRP	GO_CGT
100	52.289	39.592	29.343	33
200	85.482	71.912	60.769	33.6
300	12.212	93.281	85.227	34.7
400	37.379	18.934	99.338	35
500	79.985	58.912	30.268	35.6

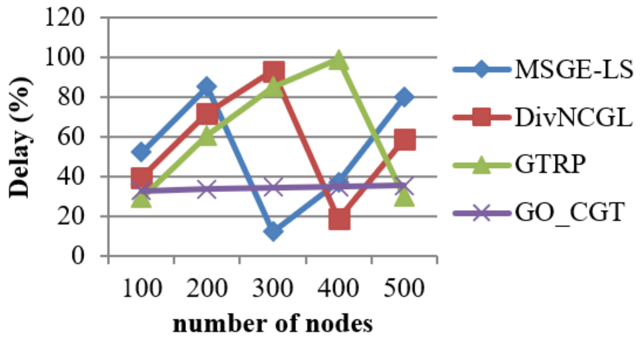

Figure 6. End-to-end delay

Table 6. Overall comparative analysis

Parameters	MSGE-LS	DivNCGL	GTRP	GO_CGT
Throughput (kbps)	168	139	201	247
Packet delivery ratio (%)	39.18	42.55	46.34	78.2
Energy consumption (%)	23	32	31	12
End-to-end delay (%)	94.55	80.4	67.49	34.7

8. CONCLUSIONS

The present study introduces a WSN-based intelligent agricultural environment information-gathering system. This system is designed to address the practical requirements and objective circumstances encountered in the domain of intelligent agricultural production. The network exhibits many notable characteristics, including strong scalability, exceptional dependability, minimal power consumption, cost-effectiveness, and excellent cost-performance ratio. This technology exhibits great suitability for extensive implementation and widespread adoption within the realm of agricultural production. This study presents an optimization of the routing approach based on the classic LEACH clustering algorithm, introducing the concept of metaheuristic clustering and game theory-based routing. Additionally, the use of the game-theoretic model offers WSN management a framework for determining the appropriate allocation of time to each routing protocol, taking into account optimistic, average, and pessimistic scenarios. In further research endeavors, we want to explore the difficulties associated with the implementation of this methodology in actual networks. Furthermore, we aim to examine the effects of other potential benefits on network performance, including computational complexity, bandwidth utilization, and memory consumption. In future we plan to explore the development of digital agriculture infrastructure, including data standards, interoperability frameworks, and cybersecurity protocols, to support the widespread adoption of precision agriculture technologies.

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