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An Enhanced Sector Low Energy Adaptive Clustering Hierarchy (S-LEACH) using Modified Grey Wolf Optimisation Algorithm and Game Theory

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Abstract

Wireless Sensor Networks (WSN) and other sensing and communication technologies have given man the ability to keep tabs on his surroundings. Distributed sensors in the form of WSNs are used to keep tabs on environmental or physics-related variables. These sensors operate together to send information via the internet to a central location, where it may be used to inform decisions that have real consequences for people's lives. As detecting, processing, and transmitting all take a lot of energy, WSNs are powered by batteries that cannot be replaced during data transmission. Therefore, it is essential to increase the network's durability by reducing the energy consumption of each sensor node. Power consumption problems exist in network's communication routes between the sensor nodes might have disastrous effects on a network that relies on timely data transmission. Since the sensor nodes need electricity to function, losing that power disrupts data transmission and, in most situations, kills the network. A serious issue with WSNs is their rapid loss of energy. Studies have shown that switching the node from active to sleep mode while it is not in use may extend the lifespan of WSNs. Some have argued that a mobile charger should be made available instead of a sensor node with a changeable battery. Even though energy harvesting the practice of drawing power from the surroundings and transforming it into electrical energy has the potential to address this issue, there are situations in which this is not possible. The objective of this study is to design a more energy-efficient algorithm for usage by sensor nodes in order to decrease their power consumption. By combining game theory and Grey Wolf Optimisation with the existing Sector Low Energy Adaptive Clustering Hierarchy (LEACH) routing system, a more efficient and effective algorithm was developed called Enhance Game and Grey Wolf Algorithm (EG-GWA).

Keywords: Cluster Head, Cluster Member, Base Station, Game Theory, Grey Wolf Optimisation.

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Introduction

Wireless sensor networks (WSNs) are networks made up of many tiny sensor nodes that collect data from their environment, analyse it, and then send it to a central location for further processing and analysis. The role of WSN is to monitor and move data packets throughout a network, tiny sensors are linked together. The sensor nodes are sent out into the field to collect data on a wide range of environmental and physiologic factors. Typical environmental variables that WSNs keep watch on include humidity, temperature, wind speed, and pressure. Massive developments in Micro-Electro-Mechanical systems and radio communication technology made WSNs a practical reality. It may be used to continuously or intermittently monitor the deployed area for sensing, target tracking, and event detection. Furthermore, it works in a wide range of data collecting use cases. WSN sensor nodes provide four crucial functions: data collection, transmission, reception, and processing (Najmeh, 2015).

Using a combination function (such as duplicate suppression, minimum amount, maximum amount, or average), data aggregation brings together information from several sources. In dense WSNs, in particular, the transmission of detected data may raise the traffic load and lead to congestion at the terminal nodes. As a corollary, this may cause an excessive drain on the network's energy supply. By merging data at many points along the journey from the nodes to the sink, a multiple-hop WSN may significantly cut down on network traffic. Data redundancy and lack of correlation can be eliminated by aggregating data at the cluster head (CH) (Song, Zhigui, & Xiaoli, 2020). Sensor nodes, which include signal-processing microelectronic circuits, micro-controllers, and wireless masts or receiver antennas, have limited processing and storage capabilities. Node devices gather data and information from the field where the network is placed, then send it to the base station (BS) if it is within transmission distance, or to sensor nodes within the cluster via routing mechanisms if the BS is not in range. The main contribution of this paper is that it addresses the issue of energy conservation in WSNs using location-based and quality of service (QoS) based routing.

Afraa (2018), undertook research titled "Energy Efficient and Secure Wireless Sensor Networks Design", the researcher used game theory to optimise WSN communication, in terms of energy efficiency, latency, congestion, traffic load, and the data safety. The research, also presented a self-motivated game theoretic context to investigate the communications between enemy and defender as a non-cooperative security game in a WSN used for military operations. Some of the major contributions of the research are:

a) Enhanced energy efficiency through optimized sleep intervals.
b) Developed the direction-finding protocol in order to mitigate energy wastage, congestion, and clustering which is premise on optimisation and game theory.

While the limitations also are:

a) The work focused mainly on making a node to change its mode so as to conserve energy.
b) When there is high traffic on the Network the lifetime will reduce since the nodes are highly active.

Maheshwari, Sharma, & Verma (2020), also did research titled "Game theoretic application for energy efficient mobility handling in wireless sensor network", which investigated the problem associated with a new node joining a cluster, it also presents a model to addresses the problem of allocation reserved slots for potential members of a cluster. Evolutionary game theory (EGT) was used in allocation of slot for nodes joining the cluster; new CM and achieving Nash equilibrium. The notable contribution of the research is:

a) Used Game Theory to model slot allocation for mobile nodes.
b) Reduced delay and Network congestion.
c) Model was better than other in relations to Network lifespan, PDR and throughput.

While the limitations are:

a) Only node close to recharge point is recharge during transmission.
b) CH selection did not consider link quality and distance.
c) Time Division Multiple Access (TDMA) scheduling was the only techniques used for allocating reserve slot (RS); this technique is subject to multipath distortion.
d) With high mobility rate and reserved slot allocation, there is high rate of data collision and information loss.

There is need for further research that will reduce interference of the radio frequency (RF), and energy consumption across the network.

Golrasan & Varposhti (2021), in their research titled “A New Game Theory-Based Algorithm for Target Coverage in Directional Sensor Network”, proffered solution to the problem of maximising network lifetime with adjustable ranges (MNLAR), redundant sensors are turned off, so as to reduce the level of energy used up by the sensor node. Some of the notable contributions are:

a) Developed a game theory-based algorithm in where sensor nodes adjust their detection range so has to minimise energy consumption.
b) Developed a pay-off matrix which maximise the utility function obtained from the strategy applied by players in the game.

While the limitations are:

a) High data redundancy in the network due to its dense nature.
b) No room for new members to join the network so as to address to issue of node not been able to sense data in areas outside the sensing range.

Mohammed, Mekky, Suleiman and Hikal (2022), in their work called Sector LEACH (S-LEACH); they enhanced LEACH to address it limitations. The research decreased the transmission distance between nodes by splitting the area for communication into sectors centred on the BS. Considering the volume of energy required to transmit data is relative to its distance, minimizing the distance between nodes increases its lifespan.

Game theory is a mathematical framework for formulating policies that take into account the interactions among several parties. Decisions on which routes should be taken are crucial. Several players are involved, and all of them must make choices. Each player's outcome is affected by the preferences made of all the other players that are participating in the game. In game theory, one of the most significant concepts is the players' rationale. Players are able to choose the most successful tactic for achieving their goals because they are intelligent individuals who are aware of all of their options. The Grey Wolf Optimisation (GWO) algorithm is a subset of swarm intelligence techniques that takes its cues from the leadership and hunting abilities of the wolf. Researchers from various fields have used this method to address issues peculiar to their area. The non-deterministic polynomial (NP) tough problems can often be solved using the iterative GWO technique, which uses a small number of parameters (Sekaran, Rajakumar, Dinesh, Rajkumar, Latchoumi, Kadry & Lim

(2020). The GWO is advantageous because it reduces the computing time and complexity needed to tackle real-world problems while increasing convergence and exploration (Kavita & Veena, 2021).

Sekaran, Rajakumar, Dinesh, Rajkumar, Latchoumi, Kadry & Lim (2020), selecting the best CH is a priority, therefore, it is important to take into account residual energy, intra-cluster distance, and BS distance. Also, an objective function was developed in the research, which contains all the necessary characteristics for determining the best option. The objective function is an equation that defines the desired level of output that will result in maximum profitability; in this case, the profit is to optimise the energy of the sensor nodes in the network. The value of the result is then calculated by considering the correlation between all the different variables. In other words, it is a formula for success followed to maximize profits and output.

Methodology

Network and Energy Models

The sensor nodes can be considered a game problem as seen in equation (1):

$$G = \{N, S_s, U\} \tag{1}$$

where:

N is the number of players in the game.

S_s is the strategy a player employs.

U is the utility function a player gets.

Likewise, a player in a game is a sensor node (S_i). Where:

i = {1, 2, 3…, n}

$$P_{fi_{Strategy}} = \frac{Mxh_{Si}}{Mnh_{Si}} + \frac{E_i}{E_{initials}} + PQ_{(i,j)} + NL_{(i,j)} \tag{2}$$

where:

Mxh_{Si} is the maximum number of hops between Sensor *i* and *j*.

Mnh_{Si} is the minimum number of hops between Sensor *i* and *j*.

$PQ_{(i,j)}$ is the path quality between *i* and *j*.

$NL_{(i,j)}$ is the noise level between *i* and *j*.

$$C_{i_{Strategy}} = C_{np} + C_{ppq} \tag{3}$$

where:

C_{np} is cost for routing through a noisy path

C_{ppq} is the cost a taking a path with poor quality

The Utility function of a player *i* is given by:

$$U_{i\ strategy} = P_{fi_{Strategy}} - C_{i_{Strategy}} \tag{4}$$

where:

$U_{i\ strategy}$ is the utility for a player gets from applying a particular strategy for routing to its destination.

$P_{fi_{Strategy}}$ is the payoff gotten by a player for the strategy of route taken

$C_{i_{Strategy}}$ is the cost incurred by a player *i*, for using a particular routing strategy

Since WSNs use multi-hop communication to forward data packets. A sensor node's gets a reward it receives for properly transferring the data packet to the subsequent sensor node. The reward is therefore modelled as:

$$R_{Tx_S} = DP \tag{5}$$

Where:

R is the reward

Tx is transmission of data

s is the sensors in the network
D is the reward for successful delivery of sensed data packets.
P is the probability of a successfully delivery of data packets.

Energy Harvesting Model

A wireless sensing node can carry out a range of sensing while obtaining power from local RF power sources. The volume of energy harvested by a node is affected by several variables: the RF source's transmitting power, frequency, the node's distance from the source, and the node's antennae strengths.
The energy model is given as:

$$E_{Harvest} = cPS_{Node}\, S_{Source}\, T_{harvest}\, (\lambda/\pi d)^{2} \quad (6)$$

P is the power transmitted from the energy source
S_{Node} is the strength of the Sensor node
S_{Source} is the strength of the RF source
c is the charging efficiency of the energy source
λ is the wavelength of the energy transmitting source
d is the distance between the node and the RF source
$T_{harvest}$ is duration of the energy harvest
Π is the ratio of a circumference to the RF source to its diameter.

Signal to Noise Ratio

The level of noise in a communication channel can result to packet loss, therefore it is important for routing algorithms to consider the signal to noise ratio of the receiver before sending data packets especially in a multi hop communication system. Hence, SNR can be computed by equation (7).

$$\text{SNR} = \frac{Signal\ Power}{Noise\ Power} \quad (7)$$

Results and Discussion

Algorithm 1: Enhance Game and Grey Wolf Algorithm (EG-GWA)

Start
BS sends a message to inform N
BS send message on geographical location details to all N

Start Setup Phase

Step 1.
For Each (N)
    Group N into clusters based on Sectors and shapes using theory of diagonal line symmetry and square formation
    triangular and quadrilateral Sectors are formed
    Calculate and compare the distance of N to BS
End for

Step 2.
For Each (N)
    Calculate its distance from CH
    Compute its residual energy and SNR

```
End for

Step 3.
For Each (CH)
        Prepare TDMA schedule for CH to transfer data
        Prepare TDMA schedule for CM to transfer data
        Advertise TDMA schedule to each CH and CM
End for

Step 4.
For Each Sector
        Every N sends its Energy and SNR to all other N
        Every N compares its E to that of others
        If E is not equal
                N with highest Energy level becomes next CH
        Else
                Choose N using modified GWO from Algorithm 2
        End if
 End for

Step 5.
Repeat step 3
End of Setup Phase
```

Start Steady-state Phase

```
Step 1.
For Each (N)
   N collects the data that it sensed
   Harvest energy if their Energy_Level ≤ Energy_Threshold from   RF sources
   If N is a CM
        N uses a multi hop routing/free space algorithm based on game theory for routing
        N forwards sensed data packets to the neighbouring CM
   Else
        N transfers the sensed data to the BS
   End if
  End for

Step 2.
For Each CH
    Receives data from the CM
    Performs data aggregation/fusion
    Transmits the data to the BS
     End for
End of Steady-state Phase
End
```

Algorithm 2: Modified GWO Algorithm

Input: Initialise the population size of the wolves X_i = (1,2, 3…n)

Step 1: Randomly create X_i within the sectors of hunting
Step 2: while $r \leq Max_r$
Step 3: For i= 1,2, 3,…,n
Step 4: Evaluate the fitness of the wolves F_i
Step 5: Pick the first best result as Alpha, second best as Beta, and rest as Delta.
Step 6: Recharge all Delta using the energy harvesting from equation (6)
Step 7: Endfor
Step 8: Return Alpha as CH

Algorithm 3: Game Algorithm

Step 1. Initialise:
Step 2. r = current round
Step 3. Begin
Step 4. for r = 1:max
Step 5. if the sensor network continues operates normally
Step 6. The sensors nodes are clustered in sectors
Step 7. if the sensors in the cluster adopt cooperative strategy
Step 8. The sensor node enters sleep, active or idle state according to its E_0 and
Step 9. TDMA
Step 10. else
Step 11. Penalise the node
Step 12. Calculate the number of penalties for each round for nodes N
Step 13. Mark the ID of the nodes and punish N rounds
Step 14. end if
Step 15. if
Step 16. node route data packets intelligently and cooperatively to the next node
Step 17. Reward the node by payoff from equations (2)
Step 18. Compute the utility of each node, N for equation (4)
Step 19. else
Step 20. End of simulation
Step 21. endif
Step 22. endif
Step 23. end for

The issue of energy depletion and uneven energy consumption WSN remains a major problem hence the need to mitigate this problem. To achieve network load balancing, Algorithm 1 (EG-GWA) evenly distributes sensor nodes around the geographical region. When choosing the CH, several criteria are taken into account, including SNR, energy level, distance between nodes, and BS. As a result of their combined effects, nodes' energy levels gradually decline. To recharge the node when its power consumption drops below a certain point, Algorithm 2 implements an energy-extracting method from the environment. In Algorithm 3, nodes are penalized for not using intelligent routing and rewarded for intelligently routing packets (taking into account Energy level and distance from nodes to

BS). Because sensor nodes might act selfishly at times, this forces the nodes to do what is necessary when routing packets.

Conclusion

Clustering routing methods may divide a WSN into evenly-spaced clusters to handle fundamental issues, including decreased power usage, routing m packet loss, and load balancing. This research was intended for WSNs and the optimum CH Selection process. The objective is to increase network efficiency by distributing the network and introducing a reward system for efficient packet forwarding from CM to CH to BS. This will stop the sensor node from behaving selfishly and collaborate with other CM and CH for effective and continuous transmission of data packets. More research should be done on clustering, energy as it is one of the major aspects of WSNs operations that consume more energy.

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