PARTICLE SWARM OPTIMIZATION IN WSN

6.1 INTRODUCTION

Wireless Sensor Networks are developing technology that has the potential applications in habitat monitoring, healthcare, disaster management, surveillance, and structural monitoring. It monitors the environment based on sensing the physical properties. It is a network of small and low-cost independent nodes that can attain, transmit and process the sensory data over the wireless medium. One or more authoritative Base Station serves as the final destination of the data. The properties of WSNs that pose technical challenges are dynamic topology, dense ad-hoc deployment, energy, spatial distribution and constraints in bandwidth, computer storage and computational resources. There are issues in WSN such as node deployment, localization, energy-aware clustering and data-aggregation. Customary analytical optimization techniques require huge computational efforts, which grow exponentially depending on the increase in the problem size (Sung and Chung, 2014). Clustering is one of the design procedures which is used to manage the network energy consumption. Clustering techniques are used by diminishing the number of nodes that take part in long-distance communication with the BS and then distributing the energy consumption consistently among the nodes in the network. The clustering-based approaches have the advantage of minimizing the amount of information that needs to be transmitted to increase the resource allocation and bandwidth reusability.
Numerous protocols have been already proposed with the objective of maximizing the sensor network lifespan by adopting cluster-based network constructions. One of the eminent clustering protocols called LEACH has been introduced to improve the network lifetime. LEACH provides important energy savings and extended network lifespan over conservative multi hop routing systems, such as the minimum transmission energy routing protocol (Khediri et al., 2014). However, LEACH does not promise that the preferred number of Cluster Heads is selected and Cluster Heads are not evenly positioned across the network. Nevertheless, an optimization method that requires reasonable computational and memory resources yields good results, exclusively for implementation on an individual sensor node. Bio-inspired optimization techniques are computationally efficient alternatives when compared to analytical methods. Particle swarm optimization (PSO) is a standard multidimensional optimization technique. The strengths of PSO are ease of implementation and yield high quality of solutions besides computational efficiency and an improved speed of coverage.

A framework to designed to improve the energy efficiency of the sensor node is discussed in chapter 3. In this proposed work, an energy efficient PSO protocol is implemented based on the discussion of the framework in chapter 3. The proposed method uses an Active Clustering Rule based LEACH (ACR-LEACH) to cluster the nodes and select the Cluster Heads for sensor node, information updating and sensor node management. In this method, TDMA is used to improve the conflict free transmissions under any traffic loading. Here, the time is slotted and the slots are grouped into frames. By scheduling the slots, the proposed method provides the QoS guarantees (bandwidth reservation, flow control and fairness). The cyclic scheduling algorithm is used to develop an energy saving MAC, which saves the energy which is twice the amount of the 802.11. Here, energy saving mechanism is used to turn the node into sleep mode once it is not used for data forwarding which is called as Cyclic LEACH. PSO
energy optimizer is designed to select the energy efficient forwarding nodes for data transmission between the source nodes to BS.

6.2 PSO_ACR-LEACH: AN ENERGY EFFICIENT PSO BASED ON ACR-LEACH

The proposed Energy Efficient PSO based Active Clustering Rule (PSO_ACR-LEACH) protocol is introduced with the wide use of cyclic scheduling of TDMA is shown in Fig. 6.1. The following subsection describes the proposed techniques and algorithms in detail.

6.2.1 NETWORK FORMATION

In the sensor network, each node achieves the sensing tasks periodically and sends the data to the BS. A fixed BS can be placed inside or outside the sensor network fields. All sensor nodes are stationary and energy constrained. Also, the nodes have power control capabilities to change their transmitted power. The nodes are capable of operating as Cluster Head mode and sensing mode. The proposed system uses the ACR-LEACH protocol to formulate the clustering environment and CHs are selected to manage and control the sensor nodes. The distance between the nodes are estimated based on the Euclidean distance.

6.2.2 CLUSTERING OF SENSOR NODES: ACR-LEACH PROTOCOL

Each node makes a decision independent of other nodes to select the CH or non CH node. In the advertisement stage, the CH informs their neighbouring nodes with a broadcast packet that they should become CHs. The sensor nodes receive the broadcast packet with the strongest received signal strength. In the cluster formulation stage, the member nodes inform the CH that they become a member to the corresponding cluster with the help of the join packet. The join packet includes the IDs using the CSMA. After this stage, all the CHs know that the number of sensor comes under the cluster and their IDs. Based on that, all packets received within the cluster, CH creates a TDMA schedule and accepts the CSMA code randomly.
Fig. 6.1 Flow of the proposed PSO based ACR-LEACH protocol for data transmission from sensor nodes to BS.
The CH node is selected based on the following three parameters:

1. Source of energy consumption in every node
2. Node centrality among every node and
3. Minimal energy consumption which increases the lifespan.

All nodes transfer the data with adequate power to reach the base station. Each node nominate itself as CH at the initial round r+1 with probability \( P_x(t) \) and \( n \) is the number of clusters.

\[
\sum_{x=1}^{N} P_x(t) \times 1 = n(6.1)
\]

All nodes have the chance to become CH, same number of times. All nodes have the same energy after \( N/n \) rounds. Every node is selected as CH that requires the least energy utilization for communication.

### 6.3 CYCLIC SCHEDULING FOR TDMA

Each node desires its neighbouring node’s information to choose the conflict free slots. When a node requires a slot, then the neighbour should use the known neighbour’s information to calculate the new slots within the 2-hop distance in order to create the New Slotted (NS) List. It overlaps all of the NS Lists received from the neighbouring nodes to retrieve the common NS. Later, these slots are organized into a Functional Slot (FS) List.

#### 6.3.1 STEPS FOR INITIAL SLOT ASSIGNMENT

**Step 1:** The nodes must synchronize with each other based on the synchronization protocol Ardakani et al. (2014).

**Step 2:** Every node finds 2 hop neighbours information by advertising the information and creates its Neighbour Information (NGI) List. Node H can know that it has four neighbours and 6 nodes within its 2 hop distance.

**Step 3:** A node finds the \( M_{\text{min}} \) and selects a exclusive primary node by distributing the known information.

- Every node formulates a Hamilton Cycle within 1 hop based on Lower-Degree-First.
If a node finds a cycle

Set candidate primary node to itself and set candidate weight to the number of its neighbour nodes.

Else

The node sets both candidate primary node and candidate weight to 0.

Fig. 6.2 Initial Slot Assignment

The node temporarily set its $S_{\text{maxNgbr}}$ to the quantity of its neighbours and J to itself. In Fig. 6.2 the node D finds no cycle and sets the candidate primary node and candidate weight to 0, $S_{\text{maxNgbr}}$ to 4, and J to D. Node D has the information of candidate:0, weight:0, $S_{\text{maxNgbr}}$:4 and J: D. Node B finds a cycle and has the information candidate: C, weight: 2, $S_{\text{maxNgbr}}$: 2 and J and B.
• Every node advertises its information comprising $S_{\text{maxNgbr}}$, $J$, candidate and weight.

• Each node updates the information, after receiving the information from the neighbours. Once it is updated, it backs to step b and repeat up to the diffusing timer is terminated. When a node D receives information candidate: E, weight: 4, $S_{\text{maxNgbr}}$: 4, $J$: E and it updates the information.

• Each node sets primary node to the temporary candidate and calculates $M_{\text{min}}$ with the temporary $S_{\text{maxNgbr}}$. If no primary node is found, then each node sets primary node to $J$. For example, in Fig. 6.2, each node knows the primary node E and $M_{\text{min}}$ is 5.

**Step 4:** The primary node schedules the succeeding slots with 0 and the path created using the Lower-Degree-First. It results one more slot to those nodes with more than three neighbour nodes. If there is no cycle, then the primary node randomly allocates the neighbours to the slots. The $M_{\text{max}}$ is 8 for the given Fig. 6.2.

**Step 5:** Each node on the main ring is carefully chosen step by step and FS List is advertised. Every selected node precedes a slot from the FS List in order to guarantee the cyclic slot sequence. Here, node B is selected by D and then B takes slot 6. Node C is selected by B to remain in the assignment procedure. Finally, A is selected by B or C and then node A picks slot 1.

**Step 6:** In addition to one slot, the nodes have one or more slots. Here, the node J and A have its second slot. After completing this step, the initial scheduling is completed and thus each node has $S_1$ and $S_2$.

**6.3.2 FUNDAMENTAL OPERATION**

After the initial slot assignment, each node has at most two slots. When nodes enter the operation stage, it first works on the initial synchronization. Each node advertises the synchronization packets (SN) to its neighbouring nodes at slot $S_1$ or $S_2$. The neighbouring nodes update their information. When a node
wants to transmit a slot alteration request or reassign slots, it can transmit a packet at slot $S_{\text{reserve}}$. Fig. 6.3 describes the Time Division Multiple Access (TDMA). When a node wants to connect in the network, it first pay attention to the network channel and obtains the TDMA process parameters. At $S_{\text{guard}}$, a node transmits REQ and receives the REP from the neighbours to create NGI List during the period of $T_{\text{TDMA}}$. When the next $S_{\text{guard}}$ comes, the node choose the two slots at most from FS List. If the list is null, then the node withdraws its neighbours of one slot.

### 6.3.3 ENERGY SAVING MECHANISM

In order to guarantee the node usage, each node is set into IDLE or SLEEP state. Let us consider $N_A$, $N_B$ and $N_C$ represents the nodes allocated to slot $t-1$, $t+1$ and $t$ respectively and $K_{\text{type}}$ denotes the frame type. The energy saving algorithm is depicted as follows:

![Fig. 6.3 Time Division Multiple Access (TDMA)](image-url)
Algorithm: Energy Saving Mechanism

1: Energy-Saving ()
2: If $K_{type} = \text{Sync}$ or $t = S_{\text{reserve}}$ then
3: IDLE ()
4: Else
5: If $t = S_1$ or $t = S_2$ then
6: IDLE () and wait $T_{\text{guard}}$
7: If no packet to transmit then
8: SLEEP ()
9: Else
10: If $t = S_{\text{guard}}$ then
11: If $N_B \in N_{1\text{-hop}}$ then
12: IDLE ()
13: Else
14: If $N_C \in N_{1\text{-hop}}$ then
15: IDLE () and wait $T_{\text{guard}}$
16: If no packet to receive then
17: SLEEP ()
18: Else
19: If $N_A \in N_{1\text{-hop}}$ and receiving packet then
20: IDLE ()
21: Else
22: SLEEP ()

The energy saving mechanism helps in reducing the energy dissipation among the sensor nodes. Based on these, the sensor node can turn into sleep mode, once it is not used for data transmission.

6.4 PSO ENERGY OPTIMIZER

The forwarding nodes from the source to the destination are selected based on the common PSO algorithm. In this proposed system, the common PSO algorithm is adopted into the energy model by updating the fitness criteria. The fitness function is applied based on the following three criteria:

1. Residual energy among sensor nodes
2. Logical parameters (packet information, traffic parameters)
3. Distance between the nodes to BS.

The fitness function is calculated using the following formula

\[
\text{Fitness function } f(x) = a \times \left( \frac{1}{d} \right) + b \times \left( \frac{1}{E_C} \right) + N_l \times E_R \tag{6.2}
\]

Where

\[
\begin{align*}
  a & \quad \text{- Weighted factor based on distance} \\
  d & \quad \text{- Distance from sensor to receiver} \\
  b & \quad \text{- Weighted factor based on energy} \\
  E_C & \quad \text{- Energy consumed} \\
  N_l & \quad \text{- Node information} \\
  E_R & \quad \text{- Residual energy}
\end{align*}
\]

6.4.1 STEPS OF PSO USED IN THE PROPOSED PSO_ACR-LEACH

The following are the steps used in Energy efficient PSO_ACR-LEACH protocol.

1. For each node, the nodes' position and mobility is calculated
2. Calculate the fitness function
3. For each iteration i and node n
4. Map the nodes' position with nearest (x,y) coordinates
5. Update node mob and pos
6. Validate fitness function
7. If node fitness < C_{fit}
8. Update C_{fit}
9. This process gets repeated until the energy efficient path has been identified from source to BS.

Here, mob denotes the node mobility, pos denote the position and C_{fit} represents the current fitness of the nodes n. The energy efficient and scalable route is discovered from the source to BS. As it is an energy efficient path, the network lifetime among the sensors and the sensor networks is also sequentially increased.
6.5 PERFORMANCE ANALYSIS

The performance of the proposed Energy Efficient PSO based ACR-LEACH is analysed and compared to the ACR-LEACH, Cyclic LEACH and the existing LEACH and R-HEED protocols. The protocols are compared to various metrics namely, variance of energy, energy consumption, residual energy, throughput, packet delivery ratio and end-to-end delay. The results are evaluated and noted by varying the simulation time up to 100ms.

6.5.1 ANALYZING THE ENERGY CALCULATION FOR DATA TRANSMISSION

The energy variance is determined based on the packet loss at the data forwarding due to the energy drain among the sensors. The energy drain does not occur in the proposed protocol, because the CH and forwarding nodes are selected based on the highest energy level. Also, the nodes are turned into sleep mode until it is used for data transmission. Hence, the energy variation is minimum for the proposed protocol. Fig. 6.4 shows the energy variance simulation result for the proposed PSO_ACR-LEACH, ACR-LEACH, Cyclic LEACH with the existing RHEED and LEACH protocols and the results are tabulated in Table 6.1. It graphically proves that the proposed results have lesser energy variance than the existing protocols.
Table 6.1 Variance of energy with time between PSO_ACR-LEACH, Cyclic LEACH, ACR-LEACH, R-HEED and LEACH Protocols

<table>
<thead>
<tr>
<th>Time (ms)</th>
<th>LEACH</th>
<th>R-HEED</th>
<th>ACR-LEACH</th>
<th>Cyclic LEACH</th>
<th>PSO_ACR-LEACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>560000</td>
<td>370000</td>
<td>285600</td>
<td>250000</td>
<td>180000</td>
</tr>
<tr>
<td>20</td>
<td>620000</td>
<td>440000</td>
<td>358974</td>
<td>320000</td>
<td>280000</td>
</tr>
<tr>
<td>30</td>
<td>750000</td>
<td>530000</td>
<td>406250</td>
<td>410000</td>
<td>385000</td>
</tr>
<tr>
<td>40</td>
<td>870000</td>
<td>610000</td>
<td>579085</td>
<td>390000</td>
<td>350000</td>
</tr>
<tr>
<td>50</td>
<td>960000</td>
<td>730000</td>
<td>702514</td>
<td>510000</td>
<td>480000</td>
</tr>
</tbody>
</table>

In order to design the protocol with increasing network lifespan, the residual energy of the nodes should be maximum. The proposed system uses the energy constraint to select the CHs and then forwards nodes from the source to BS. Hence, the system yields higher residual energy among the nodes at the end of the data transmission or data collection. It is obviously shown in Fig. 6.5 and the values are tabulated as shown in table 6.1. The proposed PSO_ACR-LEACH
yields higher residual energy than ACR-LEACH, Cyclic LEACH, R-HEED and LEACH protocols.

Fig. 6.5 Residual energy with varying time between PSO_ACR-LEACH, ACR-LEACH, Cyclic-LEACH, R-HEED and LEACH protocols

Table 6.2 Residual energy with varying time between PSO_ACR-LEACH, ACR-LEACH, Cyclic-LEACH, R-HEED and LEACH protocols

<table>
<thead>
<tr>
<th>Residual Energy (nJ)</th>
<th>LEACH</th>
<th>R-HEED</th>
<th>ACR-LEACH</th>
<th>Cyclic LEACH</th>
<th>PSO_ACR-LEACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>50000</td>
<td>5</td>
<td>12</td>
<td>8</td>
<td>10</td>
<td>15</td>
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<tr>
<td>100000</td>
<td>12</td>
<td>22</td>
<td>16</td>
<td>18</td>
<td>25</td>
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<tr>
<td>150000</td>
<td>18</td>
<td>31</td>
<td>23</td>
<td>26</td>
<td>38</td>
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<tr>
<td>200000</td>
<td>28</td>
<td>40</td>
<td>32</td>
<td>38</td>
<td>49</td>
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<tr>
<td>250000</td>
<td>35</td>
<td>62</td>
<td>39</td>
<td>43</td>
<td>85</td>
</tr>
</tbody>
</table>

Fig. 6.6 shows the overall energy consumed for the entire data transmission from source to BS. It shows the existing protocol to be consuming more energy to complete the data transmission than the proposed PSO_ACR-
LEACH and Table 6.3 which shows the analysis of LEACH, R-HEED, ACR-LEACH, Cyclic LEACH and PSO_ACR-LEACH.

Table 6.3 Energy consumption with varying time between PSO_ACR-LEACH, ACR-LEACH, Cyclic-LEACH, R-HEED and LEACH protocols

<table>
<thead>
<tr>
<th>Time (ms)</th>
<th>LEACH (nJ)</th>
<th>R-HEED (nJ)</th>
<th>ACR-LEACH (nJ)</th>
<th>Cyclic LEACH (nJ)</th>
<th>PSO_ACR-LEACH (nJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>250000</td>
<td>240000</td>
<td>200000</td>
<td>190000</td>
<td>160000</td>
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<td>210000</td>
<td>162000</td>
<td>150000</td>
<td>140000</td>
<td>100000</td>
</tr>
</tbody>
</table>

6.5.2 SUCCESS RATIO ESTIMATION

Throughput is defined as the total number of successfully received messages in a predetermined time. It is usually measured in terms of bits/sec. The proposed PSO_ACR-LEACH protocol uses the cyclic scheduling to allocate the slots and it leads to an improved throughput performance. Fig. 6.6 shows the
throughput analysis of PSO_ACR-LEACH, ACR-LEACH, Cyclic LEACH, R-HEED and LEACH and the results are tabulated in Table 6.3. From the results, it is evident that the proposed protocol yields higher throughput than the existing protocols.

Table 6.4 Throughput analysis with varying time between PSO_ACR-LEACH, ACR-LEACH, Cyclic-LEACH and LEACH protocols

<table>
<thead>
<tr>
<th>Time (ms)</th>
<th>LEACH</th>
<th>R-HEED</th>
<th>ACR-LEACH</th>
<th>Cyclic LEACH</th>
<th>PSO_ACR-LEACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>60</td>
<td>71</td>
<td>69</td>
<td>78</td>
<td>79</td>
</tr>
</tbody>
</table>
Packet Delivery Ratio (PDR) is defined as the ratio of the number of delivered data from the source sensor node to the BS. The greater percentage of PDR improves the success rate of the data transmission.

\[
PDR = \frac{\text{Total number of packet received}}{\text{Total number of packet sent}}
\]  

(6.3)

Fig. 6.8 depicts the packet delivery ratio analysis between the proposed and the existing protocols which is tabulated in Table 6.4. It shows that the proposed protocol yields higher PDR percentage than the existing protocols.

![Packet delivery ratio with varying time between PSO_ACR-LEACH, ACR-LEACH, Cyclic-LEACH and LEACH protocols](image)

**Table 6.5** Packet delivery ratio with varying simulation time between PSO_ACR-LEACH, ACR-LEACH, Cyclic-LEACH and LEACH protocols

<table>
<thead>
<tr>
<th>Time (ms)</th>
<th>LEACH</th>
<th>R-HEED</th>
<th>ACR-LEACH</th>
<th>Cyclic LEACH</th>
<th>PSO_ACR-LEACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
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<td>96</td>
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</tr>
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<td>89.8</td>
<td>90.9</td>
<td>91</td>
<td>95</td>
<td>96.7</td>
</tr>
</tbody>
</table>
6.5.3 TIME TAKEN FOR DATA TRANSMISSION

An End-to-End delay is defined as the total amount of time the system takes to aggregate the data from the source to BS. It is calculated based on the following equation:

\[
End\_to\_End\ Delay = \frac{Total\ arrive\ time - Total\ send\ time}{Total\ numbr\ of\ connections}
\] (6.4)

The minimum amount of delay is essential for any system to forward the data across the sensor network. The entire transmission occurs within 100ms and the delay is noted between the proposed and the existing protocols. From the Fig. 6.9, the proposed PSO_ACR-LEACH forwards the data within lesser delay than the existing ACR-LEACH, CyclicLEACH and the LEACH protocol and the values are tabulated as shown in Table. 6.5.

![Fig. 6.9 End-to-End Delay with varying time between PSO_ACR-LEACH, ACR-LEACH, Cyclic-LEACH and LEACH protocols](image-url)
### Table 6.6 End-to-End delay with varying time between PSO_ACR-LEACH, ACR-LEACH, Cyclic-LEACH and LEACH protocols

<table>
<thead>
<tr>
<th>Time (ms)</th>
<th>LEACH</th>
<th>R-HEED</th>
<th>ACR-LEACH</th>
<th>Cyclic LEACH</th>
<th>PSO_ACR-LEACH</th>
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<tbody>
<tr>
<td>10</td>
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<td>0.45</td>
<td>0.312</td>
<td>0.297</td>
<td>0.1721</td>
</tr>
</tbody>
</table>

### 6.6 CONCLUSION

An energy efficient PSO_ACR-LEACH protocol is proposed and implemented. It uses the ACR-LEACH to cluster the sensor network nodes into disjoint clusters and elect the CHs. The cyclic scheduling algorithm is used to allocate the slots and turn the nodes into sleep mode once it is not used. This is performed to reduce the consumption of energy, considerably. Then, the data is forwarded from the source to BS based on the energy efficient forwarding node selection with the help of PSO energy optimizer. The experimental results are compared to the existing techniques such as ACR-LEACH, Cyclic LEACH with the existing LEACH and R-HEED protocols. The proposed PSO_ACR-LEACH yields better performance in terms of lesser energy consumption, End-to-End delay, maximum residual energy, throughput and packet delivery ratio. While using PSO_ACR-LEACH, the system increases the lifespan of the sensor nodes and network.