Energy Efficient Cross Layer Based Multi-Hop Clustered Routing Protocol For Wireless Sensor Networks

Parvinder Singh, Rajeshwar Singh

Abstract: Wireless Sensor network becomes an essential part of Internet of things paradigm due its scalability, ease of deployment and user-friendly interface. However, certain issues like high energy consumption, low network lifetime and optimum quality of service requirement force researchers to develop new routing protocols. In WSNs, the routing protocols are utilized to obtain paths having high quality links and high residual energy nodes for forwarding data towards the sink. Clustering provide the better solution to the WSN challenges by creating access points in the form of cluster head (CH). However, CH must tolerate additional burden for coordinating network activities. After considering these issues, the proposed work designs a moth flame optimization (MFO) based Cross Layer Clustering Optimal (MFO-CLCO) algorithm to consequently optimize the network energy, network lifetime, network delay and network throughput. Multi-hop wireless communication between cluster heads (CHs) and base station (BS) is employed along with MFO to attain optimum path cost. The simulation results demonstrate that the proposed scheme outperforms existing schemes in terms of energy consumption, network lifetime, delay and throughput.

Keywords: WSNs, MFO, Network lifetime, Cross layer, Energy efficiency.

I. INTRODUCTION

The technological developments in sensor devices increase their use in internet of things system. The Internet of things has become one of the primary parts of the various smart projects like smart city, smart waste management, smart hospital, smart transportation systems and many other applications [1]. WSNs helps to monitor environments by scattering smart sensor devices in a geographical region. The sensor nodes are easy to deploy and having low cost [2]. However, smart sensing devices are battery powered and have low storage and data processing capability. To improve the capability of nodes, the wireless sensor network is divided into small clusters and a high-power node is selected as cluster head (CH) [3]. The cluster head co-ordinate various networks activities and helps member nodes to communicate with base station (BS) via multi-hop wireless links. However, improper CH selection may increase network overhead which further decreases network lifetime and energy efficiency [4]. The Quality of service (QoS) and energy efficiency of wireless sensor network is proportional to the data routing decisions which are taken by the routing protocols. Routing protocols find an optimal path for data transmission from member nodes to sink node based on path metrics [5]. However, single layer cannot optimize the performance parameters because of the inter-layer dependency. So, the cross-layer concept has been introduced. In cross layer strategy [6], the routing layer obtain the expected values of path metrics like residual node energy, link quality, expected delay and expected throughput. Based on these parameters, the routing layer select an optimum path and direct MAC layer [7] to choose optimum transmission range. Network energy is consumed during sensing, data processing and transmission from member node to sink node [8]. Out of these processes, most of the energy is consumed during data transmission. Therefore, an efficient and reliable transmission technique is required to improve the lifetime of network. The proposed technique helps to decrease the energy consumption, improve the network lifetime and optimize various QoS parameters by intelligently selecting the CH based on fitness function.

In WSN based IOT networks, the lower layers perform the real time data (event related data) aggregation. Middle layers help to access the wireless medium and control transmission power level and higher layers interface to the user applications stored in IOT system. Due to power constrained nodes and weak wireless links, the lower layers acquired lesser data reliability and energy efficiency. The upper layers suffer from data management, data processing and storage problem due to large amount of available data. Therefore, designing an efficient routing protocol requires the communication and understanding between lower, middle and upper layers. Figure 1 and figure 2 shows the cross layered architecture of wireless sensor network.

In WSN assisted low power IOT networks, the connected sensor devices have limited battery power, and these are connected via weak wireless links as compared to LAN, MAN or WAN devices. In certain critical applications, it may not be possible to replace device battery or tolerate the link breakage. Therefore, in such cases an energy efficient, reliable and QoS aware routing protocol needs to be developed which optimize the performance of the network [9].

Most of the existing WSN clustering based routing protocols optimize the single objective of the IOT networks through meta-heuristic techniques like Ant colony optimization (ACO), Genetic algorithm (GA) and Particle swarm optimization (PSO).
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Furthermore, previous techniques ignore critical Quality of service parameters like delay and throughput etc. Therefore, in this work we designed a new energy efficient clustered routing protocol based on moth flame optimization technique which solve multi-objective optimization problem [10]. Cross layer-based energy efficient Cluster head selection and data transmission problem is NP-hard. Thus, such problems required recent optimization algorithm such as moth flame optimization. Moth flame optimization (MFO) is a recent population-based algorithm [11]. This algorithm is inspired from the traverse flying nature of insects called moths. Moths are attracted by the moon and they travel in straight line by making a constant angle with respect to moon. The highlights of the findings in the proposed work are summarized below.

1. Proposed an energy efficient multi-hop routing protocol for high density wireless sensor networks (WSNs).
2. The proposed routing protocol called as MFO-CLCO is evaluated based on four quality of service (QoS) parameters such as energy consumption, end to end network delay, network throughput and network lifetime.
3. The simulation results show that the proposed routing protocol outperform with respect to the existing state of the art routing protocols.

The rest of the paper is organized as follows: Section 2 discuss the related work to the proposed protocol. Section 3 elaborates the proposed fitness functions and new algorithm called as MFO-CLCO. Results and their discussions are presented in section 5. Finally, conclusion and future work is presented in section 6.

![Figure 1. Cross layer architecture in WSN.](image1.png)

**II. RELATED WORK**

Fahad et al. proposed a GWO-based clustering algorithm for vehicular adhoc network [12]. This algorithm is based on hunting mechanism and social behavior of grey wolfs. The authors presented a framework which selects an optimum number of clusters with in a vehicular adhoc network. This technique helps to reduce the routing cost metric of the network. Hasan et al. presented a cross layer based analytical model to find an optimum path which satisfies quality of service parameters for WSN based IOT applications [13]. This work considers hop by hop as well as end to end retransmission schemes. This work reduces the network energy consumption, network delay and increase the average throughput of the IOT network.Zhang et al. classified the industrial data into different categories and assign them priority [14]. In addition, the authors formulated a timeliness, reliability and energy consumption parameters-based problem. To solve this problem an energy efficient and QoS aware algorithm is proposed. Most important industrial data as well as common data is sent towards the sink after considering timeliness and link reliability. Yahiaoui et al. proposed an energy efficient and QoS aware clustering routing algorithm [15]. In this work, the node having high residual energy, high link reliability and high node density is elected as cluster head. This technique significantly helps to reduce delay and energy consumption of the network. In the set-up phase the CH is elected and during steady state phase the sensed data is transmitted to the base station. Shen et al. discussed a new centroid based energy efficient protocol in WSN-IOT environment [16]. The proposed technique has few key characteristics such as self-configuration of nodes, rotating and adapting the clusters head depending on the position of centroid for equal load distribution and strategy to decrease the energy consumption for large-distance communications. This technique is named as EECRP that performs better than LEACH, GEEC and LEACH-C in terms of energy efficiency and network lifetime. Darabkh et al. developed a technique which convert network into equal size clusters and layers [17]. Furthermore, a new clustering algorithm named as BPA-CRP is proposed which permit each cluster to work for multiple rounds without set-up phase overhead. This technique helps to prevent critical node to become a cluster head and balance the energy among nodes. This scheme improves network lifetime and energy utilization ratio.

Deepa et al. proposed a multipath QoS aware clustering algorithm named as OQoS-CMRP for WSNs [18]. This technique incorporated a modified-PSO based clustering scheme for selection of cluster head. A new technique called a round robin path selection is used to send data to the sink. This technique reduces the delay and transmission overhead of the network.

![Figure 2. Data flow between layers in WSN.](image2.png)
III. MOTH FLAME OPTIMIZATION (MFO) ALGORITHM

Moth flame optimization is one of the recent meta-heuristic algorithms, which is inspired from navigational behavior of insects called moths. These insects are attracted towards the moon and fly in the night in a straight line by maintaining a constant angle. This mechanism is called traverse orientation. The traverse orientation is sketched in figure 1. However, we normally observe that moths fly in spiral path around the light. The moths are deceived by artificial lights. The traverse orientation is beneficial if the light source is far away but fails if light source is nearer. Therefore, when moths observe an artificial light, they try to move in straight path with analogous angle. However, due to smaller distance between moths and artificial lights, the path becomes spiral. The spiral flying path is depicted in figure 2.

In the moth flame optimization algorithm, it is supposed that the problem solutions are the moths and the position of moths in the search space are the variables of problem. Accordingly, the moths can move in one dimensional, two dimensional and three-dimensional regions with changing their positions. The MFO is a population-based technique.

The collection of moths can be represented by a matrix \( M \).

\[
M = \begin{bmatrix}
  m_{11} & m_{12} & \cdots & m_{1d} \\
  m_{21} & m_{22} & \cdots & m_{2d} \\
  \vdots & \vdots & \ddots & \vdots \\
  m_{n1} & m_{n2} & \cdots & m_{nd}
\end{bmatrix}
\]  

(1)

Where \( n \) is the number of moths (solutions) and \( d \) represents the number of variables (dimensions). The fitness function return fitness value and these values are captured in an array as given in equation below:

\[
OM = \begin{bmatrix}
  OM_1 \\
  OM_2 \\
  OM_3 \\
  \vdots \\
  OM_n
\end{bmatrix}
\]  

(2)

In the same way, to illustrate another important element (flames) of the MFO, \( F \) matrix is designed, and its fitness value matrix \( OF \) is described in equation below:

\[
F = \begin{bmatrix}
  F_{11} & F_{12} & \cdots & F_{1d} \\
  F_{21} & F_{22} & \cdots & F_{2d} \\
  \vdots & \vdots & \ddots & \vdots \\
  F_{n1} & F_{n2} & \cdots & F_{nd}
\end{bmatrix}
\]  

(3)

\[
OF = \begin{bmatrix}
  OF_1 \\
  OF_2 \\
  \vdots \\
  OF_n
\end{bmatrix}
\]  

(4)

Where, \( n \) represents the number of moths. The search agents revolve around search area whereas the flames are the optimum moth position. The MFO algorithm generates an approximation function and it is a three-tuple function. This function is defined in Eq (5).

\[
MFO = (I, P, T)
\]  

(5)

The component \( I \) generates random distribution of moths and their corresponding fitness values. The component \( I \) is represented below:

\[
I : \phi \rightarrow \{ M, OM \}
\]  

(6)

P function assist the moths to progress towards the flames in search space. The function P is represented below:

\[
P : M \rightarrow M
\]  

(7)

The T function returns true or false value depending upon termination criteria. The function T is represented below:

\[
T : M \rightarrow \{ true, false \}
\]  

(8)

For mathematical representation of moth behavior, the moth position is updated around flame using Eq (9).

\[
M_i = S(M_i, F_k)
\]  

(9)
Here $M_i$ indicates the $i^{th}$ moth, $F_k$ indicates $k^{th}$ flame, and $S$ is the spiral function. Any kind of spiral can be used subject to the following constraints:

1. Moth represents the starting point of the spiral.
2. Flame represents the end point of the spiral.
3. Spiral’s variation range must not surpass the search space.

The logarithmic spiral equation considered for revising mechanism of the MFO is defined below:

$$S(M_i, F_k) = D_i e^{b_i} \cdot \cos(2\pi t) + F_k$$

(10)

where $D_i$ indicates the distance of the $i^{th}$ moth for the $k^{th}$ flame. $D_i$ can be defined as follows:

$$D_i \left| F_k - M_i \right|$$

(11)

where $b$ is a constant that indicate the shape of spiral, and $t$ is a random number between $[-1, 1]$. The $t$ determines the step size of moth position with respect to flame ($t = -1$ is the nearest position to the flame and $t = 1$ indicate the distant position to the flame).

However, equation (10) might trap in local minima because it requires the moths to progress towards the flame. Another problem here is that the location updating of moth relating to different locations in search area may reduce the exploitation of the most promising solution.

Suppose $Y = (Y_1, Y_2, Y_3, \ldots, Y_n)$ represent the population vector of wireless sensor network having $m$ number of sensors, here $Y_j(k) \in \{0, 1\}$. Member nodes and CH are represented by value 0 and 1 respectively. The initial value of required number of NP variables is randomly considered as 1s and 0s in accordance to optimize CHs number and is represented as follows.

$$Y_j(k) = \begin{cases} 1 & \text{for (rand } \leq p_{\text{optimal}}) \\ 0 & \text{otherwise} \end{cases}$$

(12)

$p_{\text{optimal}}$ represents the desired percentage of cluster heads and rand is a constant number whose value lies between 0 and 1.

The randomly deployed nodes are arranged into $n$ number of clusters: $C_1, C_2, C_3, \ldots, C_n$. The elected CHs are subject to minimize the fitness function cost. The fitness function for cluster head selection is defined as follows.

$$f_{\text{opt - CH}} = \sum_{j=1}^{2} w_j \times f_j$$

(13)
Where, $\sum_{j=1}^{2} w_j = 1$.

To achieve the optimum load among the nodes for network stability, the residual energy of each node needs to be considered. The standard deviation of residual energy of nodes measure the correct load distribution among the sensor nodes and is defined as:

\[
\mu_{res} = \frac{1}{m} \sum_{j=1}^{m} E(node_j)
\]

Where, $\mu_{res}$ represents the jth node residual energy and m represents the number of nodes.

The second parameter deal with the clustering quality, which depends on the cohesion [19] and cluster separation. If cluster separation to cohesion ratio is small, then cluster formation is assumed to be ideal. Thus, to achieve better clustering the distance between the CHs and their respective member nodes must be minimized; and the distance between CHs of different clusters should be maximize. Therefore, this objective can be achieved by defining a fitness function as ratio of Euclidian distance between CHs and their member nodes and minimum Euclidian distance of two different cluster heads [20].

\[
fitness_2 = CQ = \frac{\min_{\forall j \neq k} d(node_j, CH_k)}{\text{distance} \times \text{cohesion}}
\]

Steady-state phase: The proposed protocol is reactive in nature, therefore, in this phase, the nodes send information to their respective cluster heads as per the TDMA schedule only when an event occurs and goes into the sleeping mode. The CH receive data from the member nodes and forward the aggregated data to the BS via multi-hop propagation. The number of hops depends upon the separation between the CHs and BS.

In the proposed protocol, the multi-hop communication is utilized to enhance the system efficiency and decrease the energy cost using moth flame optimization algorithm. If the separation between the base station and cluster head is greater than the Euclidian distance, an intermediate CH node is required to forward its aggregated data to the base station. For balancing the load among the nodes, the residual energy cost and distance factor are obtained as follows.

\[
fitness_4 = D_{\text{factor}} = \frac{d(CH_j, CH_k) + d(CH_i, BS)\sqrt{2}}{d(CH_j, CH_k) + d(CH_i, BS)\sqrt{2}}
\]

Where, $E(CH_k)$ represents the residual energy of cluster heads. $D_{\text{factor}}$ represents the aggregated distance between source cluster head, intermediate cluster head and base station. $CH_j$ represents the source cluster head and if it is far away from base station, it required $CH_k$ as intermediate node. The Cluster head having lowest link cost will be chosen as intermediate node $CH_k$. The link cost between $CH_j$ and $CH_k$ is defined as the fitness function for routing of sensed data from cluster head to base station. It is evaluated as follows.

\[
fitness_3 = \sigma_{res} = \sqrt{\frac{1}{m} \sum_{j=1}^{m} (\mu_{res} - E(node_j))^2}
\]
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\[ f_{\text{routing\_obj}} = \sum_{j=3}^{4} w_j \times f_j \]  \hspace{1cm} (18)

Where, \( \sum_{j=3}^{4} w_j = 1 \).

V. SIMULATION RESULTS AND DISCUSSIONS

The MATLAB software is used for simulations and it is installed in Windows 10. The simulation parameters used for evaluation of MFO-CLCO protocol are shown in Table 1. The performance of proposed MFO-CLCO protocol is evaluated based on various quality of service (QoS) parameters and compared with existing routing protocols such as ETRT, EQSR, standard model and cross layer design based on distance. This work analyzes the performance of MFO-CLCO protocol in heterogenous and homogenous network scenario.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routing protocol</td>
<td>AODV, AODV (MFO-CLCO)</td>
</tr>
<tr>
<td>MAC/Physical layer</td>
<td>IEEE 802.15.4</td>
</tr>
<tr>
<td>Channel propagation model</td>
<td>Wireless two way ground</td>
</tr>
<tr>
<td>Type of traffic</td>
<td>Constant bit rate (CBR)</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>200</td>
</tr>
<tr>
<td>Network size</td>
<td>100m x 100m</td>
</tr>
<tr>
<td>Normal node initial energy</td>
<td>0.30 J, 0.60 J and 1 J</td>
</tr>
<tr>
<td>CH selection probability</td>
<td>0.05</td>
</tr>
<tr>
<td>Radio electronics processing energy</td>
<td>55 nJ/bit</td>
</tr>
<tr>
<td>Data aggregation electronics energy</td>
<td>10 nJ/bit</td>
</tr>
<tr>
<td>Amplifier radio energy for free space</td>
<td>90 pJ/bit/m²</td>
</tr>
<tr>
<td>Amplifier radio energy for multipath</td>
<td>0.0014 pJ/bit/m⁴</td>
</tr>
</tbody>
</table>

Table 1. Simulation setup.

A. Network lifetime

Due to the presence of low power sensor devices in WSNs, the biggest challenge is to conserve energy of nodes while they collect data from the environment. The load balancing among nodes and control of power consumption are the best solution to maintain high lifetime of a wireless sensor network.

Figure 5. Network lifetime of protocols

The network lifetime is adjudged by the time after which first node dead (FND) in the network. The network lifetime of the proposed protocol is compared with the existing ones and it is shown in figure. The main cause of high network lifetime is due to the use of multi-hop transmission of data packets between the clusters through MFO algorithm. The differentiation of network lifetime of existing algorithm with the MFO-CLCO protocol is shown in figure 5.

B. Average network energy consumption

The energy efficiency performance of the MFO-CLCO is much better than the existing techniques and it is shown in figure 6. This improvement is based on the energy balancing technique adopted by the proposed method. MFO-CLCO technique consider the residual energy and distance between the nodes during the selection of CH. Therefore, both these factors

Figure 6. Average network energy consumption.
affect the overall energy consumption of the network.

end to end delay differentiation of the MFO-CLCO technique with respect to the existing techniques.

VI. CONCLUSION

The primary challenges in design of routing algorithms in wireless sensor network include network lifetime maximization, energy efficiency maximization, throughput optimization and delay minimization. This paper focused on clustering-based energy efficient design using MFO. The cluster heads are selected using fitness function which include important parameters such as cluster cohesion and cluster separation. The network lifetime is improved through link quality-based CH communication algorithm. MFO based multi-hop communication is employed between BS and CHs to minimize the energy consumption and optimize the workload. The metrics such as energy consumption, delay, throughput and network lifetime are evaluated and compared with existing competitive routing protocols.

REFERENCES


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