An energy optimized routing algorithm for IoT-enabled WSN

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***Abstract*—Nowadays, the Internet of Things (IoT) has gained significant importance. The Wireless Sensor Networks (WSNs) is a subset of IoT that is used as a major data-gathering component of any IoT-based system. An energy-efficient routing scheme is very important for resource-constraint IoT-enabled WSNs that can effectively improve the network lifetime and performance of the network. The existing routing scheme does not consider the battery limitation and successful packet delivery. The proposed scheme provides an energy-efficient solution through the meta-heuristic algorithm of modified firefly to perform routing within the networks. The results show that the proposed scheme outperforms compared to state-of-the-art algorithms in terms of different network parameters such as network lifetime, average residual energy, and the number of packets delivered to the base station.**

Keywords-Wireless Sensor Network (WSN), Residual energy, routing protocol, firefly algorithm, alive nodes, IoT.

I. INTRODUCTION

IoT makes any physical object smarter by providing sensing capabilities. WSNs play a significant role in IoT. It can be deployed in harsh environment applications where deploying another network infrastructure is complex or virtually impossible, such as in battlefields, high thermal environments, and hazardous chemical plants. The IoT-enabled WSNs find their role in many real-time applications, including commercial and industrial automation [1]. However, the sensors used in IoT are battery limited that require an efficient scheme for energy conservation. There are many approaches for energy efficiency, such as duty cycling, mules [2]. Clustering is the most promising method to save energy consumption in IoT-enabled WSNs [3]. The existing schemes have exploited optimization to determine the Cluster Heads (CHs). However, these meta-heuristic algorithms still require stability in energy consumption and require an increase in network robustness.

WSNs are widely expected to have limitless possibilities for a variety of real-time applications. However, most sensors are powered by non-rechargeable batteries, thus the lifetime of such a network is minimal. Due to these constraints, many research issues have arisen, which are described as optimization problems aimed at discovering useful design techniques, such as the sensor deployment problem, routing problem, and clustering problem. As a result, various effective strategies for minimizing the effect of these constraints on WSN are needed to provide better services [4]. However, with the increasing demands of the new era, we need to modify and develop new sensor technologies. Thus, with the development of IoT with huge heterogeneous data being gathered by a large number of devices and for better energy efficiency and packet delivery, it becomes necessary to further improve the existing routing algorithms.

In the remaining paper, related work is described in section II. Section III. illustrates assumptions and energy model. In section IV the proposed scheme is described. Section V shows the results. The conclusion is described in section VI.

II. RELATED WORK

The most fundamental clustering algorithms is the Low-energy adaptive clustering hierarchy (LEACH) that aims to save an optimal amount of energy in WSNs [5]. Many routing approaches are proposed in the literature to solve the limitations of LEACH and its associated algorithms. M. R. Senouci et al. [6] proposed an approach that considers residual energy for CH selection. The cost function is calculated to determine CH among candidate nodes with the same residual energy. However, it has poor packet delivery. O. Younis et al. [7] improved Hybrid Energy-Efficient Distributed (HEED) protocol by using multiple hops within the cluster. W.K. Lai et al. [8] present a scheme that creates different size clusters based on cluster load. As a result, it reduces the probability of cluster reformation while increasing network efficiency. However, the technique has a poor packet delivery ratio. J. Yu et al. [9] proposed a scheme where node degree and residual energy are considered for next-hop selection. However, distance is not taken into account, which results in poor end-to-end delays. M. Sabet et al. [10] proposed a scheme where residual energy, node degree, and transmission power are considered for next-hop selection. H. Pakdel et al. [11] proposed routing using the firefly algorithm. In the network, all nodes announce their energy level, and each node compares it with its energy to determine the attraction ratio. However, it has extra message overhead within the networks. L. Tang et al. [12] consider the availability, throughput, and lifetime for routing in the WSNs. T.M Behera et al. [13] proposed IoT-LEACH (I-LEACH) that

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is an advancement in LEACH protocol. It incorporates a threshold value, if the CH is discovered to have greater energy than the threshold value, it will remain as the CH for the next round as well. However, protocol suffers from extra message overhead and poor packet delivery.

TABLE I: VARIABLES AND MEANING

Notations	**Meaning**
ε_{fs}	free space propagation model
ε_{mp}	multipath propagation model
$E(CHi)$	Energy of CH
$Cluster_{cpt}$	Cluster compactness
w_i	Weight for parameter i
$DM(m*n)$	Proximity matrix of size m*n
dNc	distance between CH (Nc) and node xi
$Eelec$	Electronic energy
xi	Spatial coordinate of a node
$dist(i, j)$	distance between i and j nodes
ND_i,	number of sensor nodes within range
$(ND * Er(k))$	Required energy to receive k-bits data from each sensor node
$Et(k, dist_{BS})$	Required energy to transmit data to Base Station (BS)
dNc	distance between CH (Nc) and a node
y and z	Coordinates of nodes p and q
I_s	light intensity
v	absorption coefficient of the medium
β	attractiveness
β_0	attractiveness at r = 0
m	constant number which modifies the distance metric
k	number of dimensions
$x_{i;n}$	nth constituent of the spatial coordinate x_i
$E_{in}(i)$	Initial energy of node
$E_{res}(i)$	Remaining energy of node

III. ASSUMPTIONS AND ENERGY MODEL

The N sensor nodes are fixed in the network and deployed in the $M X M$ [m^2] monitoring area. Each node has fixed initial energy. Node expends energy on message transmission and reception. The network nodes are similar having the same hardware, radiofrequency, and capacity. Any two nodes will connect as long as their radio ranges overlap. The routing scheme described in this paper is hierarchical. As a result, the creation of clusters is a critical stage in the routing process. There is a BS in a fixed position that has an infinite power supply. The energy consumption model describes energy consumed during various operations such as transmission and reception. The following equation defines the energy consumed to transmit k bits of data:

$$\begin{aligned} E_{tx} &= k * E_{elec} + k * \varepsilon_{fs} * d^2 \qquad d < d_0 \\ E_{tx} &= k * E_{elec} + k * \varepsilon_{mp} * d^4 \qquad d \geq d_0 \end{aligned} \tag{1}$$

$$d_0 = \left(\frac{\varepsilon_{fs}}{\varepsilon_{mp}}\right)^{1/2} \tag{2}$$

The following equation defines the energy consumed to receive k bits of data:

$$E_{rx} = E_{elec} * k \tag{3}$$

Table I describes the variables and their meaning used in this paper.

IV. PROPOSED SCHEME

This section describes the proposed scheme, which includes two phases, namely CH selection and data transmission.

A. Proposed CH selection phase

Fireflies have different flashing lights produced because of bioluminescence [4]. This can be done in order to attract mates or ward off predators. One of its primary functions is to use their light to communicate among themselves. This principle is used in the proposed scheme to communicate and transmit data packets within the network. During the formulation of the firefly algorithm, three theoretical rules must be obeyed.
The theoretical rules are as follows:

1. All fireflies are unisex. The firefly brightness is determined using objective functions.
2. The attraction between fireflies depends on the brightness.
3. The firefly moves randomly if it does not find any other brighter one.

In the proposed scheme, nodes of the network are static, and they have identical capabilities. A sensor node can function in two methods, one as CH, and the other as an active sensor. The network lifetime is enhanced by the proposed CH selection algorithm. CH is chosen among the sensor nodes, and a cluster is formed by a group of nodes. The network lifetime can be extended with a good CH election approach. Fig. 1 shows the proposed CH selection flowchart. Algorithm.1 describes the proposed CH selection phase. The fitness function is calculated based on the following parameters:

Node density ($N_D^{(i)}$)*:* It is the number of neighboring nodes of node i that are within its transmission range. Fitness function (t_1) is given by:

$$N_D^{(i)} = \mid Neighbor^{(i)} \mid \tag{4}$$

where $Neighbor^{(i)}$ are the neighboring nodes to a sensor node.

Cluster compactness ($Cluster_{cpt}$)*:* It is defined as the compactness of member nodes. $Cluster_{cpt}$ is calculated for each participating node. Fitness function (t_2) is given by:

$$\text{Cluster}_{cpt}^{(i)} = \frac{N_D^{(i)}}{\sum_{j \in \text{Neighbour}^{(i)}} dist(i,j)} \tag{5}$$

Remaining Energy: It is defined as the energy remaining in a sensor node. Fitness function (t_3) is given by:

$$\sum_{i=1}^{n} \frac{E_{res}(i)}{E_{in}(i)} \tag{6}$$

E*nergy prediction*: It is the estimated energy that is spent by a CH node. It depends on the energy consumed to receive data from intra-cluster nodes and then transmitting to BS. Fitness function (t_4) is given by:

$$E^{(i)}_{\text{ToBeExpended}} = \left[E_t^{(i)}(k, dist_{BS}) + \left(N_D^{(i)} r^{(i)}(k)\right)\right] \quad (7)$$

Since parameters are measured on various scales, a standardized score is determined to facilitate comparison. Following fitness function must be maximized in order to choose a CH node as effectively as possible.

$$fitness(i)^i = \theta_1 \times t_1 + \theta_2 \times t_2 + \theta_3 \times t_3 + \theta_4 \times t_4 \quad (8)$$

where θ_1, θ_2, θ_3, θ_4 are weights and $(\theta_1 + \theta_2 + \theta_3 + \theta_4)$ ε [0,1]

Algorithm 1: Proposed CH selection phase

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Input: $N_D$, $Cluster_{cpt}$, $E^{(i)}_{ToBeExpended}$ and $E_r$
       $X_i$= Fireflies (i=1,2,3……n)
1. Evaluate fitness function value for all
   fireflies(i=1,2,3…n) using Eq.(8).
2. Ranking
3. for i=1 to n
       for j=1 to i
           if (fitness($X_i$)>fitness($X_j$))
               Update $X_i$ position
           else go to step 4.
       End for
4. Again calculate fitness and update best and rank the
   fireflies.
   End for
   End procedure
```

B. Data transmission phase:

The CHs that are selected initially, transmit the message among the sensor nodes, stating that they are CHs. Following that, the network sensor nodes measure the distance between themselves and each CH. The nodes connect to the CH with the shortest distance and send data to it. If the distance between sensor node and sink is lower even after iterating through all the CHs, the sensor node directly communicates to the sink. In every other case, it connects with a cluster based on their proximity. As a result, the clusters are formed. Algorithm.2 describes the proposed data transmission phase.

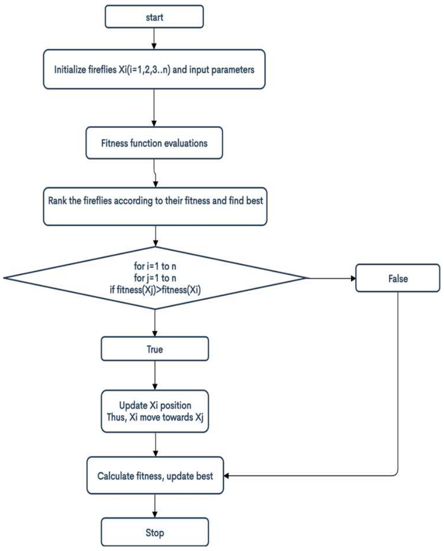

Figure 1. Flowchart

Algorithm 2: Proposed Data Transmission phase

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Input: CH nodes {$N_{c1}$, $N_{c2}$....$N_{cr}$} and nodes $x_i${ i=1,2..n}
1. For each node $x_i$ do,
2. Calculate the distance from all cluster heads as per
   Eq.(10).
3. If (distance from a node to BS< distance from all
   CH's)
   Directly transmit data to BS.
   else
       connects with a CH based on proximity and
   go to Step 3.
   End if
   End for
4. Construct a distance matrix of r*n as Eq. (9).
5. The column with the lowest value is connected using
   the related node.
   End procedure
```

$$DM(m*n) = \begin{bmatrix} d_{N_{c1},x_1} d_{N_{c1},x_2} \cdots\cdots d_{N_{c1},x_n} \\ d_{N_{c2},x_1} d_{N_{c2},x_2} \cdots\cdots d_{N_{c2},x_n} \cdot \\ \vdots \\ \vdots \\ d_{N_{cm},x_1} d_{N_{cm},x_2} \cdots\cdots d_{N_{cm},x_n} \end{bmatrix} \quad (9)$$

where $x_1, x_2, \ldots x_n$ are the sensor nodes, the Euclidean distance is given as:

$$d_{p,q} = \sqrt{\left(p_y - q_y\right)^2 + (p_z - q_z)^2} \tag{10}$$

In Eq.9, the row in the matrix represents the CH and the column represents the sensor nodes. The elements in the matrix represents the distance between the pth CH and the qth sensor node. The sensor node will join the CH having the minimum value of the matrix element. In relation to the square law, the light intensity at a distance r is given as:

$$I = \frac{I_s}{d^2} \tag{11}$$

$$I = I_s \, exp \, exp \, (vr^2) \tag{12}$$

$$\beta = \beta_0 \, exp \, exp \, (-vr^m) \tag{13}$$

The firefly i motion towards the firefly j to which it is attracted is given as:

$$x_{i+1} = x_i + \beta_0 e^{-vr_{i,j}^2}\left(x_j - x_i\right) + \alpha \tag{14}$$

$$r_{i,j} = \sqrt{\sum_{n=1}^{k}\left(x_{i,n} - x_{j,n}\right)^2} \tag{15}$$

V. RESULTS

The proposed scheme is simulated on MATLAB for 200 rounds of iterations and then compared with LEACH and i-LEACH [13] protocols. The 100 sensor nodes are deployed in 250 x 250 [m^2] area. The results show that proposed scheme outperforms both LEACH and i-LEACH under different metrics such as average residual energy, the lifetime of nodes, and packets communicated to BS.

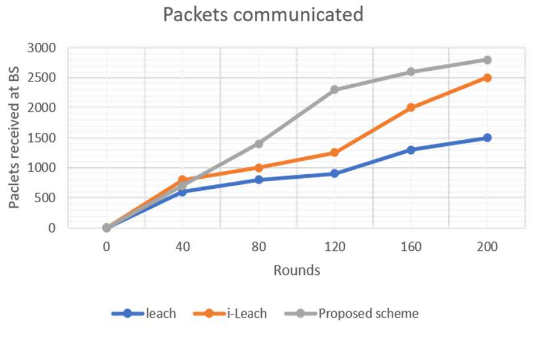

Figure 2. Successful Packets Delivery

Fig. 2 shows the successful packet delivery. For 120 rounds, it is increased by 46.67% compared to LEACH and 35% compared to i-LEACH. For 160 rounds, it is increased by 43.33% compared to LEACH and 20% compared to i-LEACH. For 200 rounds, it is increased by 43.33% compared to LEACH and 10% compared to i-LEACH.

Fig. 3 shows the average residual energy. For 120 rounds, it is increased by 24% compared to LEACH and 19% compared to i-LEACH. For 160 rounds, it is increased by 48% compared to LEACH and 38% compared to i-LEACH. For 200 rounds, it is increased by 57% compared to LEACH and 47% compared to i-LEACH.

Fig. 4 compares the network lifetime in terms of the number of alive nodes. For 120 rounds, it is increased by 2% compared to LEACH and 1% compared to i-LEACH. For 160 rounds, it is increased by 5% compared to LEACH and 4% compared to i-LEACH. For 200 rounds, it is increased by 12% compared to LEACH and 10% compared to i-LEACH.

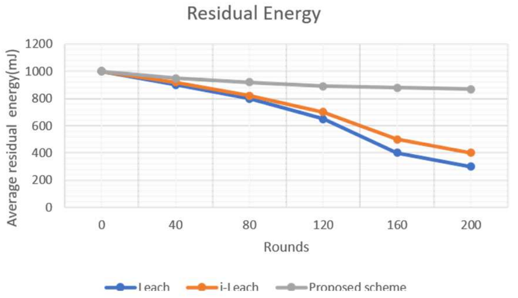

Figure 3. Average residual energy

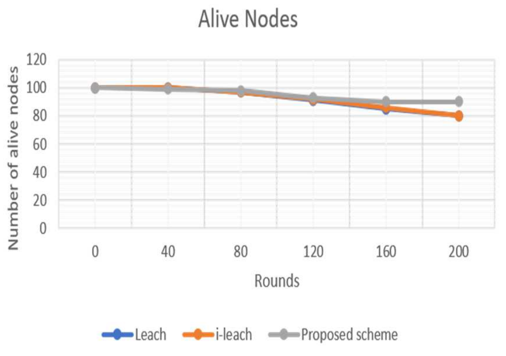

Figure 4. Lifetime Metrics (Alive Nodes)

VI. CONCLUSION

IoT provides computational intelligence to any physical object. WSN in IoT plays a significant role in monitoring remote areas effectively. The effective utilization of limited battery power is a critical challenge in IoT-based WSNs. The proposed scheme solves the aforesaid issues by presenting energy-efficient routing using a modified firefly algorithm. The simulation results show great enhancement in lifetimes metrics, average residual energy and packets received at BS as compared to other state-of-the-art algorithms. The proposed scheme is best applicable in diverse areas where a high and variable number of nodes, and spatial distribution of energy and packets are essential. In the future, we plan to improve the work by minimizing the end-to-end data delivery delay within the networks.

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