Journal of Information Hiding and Privacy Protection
DOI:10.32604/jihpp.2020.010180
Article

An Efficient Energy Routing Protocol Based on Gradient Descent Method in WSNs

Ru Jin*, Xinlian Zhou and Yue Wang

Hunan University of Science and Technology, Xiangtan, 411100, China
*Corresponding Author: Ru Jin. Email: rjin@bupt.edu.cn
Received: 02 July 2020; Accepted: 01 August 2020

Abstract: In a wireless sensor network [1], the operation of a node depends on the battery power it carries. Because of the environmental reasons, the node cannot replace the battery. In order to improve the life cycle of the network, energy becomes one of the key problems in the design of the wireless sensor network (WSN) routing protocol [2]. This paper proposes a routing protocol ERGD based on the method of gradient descent that can minimizes the consumption of energy. Within the communication radius of the current node, the distance between the current node and the next hop node is assumed that can generate a projected energy at the distance from the current node to the base station (BS), this projected energy and the remaining energy of the next hop node is the key factor in finding the next hop node. The simulation results show that the proposed protocol effectively extends the life cycle of the network and improves the reliability and fault tolerance of the system.

Keywords: Wireless sensor network; gradient descent; residual energy; communication radius; network life cycle

1 Introduction

With the advent of the artificial intelligence era, wireless sensor networks integrating sensor technology, embedded computing technology, wireless communication technology, MEMS and distributed information processing have become the focus of many international disciplines. Cross-cutting frontier hotspot research areas [3]. With the continuous development and maturity of wireless sensor network technology, it is widely used in many important fields such as military defense, industry and agriculture, urban management, biomedical, environmental monitoring, disaster relief, anti-terrorism and anti-terrorism, and remote control of dangerous areas.

Wireless sensor network is a kind of distributed network. It consists of a large number of tiny sensor nodes. It cooperatively senses and collects various information of the monitoring area through nodes. After processing and fusion, it forms a short distance in a multi-hop and self-organizing manner. The wireless communication network finally transmits the processed and fused information to the client. Due to the limitation of the working environment of the wireless sensor network and the limited energy of the node itself, once the energy of the node is exhausted, it cannot be supplemented, so energy is one of the key issues in the research of wireless sensor networks. Therefore, how to effectively utilize the limited energy of nodes and reduce the energy consumption of nodes is one of the key issues in designing routing protocols for wireless sensor networks. It is also a hot issue at home and abroad.

The routing protocols of wireless sensors can be divided into planar routing protocols and hierarchical routing protocols. Compared with the shortcomings of large routing, high data transmission and poor scalability, the hierarchical routing protocol has good performance in terms of energy efficiency and scalability, and is widely used in various routing protocols. In a wireless sensor network based on a hierarchical routing protocol, the network is divided into multiple clusters, each cluster has its own cluster head (CH), which is a node within the cluster and a base station or an adjacent cluster head. The intermediary of (CH) is responsible for collecting information in the converged cluster and transmitting it to the base station (BS) or to the cluster head (CH) close to the base station. Generally, the decision of the cluster head can be determined by reference to the remaining energy of the node, the degree of node, the distance between the node and the base station, the density of the node distribution, the communication cost within the cluster, and the like. In this paper, the cluster head is determined according to the remaining energy of the node and the distance between the node and the base station [4]. However, unlike other protocols, in the protocol, the nodes in the initial cluster do not know the cluster to which they belong, and the cluster head election will not be performed. All nodes in the middle have the opportunity to become the cluster head. The node does not consume energy to elect the cluster head. Instead, it selects the best cluster head (CH) node within the communication radius of the node based on the above two parameters, to a certain extent, using the small energy consumption has achieved the expected results.

Rest of paper is organized as follows: Section II discusses the Related Work about the model of Wireless sensor network, Energy consumption. The algorithmic design in Section III, Section IV gives the simulation of my experiment, and Section V gives the conclusion.

2 Related Works

2.1 Wireless Sensor Network Model

As shown in Fig. 1 the wireless sensor network consists of a large number of sensor nodes. The network is divided into multiple clusters. Each cluster has a cluster head node. The cluster head node is responsible for collecting the information in the fusion cluster and forwarding it to the base station or the cluster head node close to the base station.

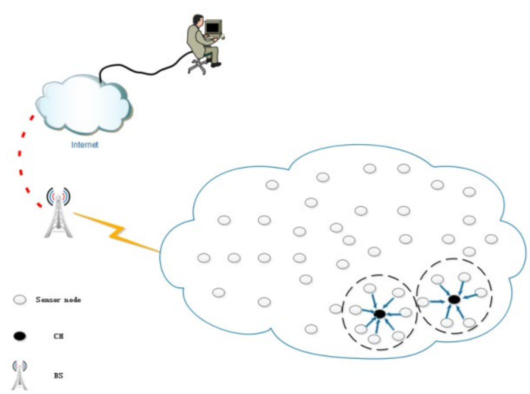

Figure 1: The model of wireless sensor network

This paper is based on the following assumption:

- Assume that the homogeneous sensor nodes are evenly distributed in the monitoring area and once deployed, the base station has only one, and the energy is sufficient and fixed on the side near the area;
- Each node sends its own collected information to the cluster head, and the cluster head merges and cooperates with other cluster heads to finally send the information to the base station.
- Assume that the wireless channel is completely symmetrical;
- The initial energy allocation of the sensor nodes is consistent;
- The node calculates the distance by using the RSSI;

2.2 Energy Consumption Model

Since the energy of wireless sensor networks is limited, energy has always been a hot-spot in wireless sensor networks. From Fig. 2 that node communication consumes 51% of the energy of the node, so the node communication of the improvement in energy consumption has greatly extended the life cycle of the network.

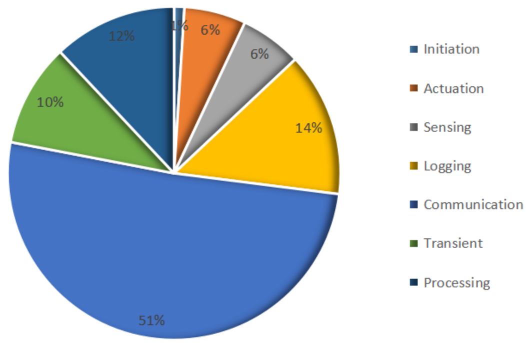

Figure 2: The model of energy consumption

In this paper, we assume that the wireless channel is symmetric, that is, when the signal-to-noise ratio is constant, node A sends n-bit data to node B and node B transmits data to A with the same energy consumption. The energy generated by transmitting n-bit messages between two nodes of distance d is calculated as shown in formulas (1) and (2).

$$E_{Tx}(n,d)=\begin{cases}n\left(E_{elec}+\varepsilon_{fs}d^2\right), & d<d_{ridge}\\ n\left(E_{elec}+\varepsilon_{fs}d^4\right), & d\geq d_{ridge}\end{cases} \tag{1}$$

$$E_{Rx}(n)=nE_{elec} \tag{2}$$

In the case of a certain circuit, the E_{elec} is a constant, the E_{Tx} E_{Rx} is the transmission and reception energy consumption, d_{ridge} is the threshold of the distance.

2.3 The Model of Gradient Descent

The gradient descent algorithm is a search algorithm whose basic idea is to assign θ an initial value and then continuously update the value of $\theta$by iterative method to minimize $J(\theta)$. This paper refers to the batch gradient descent algorithm to calculate the node with the smallest $J(\theta)$ value from the current node to the neighbor node.

$$J(\theta)=\frac{1}{2}\sum_{i=1}^{n}\left[h_\theta\left(x^{(i)}\right)-y^{(i)}\right]^2 \tag{3}$$

$$Repeat\ until\ convergence\{$$

$$\theta_j:=\theta_j+\alpha\sum_{i=1}^{m}(y^{(i)}-h_\theta\left(x^{(i)}\right))x_j \tag{4}$$

$$(for\ every\ j)\quad \}$$

3 Equations and Mathematical Expressions

Clustering [5–6] is an important idea of wireless sensor networks. The nodes of the network are divided into several clusters. Each cluster contains a cluster head (CH) and multiple member nodes. The member nodes are only responsible for transmitting information to the cluster head. The header is responsible for data fusion and transmission, and transmits the data to a base station (BS) or a cluster head of a neighboring base station (BS). In summary, the choice of cluster head is the key problem of the whole clustering algorithm, and the choice of cluster head also increases the system overhead. Typical clustering algorithms: LEACH, LEACH-C, TEEN, etc., among which the most representative It is the LEACH algorithm, but because of the randomness of its protocol, the position of the cluster head generated in each round is uncertain, which makes the cluster head distribution uneven, and increases the possibility of selecting low energy nodes, which reduces the reliability of the network. The protocol proposed in this paper is designed to reduce system overhead and improve reliability. In this protocol, each node in the cluster may become a cluster head (CH). The sensor node does not need to identify the cluster head. The node sends the neighbor node information that is one hop from itself to the base station (BS). The gradient descends the idea to find the next optimal node.

In order to improve the reliability of the network, a lot of research shows that the closer the cluster head is to the base station, the greater the energy consumption. The energy consumption of the cluster itself is only related to the cluster radius. If the cluster radius does not change, the load will accelerate. Become a "hot spot" area that limits the lifecycle of your network. For non-uniform clustering, if the cluster radius remains the same, it will still cause "hot spot" area problems. Therefore, this paper introduces a strategy that the cluster radius can be adaptively adjusted, and establishes a network structure in which the distance between the cluster radius and the base station is far and near, and the radius of the cluster is also large to small. The structure is shown in Fig. 3.

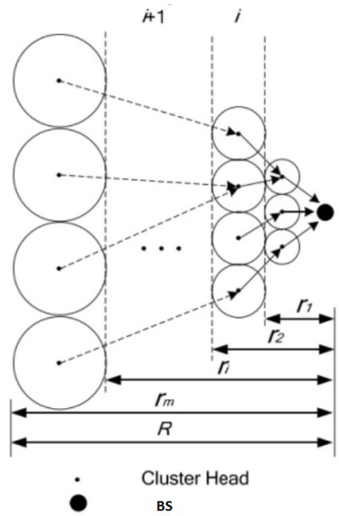

Figure 3: The network structure of cluster radius decreasing

3.1 In-Line Style

According to Section 2.2 of this paper, the energy consumption of the cluster head node is mainly reflected in two aspects: Receiving energy consumption and transmitting energy consumption. The specific energy consumption is publicized as shown in formulas (1) and (2). The receiving energy consumption of the cluster head is the energy consumed by the sensing data of the $k$bits of each member in the receiving cluster and the energy consumed by the data receiving the$l$bits of other cluster heads. The transmission energy consumption is mainly the energy consumed by transmitting n -bit data between clusters. Assuming a network with a cluster radius of R and a network node density ρ, the number of nodes of the cluster member is shown in formula (5), and the total energy consumed as follow:

$$m = \pi R^2 \rho \tag{5}$$

$$E_{total} = E_{Rx} + E_{Tx} = (k\pi R^2 \rho + l)E_{Elec} + n(E_{Elec} + \varepsilon_{fs} d^2) \tag{6}$$

It can be found that the cluster radius affects the receiving energy consumption of the node. The larger the radius, the greater the receiving energy consumption, the larger the E_{total} is, which affects the life cycle of the network. According to the network structure proposed in this paper, the research shows that the competition radius of the node is related to the distance from the node to the base station. The relationship defined in the literatures [7–9] is as follows:

$$R_i = [\varepsilon_1 (1 - c \cdot \frac{d_{max} - d(m_i, BS)}{d_{max} - d_{min}}) + \varepsilon_2 \cdot \frac{E_{residual}}{E_{init}}] * R_0 \tag{7}$$

where d_{max} and d_{min} are the maximum and minimum distances between the node and the base station; $d(m_i, BS)$ is the distance between the node $m_i$and the base station; $E_{init}$is the initial energy, and $c, \varepsilon$is a fixed parameter.

In summary, after determining the competition radius by considering the distance between itself and the base station, the node can calculate the total energy consumed by the node within the communication radius according to the competition radius.

3.2 Methods of Algorithm

The main idea of the algorithm is that the current node A is within its own communication radius, considering the ratio of the remaining energy of other nodes in the radius and the distance from the base station in formula (8), by inputting the training sample data, using BGD to continuously update the parameter values to learn the model is obtained by learning the model to find the node B that best matches the next hop.

$$E_{max} = \theta_1 E_{residual} + \theta_2 E_d \quad (8)$$

where $E_{residual}$ is the remaining energy of the next node B, and E_d is the energy generated by the projection of the distance from A to the next node B and the distance from the node B to the base station, that is, as to the current node, the energy which produced by the projection distance of the next hop node.

3.2.1 The Calculation of E_d

The projection distance generated by x for l on s_1 is as shown in formula (9). According to formula (1), the pseudo-code Algorithm 1 of the next hop node E_d can be obtained.

```
Computing the energy of E_d
//assume A is the current node and find the optimal projection energy of the next hop node B within the communication radius of A.
// E(r) is the total energy of A with radius r
// i is a node in the A communication radius and according to the formula (3.1) and (3.3) that 0<i≤m
// a is the distance from BS to A
//b is the distance from BS to B
//s is the distance from A to B
//e、 ε is a fixed value
//n is send the number of bits
// x : distance of Projection;
//E :energy of Projection
Input: a, b, s, e, ε ;
Onput: E
1. for each i∈(0,m] do 2-6 until end for;
2. x=(a^2+s^2-b^2)/2a;
3. E=n*(e+ε*x^2) ;
4. Using the algorithm of Gradient descent for E(i) do 4-5 until find the min E;
5. min E=1/2[(E(i)-E(r))^2];
6. End using;
7. end for;
```

Algorithm 1: The Calculate model of $\boldsymbol{E_d}$

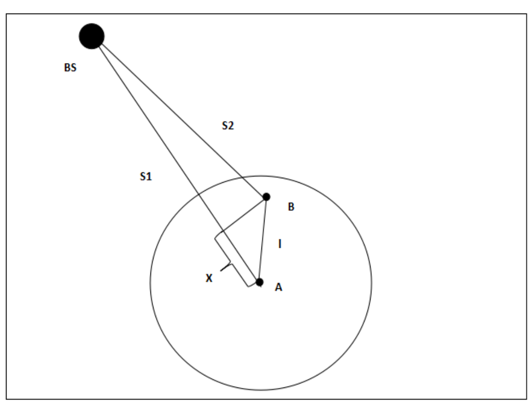

Figure 4: The Calculate model of $\boldsymbol{E_d}$

$$x = (\frac{s_1^2 + l^2 - s_2^2}{2s_1}) \quad (9)$$

The pseudo-code Algorithm 1 can calculate the node B relatively close to the base station, and calculate the energy generated by the projection distances of the nodes A to B according to the formula (9) and formula (10).

$$E_d = n(E_{elec} + \varepsilon_{fs} x^2) \quad (10)$$

3.2.2 The Calculation of E_{max}

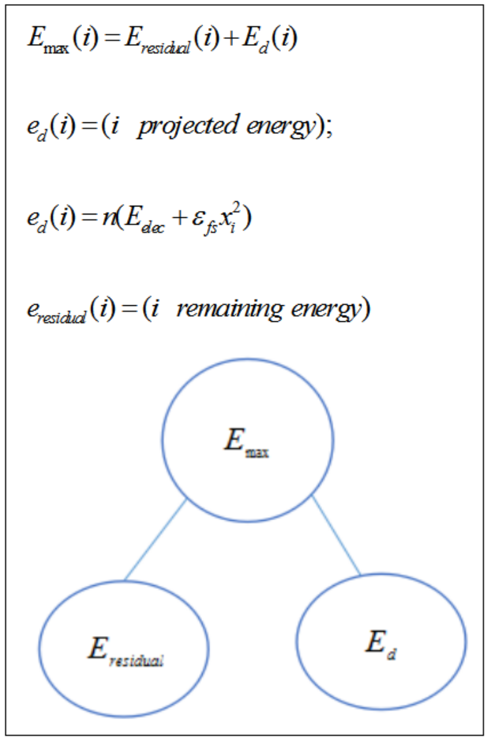

Figure 5: The Calculate model of $\boldsymbol{E_{max}}$

3.2.3 Using the Gradient Descent Methods to Calculate the Next Hop Node

for all nodes at the communication radius of the current node, the steps to use the BGD algorithm [10–13] are as follows:

1) Enter the data of the training sample and use BGD to update the value of θ_1,θ_2.

Let the machine learning algorithm have an estimateion function of $E_\theta(e)$ and it is cost function of $J(\theta)$, then:

$$\begin{bmatrix}\theta_1\\ \theta_2\end{bmatrix}[e_r,\ e_d] = \theta^T e \quad (11)$$

$$E_\theta(e) = \theta_1 e_r + \theta_2 e_d = \theta^{\ T} e \quad (12)$$

2) Update parametersθ_1,$\theta_2$in the opposite direction of the gradient

3) Enter new sample data and bring it into the training sample set to generate a newθ_1,θ_2

$$J(\theta) = \frac{1}{2}\sum_{i=1}^{n}\left[E\left(e_\theta{}^{(i)}\right) - y^{(i)}\right]^2 \quad (13)$$

Until the value ofθ_1,$\theta_2$can make the cost function to the$J(\theta)$ value to a minimum, continue to perform Steps 2, 3 until all new samples are trained to get the optimal gradient descent model.

3.3 Methods of Routing Algorithm

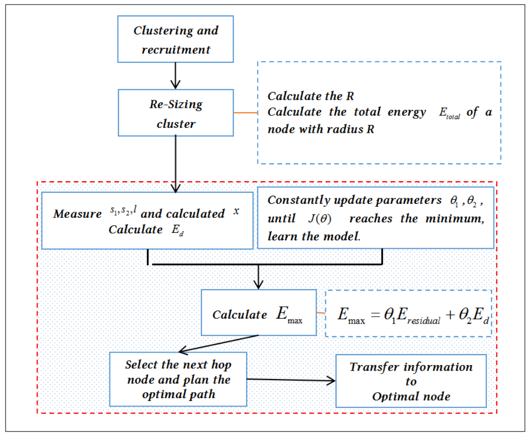

Figure 6: Routing algorithm

4 Smulation Results

In order to analyze the effectiveness and reliability of the ERGD algorithm in this paper, MATLAB is used to carry out the simulation test, and compared with the ERGD algorithm and literature based on BP neural network to estimate the energy of wireless sensor network under the same experimental conditions [5], experimental parameters set to Tab. 1.

Table 1: Experimental parameter setting

Parameter name	values
Initial energy	400 J
The range of Network	1000 m × 1000 m
Number of nodes	100
data package	512 bit
Data transfer rate	10 kbps
Transmission power	0.585 W
Received power	0.417 W

The residual energy and transmission delay of the node are compared and analyzed under the parameter setting of Tab. 1:

1) The Comparison of Node's residual energy. As is shown in Fig. 7. The residual energy of the energy algorithm of the wireless sensor network is extended with time. The BP neural network, the literature [14] and the ERGD algorithm which proposed in this paper. The average energy is decreasing at different degrees, and the residual energy of BP neural network is the least. Secondly, the algorithm proposed in literature [14], the proposed algorithm is optimal compared to the first two algorithms because of the algorithm. When selecting the next hop route, the distance between the remaining energy node and the base station of the next hop is considered, which greatly reduces the routing energy consumption of the transmitted data, balances the energy consumption of each node, and improves the utilization of node energy. The rate reflects the effectiveness of the ERGD algorithm.

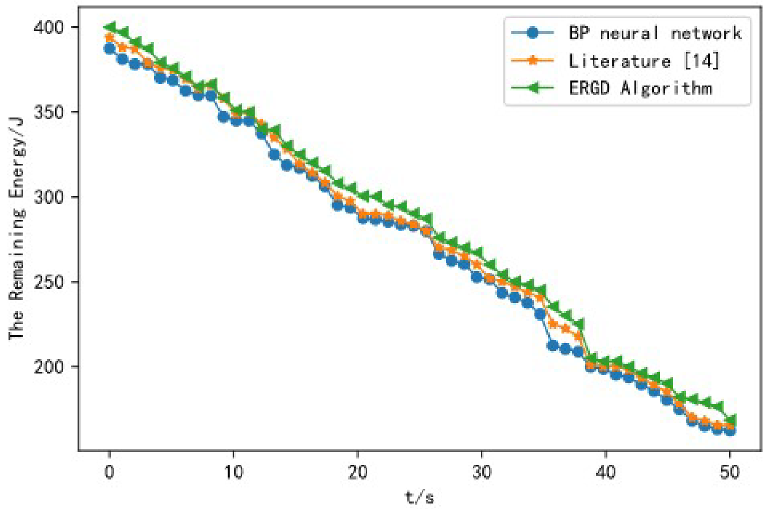

Figure 7: The Comparison of Node's residual energy

2) The Comparison of Data transmission delay. As is shown in Fig. 8. With the extension of simulation time, the ERGD algorithm is compared with BP neural network and the algorithm proposed in literature [14]. The delay is significantly higher than the latter two, because the algorithm in this paper can choose a better routing scheme, improve the data transmission speed, and improve the network throughput.

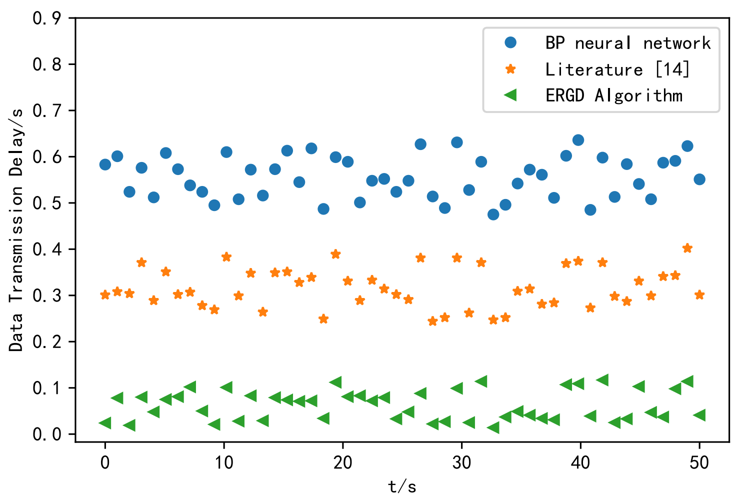

Figure 8: The Comparison of Data transmission delay

5 Conclusions

In summary, in view of the current energy consumption of wireless sensors, this paper proposes a routing protocol that minimizes energy consumption. Based on the idea of gradient descent, the current node to the next hop node are considered comprehensively within the communication radius of the node. The energy generated by the projection of the distance from the current node to the base station (BS), and the remaining energy of the next hop node, the optimal parameters are obtained by the gradient descent training samples, and the model is constructed to construct an optimal route, and the optimal route is selected. One hop node. The test results show that the residual energy of the wireless sensor network node and the delay of data transmission are improved. The overall performance of the algorithm is better than other algorithms, which can reduce energy consumption and extend the life cycle of the network.

Funding Statement: There is no fund support for this paper.

Conflicts of Interest: We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

References

[1] K. Akkaya and M. Younis, "A survey on routing protocols for wireless sensor networks," *Ad hoc Networks*, vol. 3, no. 3, pp. 325–349, 2005.

[2] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "Wireless sensor networks: A survey," *Computer Networks*, vol. 38, no. 4, pp. 393-422.

[3] C. Y. Chong and S. P. Kumar, "Sensor networks: Evolution, opportunities, and challenges," in *Proc. of the IEEE*, pp. 1247–1256, 2003.

[4] R. Hou, W. Ren and Y. Zhang, "A wireless sensor network clustering algorithm based on energy and distance," in *Int. Workshop on Computer Science & Engineering*, IEEE, pp. 439–442, 2009.

[5] M. Ye, C. Li, G. Chen and J. Wu, "EECS: An energy efficient clustering scheme in wireless sensor networks," in *Proc. of the 24th IEEE Int. Performance, Computing, and Communications Conference (IPCCC'05)*, pp. 535–540, 2005.

[6] F. Kiyani, H. Tahmasebirad, H. Chalangari and S. Yari, "DCSE: A dynamic clustering for saving energy in wireless sensor network," in *Proc. of the 2nd Int. Conf. on Communication Software and Networks (ICCSN '10)*, pp. 13–17, 2010.

[7] G. H. Chen, C. F. Li, M. Ye and J. Wu, "An unequal cluster-based routing protocol in wireless sensor networks," *Wireless Networks*, vol. 15, pp. 193–207, 2009.

[8] T. Wang, J. Y. Wu, H. Xu, J. H. Zhu *et al.,* "A cross unequal clustering routing algorithm for sensor network," *Measurement Science Review*, vol. 13, no. 4, pp. 200–205, 2013.

[9] H. Chen and S. Megerian, "Cluster sizing and head selection for efficient data aggregation and routing in sensor networks," in *IEEE Conf. on Wireless Communications and Networking Conf.*, WCNC, Las Vegas, NV, pp. 2318–2323, 2006.

[10] A. Forster, "Machine learning techniques applied to wireless ad-hoc networks: Guide and survey," in *Proc. of the Int. Conf. on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP'07)*, pp. 365–370, 2007.

[11] H. Taheri, P. Neamatollahi, M. Naghibzadeh and M. H. Yaghmaee, "Improving on HEED protocol of wireless sensor networks using non probabilistic approach and fuzzy logic (HEED-NPF)," in *Proc. of the 5th Int. Sym. on Telecommunications (IST'10)*, pp. 193–198, Tehran, Iran, 2010.

[12] Prabu and R. Maheswari, "Improving wireless sensor network lifespan by efficient routing algorithm and LZW compression," in *Int. Conf. on Information Communication and Embedded Systems (ICICES2014)*, Chennai, pp. 1–5, 2014.

[13] X. Yang and N. Vaidya, "A wakeup scheme for sensor networks: Achieving balance between energy saving and end-to-end delay," in *Proc. of the IEEE Real-Time and Embedded Technology and Applications Sym.*, 2004.

[14] Y. F. Han, G. W. Bai and G. X. Zhang, "Routing optimization algorithom of wireless sensor networks based on improved SVM. *Computer Science*, 2008, vol. 45, no. 5, pp. 131–133.