Improved Cuckoo Search-based Clustering Protocol for Wireless Sensor Networks

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ABSTRACT:
In most applications of intelligent networks equipped with wireless sensors, it is not possible to charge the nodes' battery consistency and it is impossible under some conditions. Protocols designed for this type of networks should be energy efficient. The rapid consumption of battery power in wireless sensors and high power consumption in data transmission are two main challenges of this area. Nodes' clustering is a natural way of categorizing nodes close together with the aim of using related data and removing plug-in data. However, existing clustering protocols are unbalanced in the term of energy consumption. The cluster heads are not distributed equally and overload clusters (with excess load) are much shorter than under-load clusters (low load). To solve this problem, an improved cuckoo search-based clustering algorithm (ICSCAS) has been proposed in present study. Also, performance evaluation of ICSCAS and its comparison with advanced clustering schemes in terms of total energy and residual energy consumption have been represented.

KEYWORDS: Wireless Sensor Networks, Clustering, Cuckoo Search.

1. INTRODUCTION

Advances in wireless communication and VLSI technologies (Very-large-scale integration) have led to the design of low-cost and small-size tools that can be used to design wireless sensor networks (WSNs) [1, 2]. Wireless sensor network is a distributed network that includes a group of independent nodes and one or more self-organized base stations (BSs). This type of network can be utilized for monitoring and tracking applications such as smart environments, smart cities, intelligent networks, smart homes, habitat monitoring, routing and identification of military target and so on [1, 3].

In wireless sensor networks, a sensor node has a limited source of energy. In general, AA2 batteries are used in sensor node and the rational use of energy sources in sensor nodes is an important research issue due to limited energy resources, which requires conducting essential researches in order to find a better solution for extending the life of the network. Various methods have been suggested to save energy resources and extend network life including clustering, data compression and accumulation, data gathering by mobile data collector nodes, work cycle, etc. In most cases of research literature, the cluster-based data collection scheme has been proven as an effective design to provide cost-effective, energy-efficient and scalable solutions. In the process of clustering, nodes are divided into two separate groups that are known as clusters. Each cluster has a cluster head, which its main task is to receive sensed data from cluster members (CM), gathering data and then transfer them to the base station [4-6]. In each cluster, the cluster head eliminates waste data using data accumulation. Therefore, the correct selection of cluster heads and spatial distribution is an important issue in the process of balanced energy clustering.

Choosing a cluster head with balanced energy is considered as a hard problem. To solve this problem, many clustering algorithms are proposed based on (innovative) and meta-mental methods in research literature [6-14]. Existing clustering protocols are unbalanced in the term of energy consumption. The cluster heads are not distributed equally and overload clusters are much shorter than under-load clusters. The reason for this is that the average distance between cluster head and the BS which is used in the fitness function (adaptive) can lead to the selection of all clusters near the BS [15-18]. To solve this problem, an improved cuckoo search-based clustering algorithm (ICSCAS) has been proposed. In the proposed scheme, a unique fitness function has been used that includes three parameters of energy, distance and cluster size. In order to improve the performance of cuckoo search, a different coding scheme was used to encode the population. Performance evaluation of proposed clustering scheme and comparing it with advanced clustering schemes has been discussed. The remainder of this article has been organized as follows: the other related works conducted on optimization-based meta-mental clustering have been discussed in section2, the proposed clustering scheme has been introduced in section3, sectin4 relates to performance evaluation of proposed scheme and comparing it with advanced clustering schemes and the conclusion has been provided in section5.

2. RELATED STUDIES

Clustering protocols are divided into two groups: clustering based on mental (discovery-innovative) method and clustering inspired by nature and based on computational method [6]. Several mental protocols have been developed to increase the life time of sensor network. Among them, LEACH [4] is one of the most popular clustering protocols. LEACH selects cluster head based on a probability method. For this reason, the role of cluster head is assigned to other node after each round. The main limitation of LEACH is that a low-energy sensor node can be selected as a cluster head. This will quickly destroy the cluster heads. Several clustering protocols have been developed to improve the efficiency of LEACH. Among them, HEED [5] and PEGASIS [6] are very popular. PEGASIS utilizes from an opportunistic approach to arrange sensed nodes in a structured list in which each node can be associated with its adjacent nodes in the list. In, the remaining energy of node is the main force used to select cluster head. This protocol mainly focuses on the cost-effective selection of clusters and decreasing overload. This maximizes the life time of network.

In LEACH-C (Centralized LEACH) [7], the sink nodes (nodes of data gathering) calculate the average energy for each round and nodes with a higher energy than average are selected as candidates for cluster head. The cluster arrangement is performed using a meta-mental algorithm and thermal repair simulation, which works better than LEACH due to choosing the cluster head, based on energy consumption and can increase the life time of network. However, how to balance the size of cluster is not taken into account in this protocol which can lead to the problem of unbalanced energy consumption.

Latif et al investigated a PSO (Particle Swarm Optimization) clustering scheme, also called PSO-C. This model utilizes from a fitness function, which consists of two elements i.e. residual energy and the distance between cluster heads and CMs. However, cluster size as an important factor in reducing energy consumption is not considered in this model [8]. In a study conducted by Colia et al, a clustering scheme based on differential evolution and an optimization algorithm has been proposed [9]. Lalvani et al have proposed a clustering scheme based on BBO (biogeochemical optimization) to select cluster heads and cluster arrangement [10]. The main limitation of schemes proposed in [9] and [10] is the unequal distribution of cluster heads that results in unbalanced energy consumption. In [11], Mann et al utilized from a meta-mental algorithm to investigate an artificial bee colony for selection of cluster heads as well as routing of data packs from cluster heads to BS.

In [12], a PSC-based protocol to cluster WSN network has been discussed, which is called E-OEERP. In the E-OEERP model, a PSO-based scheme was used to select a cluster head with focusing on the problem of ignored nodes during clustering process. This scheme also has the problem of unbalanced energy consumption. Rao et al investigated a PSO-based heat cluster selection method, which is called PSO-E-CLUSTER HEAD_S. The main limitation of PSO-E-CLUSTER HEAD_S is unequal distribution of cluster heads, resulting in unbalanced energy consumption during its evaluation [13]. In [14], meta-mental clustering algorithm for WSN has been studied based on cuckoo search. In the study, it has been assumed that 20% of nodes have more energy than the remaining sensor nodes, which is an impossible assumption. The main disadvantage of this scheme is that cluster heads are always selected from high-energy nodes, which can cause the problem of unbalanced energy consumption. Gupta et al. [18] used meta-metal cuckoo clustering algorithm with respect to the balanced energy clustering. This model does not consider the criteria of proximity, centralization, and transmission and displacement in network, which are important factors in decreasing energy consumption. To solve the problem of unbalanced energy consumption, an improved cuckoo search-based clustering algorithm (ICSCAS) has been proposed in present study.

3. THE PROPOSED PROTOCOL

In this section, the valuation of nodes position to select as cluster head and cost function used in the evolution of cuckoo nest has been described. Then, the explanation of improved cuckoo search-based clustering algorithm (ICSCAS) has been provided.

3.1. Valuation of Nodes Position to Select as Cluster Head

The fitness function for each node was calculated based on following equations to select appropriate cluster heads (CHs) [18].

$$fitness = a_1 * f_1 + a_2 * f_2 + a_3 + f_3 \quad (1)$$

Where, a1, a2 and a3 are constant values between 0 and 1. The value of a3 is equal to (1-a1-a2) [18].

$$f_1 = \frac{1}{m} \times \sum_{n=1}^{m} \left[\frac{\sum_{i=1}^{|c_n|} dis(CH_n CM_i}{|c_n|} \right] \quad (2)$$

Where, m indicates the number of CHs, Cn is the number of cluster members in nth cluster and dist (CHn,CMi) is the distance between cluster head nth and member ith. The second component or f2 in fitness function is obtained as follow [18]:

$$f_1 = \frac{E_{residual}}{E_{total}} \quad (3)$$

Where, Eresidual is residual energy of node and Etotal the total energy of node, which is in the particle interaction interval. The third component or f3 in fitness function is obtained as follow [18]:

$$f_3 = \frac{C_n}{N} \quad (4)$$

Where, Cn is the average number of cluster members in a particular cluster and N is the total number of nodes [18].

These criteria of previous studies are necessary but not sufficient. Therefore, the proposed method of present study emphasizes to four other criteria in addition to above mentioned criteria, which the selection of cluster would be better and the overall system energy would be more optimized by combining all seven criteria.

3.2. Proximity of Node to Sink

$$\text{NS}=\frac{\text{DISTANCE i of sink}}{\text{high L}} \quad (5)$$

Where, distance I is the distance between node i and sink, high L is the final level edge of hierarchical edges in the sink.

Utilizing from this criterion can optimize the exchanges, because whatever the distance of node to sink is lower, better cluster head can be selected.

3-3. The Criterion of Centrality Relative to Hierarchical Layers of Wireless Sensor Network

$$\text{CS}=1\frac{\text{distance i to sink}-(\frac{\text{high l}+\text{low l}}{2})}{(\frac{\text{high l}+\text{low l}}{2})} \quad (6)$$

Where, distance I is the distance between node i and sink, high L and Low L are the upper and lower edges of hierarchy layer, respectively. The advantage of utilizing from this criterion is more effective management.

3.4. Priority of Selecting the Round Numbers of Cluster Head

$$\text{RS}=\frac{1}{\text{number of round}} \quad (7)$$

Where, number of round indicates the number of round in which a node has previously selected as a cluster head. . The advantage of utilizing from this criterion is optimization of energy resources, as fewer resources are consumed.

3.5. Priority of Proximity to Necessity

$$\text{FS}=\frac{1}{\sum_{a=1}^{k} \frac{\text{Distance Sensor}_a \text{of Sensor}_i}{\text{reminder energy}_a}} \quad (8)$$

Where, the parameter of $\text{Distance Sensor}_a \text{of Sensor}_i$ is the distance of node I from sink and reminder energy_a is the remind energy of a. utilizing from this criterion is balanced energy in whole of the system. As a result, the new fitness function would be as follow:

$$\text{Pnew}= \sigma 1 * \text{NS} + \sigma 2 * \text{CS} + \sigma 3 * \text{RS} + \sigma 4 * \text{FS} \quad (9)$$

Where,(σ) is coefficient of equation, the sum of all of which is equal to one.

$$\text{F}_{\text{PROPOSED}}= \gamma * \text{PB} + (1-\gamma) * \text{Pnew} \quad (10)$$

Where, (γ) is a number between 0 and 1 and Pnew is new fitness function.

After calculating the fitness function for each node, the nodes with 20% are selected which have the highest value of fitness. Among these 20% proper nodes, a cluster is selected as cluster head, which occupied each Cuckoo nest. It means that the proper nodes are CH candidate that act as cuckoo eggs and used to value host nests. To select the best nest, the cost of each host nest is calculated based on following cost function [10]:

$$Cost = \beta * x_1 + (1+\beta) * x_2 \quad (11)$$

Where, the components of cost function (x1, x2) are defined as follows [18]:

$$x_1 = \max_{k=1,2,3,\ldots,K} \left\{ \sum d(n_i, CH_{e,k}) / |C_{e,k}| \right\} \quad (6)$$

$$x_2 = \sum_{i=1}^{N} E(n_i) / \sum_{k=1}^{K} E(CH_{e,k}) \quad (7)$$

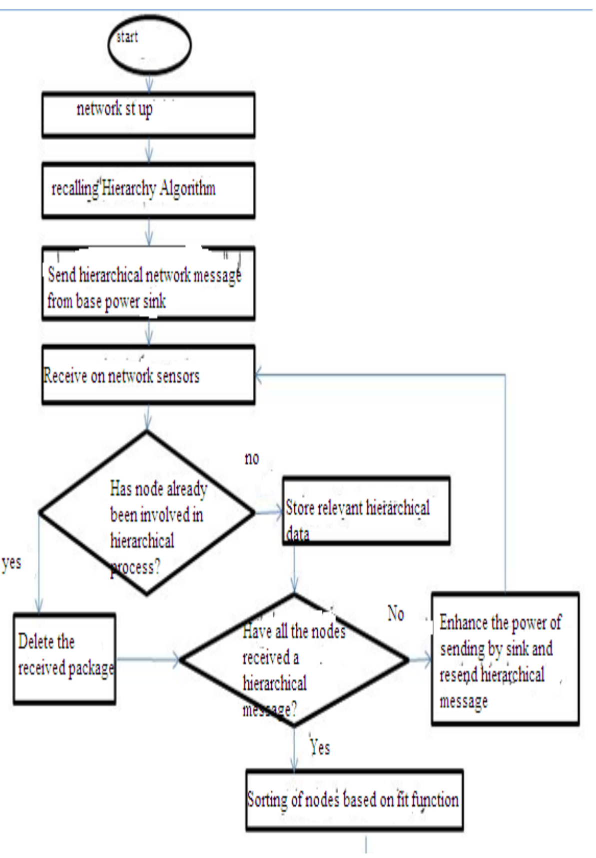
(12)

Where, x1 function is the mean maximum Euclidean distance between nodes (ni) and CHs associated with them. Ce, k indicates the number of nodes for egg e in interaction range of cluster Ck. x2 function represents the total energy ratio of all nodes to total energy of all nodes existed in the network to total energy of all CHs provided in the nest and β equals to 0.5. Minimum value of the x1 and x2 functions helps to decrease the distance between clusters and select the optimal position of CHs that reduce energy consumption.

3.6. Dynamic of Cluster Heads

After the specified time period, member nodes compute the evaluations of cluster heading and send them to nude of current cluster head. The current cluster head recalls the system select the most efficient sensor as next cluster head with taking into account the efficiency, position and requirements of network sensors and send a new cluster heading message to the member nodes. The member nodes send an attachment message to new cluster head by receiving a new cluster message. In this new round, a node is selected as cluster head and nodes are transmitted with the new cluster head.

In continue, various parts of proposed flowchart have been described.



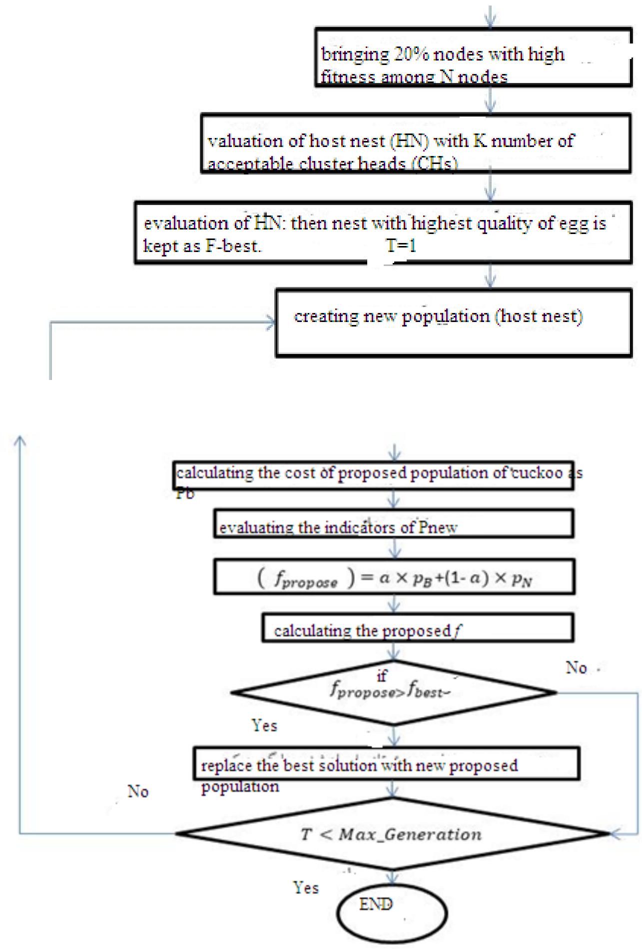


Fig. 1. Flow chart of proposed protocol.

3.7. The Proposed Clustering Algorithm

The proposed ICSCA algorithm has two main components, the valuation process and cuckoo search repetition process. The description of each component is as follows:

Valuation: in valuation step, the fitness function of each node is firstly obtained using Equation (1) and then; the list of sensor nodes is sorted in descending order based on fit value. After sorting, nodes of up to 20% are sorted from sorted list L. After this process, the host nest is evaluated through eggs. Here, the cluster heads represent eggs. These eggs are sensor nodes that are randomly selected from ordered list L and each nest is occupied with k numbers from candidate clusters. Here, the cluster heads and sensor nodes are synonymous. It is assumed that H is total number of nests and k is the number of eggs. After occupying each nest, the cost of each host nest is obtained by Equation (5). After this step, the best nest with the highest cost function is selected as best host nest. The best host nest is shown as Fbest. After this process, cuckoo search repeat process begins to select the highest quality nest including the best cluster of cluster heads.

Cuckoo search repetition process: this process is repeated until the stopping criterion is satisfied. In repetition process, a new host nest is firstly created with the help H host nest which has been built in the process of valuation. Then, the cost of new host nest is obtained using Equation (5), which is shown as Fnew. If the Fnew value is greater than Fbest, the Fbest value is replaced by Fnew. This process is repeated so that Max_ Generation is obtained. After repeating Max_ Generation, the best nest is achieved, which includes the best of cluster heads. The work flow chart of improved cuckoo search-based clustering algorithm (ICSCAS) has been presented in Fig. (1).

4. RESULTS AND DISCUSSION

In this section, the performance of proposed scheme (ICSCAS) has been evaluated and compared with a popular algorithm (ICSCA). For simulation experiments, a customized WSN was developed using MATLAB, in which 200 nodes were randomly applied in a 2-dimensional range with the size of 200-by-200. For energy use, the same energy model used in [3] was used. The simulation parameters have been listed in Table (1) simulation parameters.

Table 1. Simulation parameters.

Parametrer	Value
Initial energy	2J -200J
Dimensions of network environment	200 m^2*200
Package size and type of transmitted traffic	4000 Bit ‹CBR
Number and distribution of sensors	Randomly from 500 to 1000
Simulation time, start of transmittions	50s- 600s
Receiving energy	50*10-9 J
Enhance the power of sending in low range	10*10-12 J/b
Enhance the power of sending in high range	10*13-12 J/b

In continue the convergence diagrams of proposed algorithm and its comparison with ICSCA algorithm have been presented in the model. Also, the percentage of improvement has been calculated through following equation:

$$\text{Percentage of average improvement}=\frac{\sum_{i=1}^{n}\left(1-\frac{\text{point of proposed method}}{\text{point of Icsca method}}\right)}{n}$$

Fig. (2a) represents the efficiency of ICSCAS in terms of total energy consumption with a different number of rounds. Total energy consumption with a variable number of data gathering round has been estimated equal to 100 to 500. It can be seen from Fig. (2a) that ICSCAS has better performance compared with the other scheme in term of total energy consumption. The reason for this is balanced distribution of clusters, which improves the load of each cluster.

Fig. (2b) represents the efficiency of ICSCAS compared with other available protocols. In this experiment the size of desired ranged was considered constant 200 by 200. Also, e node density was considered variable at the range of 100 to 300 and the total energy consumption was calculated for 100 constant rounds. However, the proposed protocol showed better efficiency compared to ICSCA protocol with increase in total power consumption of the protocol node.

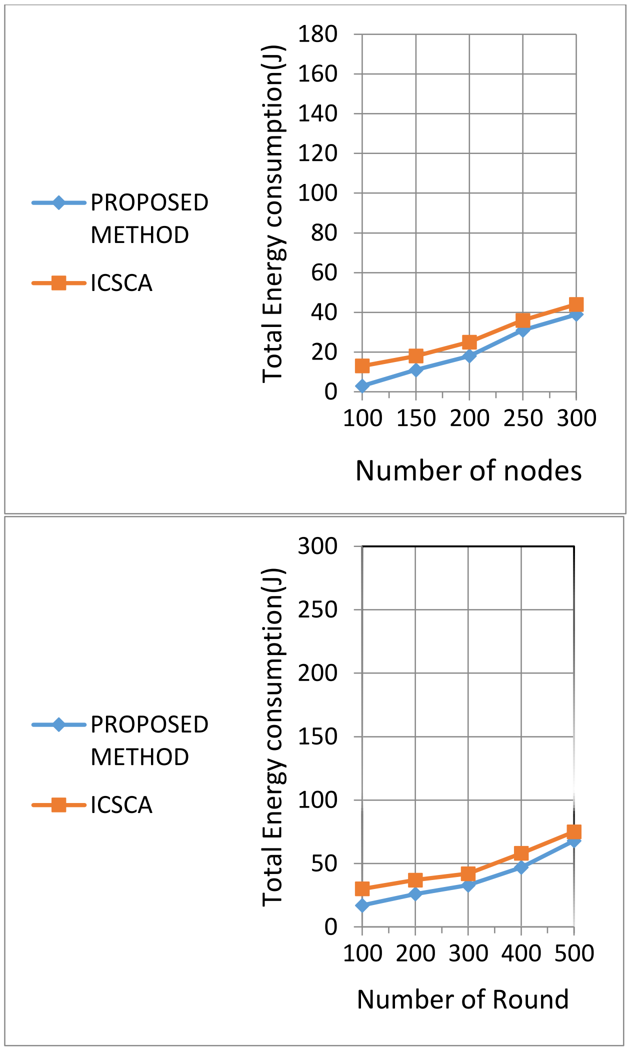
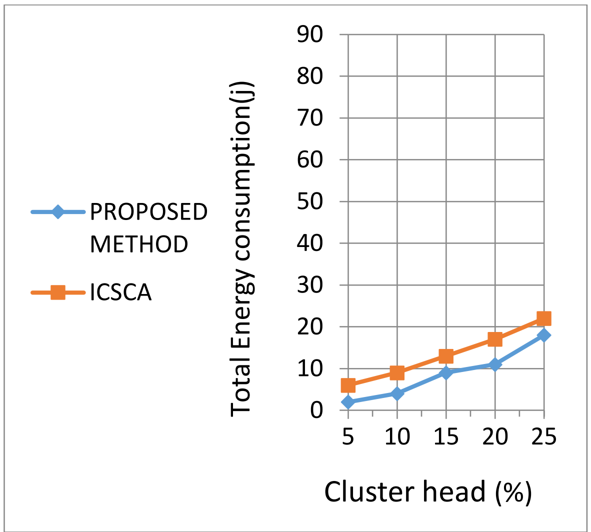


Fig. 2. a), Total energy consumption versus number of rounds, b), Total energy consumption versus number of nodes.



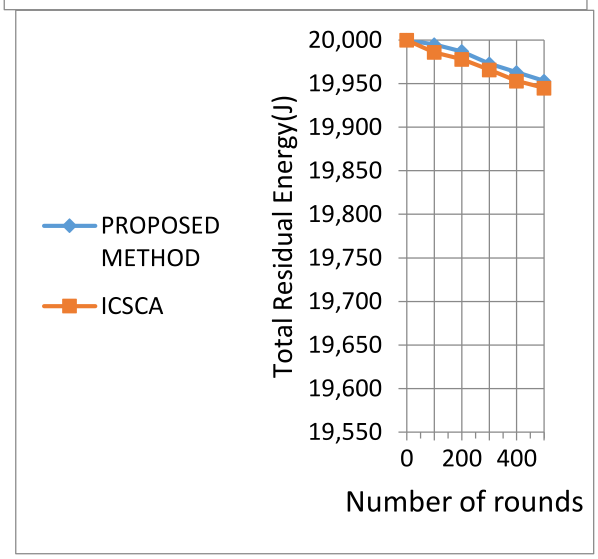


Fig. 3. a), Total residual energy versus number of rounds, b), Total residual energy versus percentage of cluster heads.

Fig. (3a) represents the efficiency of proposed scheme (ICSCAS) compared with ICSCA in the term of residual energy. In this experiment the size of desired ranged was considered constant 200 by 200 and the initial energy of 200J was applied on the nodes. It can be seen from Fig. (3a) that the residual energy of network is decreased with increase in the number of rounds. However, the proposed protocol showed better efficiency compared available protocols in the term of residual energy.

Fig. (3b) represents the efficiency of proposed scheme (ICSCAS) compared with ICSCA in the term of residual energy and with different numbers of cluster head. In this experiment the size of desired ranged was considered constant 200 by 200 and the percentage of cluster heads varied from 5 to 25 percent. Also, a total number of 200 nodes were used. The total energy consumption of protocol was increased with increase in cluster heads. However, the proposed protocol showed better efficiency. The reason is that it utilizes from better fitness function that ensures equal distribution of clusters and their load balancing. The factor that makes the proposed proposal work better.

5. CONCLUSION

In present study, an improved cuckoo search-based clustering algorithm (ICSCAS) was proposed to provide balanced clustering of energy. A unique fitness function was derived for effective selection of cluster head in the term of energy saving. The proposed clustering algorithm of present study distributes the clusters equally, so that their communicational (interactional) load can be balanced. To transmit the plug-in data from cluster heads to the sink, a multi-path routing algorithm was used to select the path with highest savings between the cluster head and BS. The efficiency of proposed scheme (ICSCAS) was comprised with ICSCA scheme. The results obtained from simulations indicated the better efficiency of proposed scheme in the terms of total energy consumption, residual energy and network lifetime. Present study can be developed for 3D wireless sensor networks and its performance can be examined with taking into account transmission and replacement factors of t network

REFERENCES

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "**Wireless Sensor Networks: A Survey**," *Computer Networks*, Vol. 38, pp. 393-422, 2002.

[2] Govind P. Gupta, Manoj Misra, Kumkum Garg, "**Energy and Trust Aware Mobile Agent Migration Protocol for Data Aggregation in Wireless Sensor Networks**," *Journal of Network and Computer Applications*, Vol. 41, pp. 300-311, 2014.

[3] Gupta, Govind P, "**Efficient Coverage and Connectivity Aware Data Gathering Protocol for Wireless Sensor Networks**," *Recent Advances in Information Technology (RAIT), 3rd International Conference on. IEEE*, 2016.

[4] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "**Energy Efficient Communication Protocol for Wireless Microsensor Networks**," *in Proc. 33rd Annual Hawaii International Conf. Syst. Sciences*, Vol. 8, pp. 8020, Hawaii, USA, Jan. 2000.

[5] O. Younis, S. Fahmy, "**HEED: A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks**," *IEEE Trans. Mobile Computing*. Vol 3(4), pp. 366–379, 2004.

[6] Adamu Murtala Zungeru, "**Classical and Swarm Intelligence Based Routing Protocols for Wireless Sensor Networks: A Survey and Comparison**," *Journal of Network and Computer Applications*, Vol. 35, pp. 1508–1536, 2012.

[7] Heinzelman, W. B., Chandrakasan, A. P., & Balakrishnan, H. "**An Application Specific Protocol**

Architecture for Wireless Microsensor Networks," *IEEE Transactions on Wireless Communications,* Vol. 1(4), pp. 660–670.

[8] Latiff, NM Abdul, Charalampos C. Tsimenidis, and Bayan S. Shari, "**Energy-Aware Clustering for Wireless Sensor Networks Using Particle Swarm Optimization**." *Ieee 18th International Symposium On Personal, Indoor and Mobile Radio Communications. IEEE*, 2007.

[9] Kuila, P., & Jana, P. K., "**A Novel Differential Evolution Based Clustering Algorithm for Wireless Sensor Networks**," *Applied Soft Computing,* 25, pp. 414–425, 2014.

[10] Lalwani, P., Banka, H. & Kumar, C., "**BERA: A Biogeography-Based Energy Saving Routing Architecture for Wireless Sensor Networks**," *Soft Computing*, pp 1–17, 2016.

[11] Mann, P.S. & Singh S., "**Artificial Bee Colony Metaheuristic for Energy-Efficient Clustering and Routing in Wireless Sensor Networks**," *Soft Computing*, pp 1–14, 2016.

[12] RejinaParvin, J., and C. Vasanthanayaki, "**Particle Swarm Optimization-Based Clustering by Preventing Residual Nodes in Wireless Sensor Networks**," *IEEE Sensors Journa*l, 15.8, pp. 4264-4274, 2015.

[13] Rao, P. C., Jana, P. K., & Banka, H., "**A Particle Swarm Optimization Based Energy Efficient Cluster Head Selection Algorithm for Wireless Sensor Networks**," Wireless Networks, pp. 1-16, 2016.

[14] Adnan, Md. Akhtaruzzaman and Razzaque et al., "**A Novel Cuckoo Search Based Clustering Algorithm for Wireless Sensor Networks**", *Advanced Computer and Communication Engineering Technology: Proceedings of ICOCOE 2015", 2016, Springer International Publishing*, pp. 621-634.

[15] Yang, X.-S., & Deb, S., "**Multi Objective Cuckoo Search for Design Optimization**," *Computers & Operations Research*, 2011.

[16] Valian, E., & Valian, E., "**A Cuckoo Search Algorithm by Lévy Flights for Solving Reliability Redundancy Allocation Problems**," *Engineering Optimization*, pp. 1–14, 2012.

[17] Yang, X.-S., & Deb, S., "**Cuckoo Search: Recent Advances and Applications**," *Neural Computing and Applications,* 1–6, 2013.

[18] Gupta, G.P., "**Improved Cuckoo Search-based Clustering Protocol for Wireless Sensor Networks**". *Procedia Computer Science*, 125: pp. 234-240, 2018.