Wireless Pers Commun (2018) 101:1457–1468
https://doi.org/10.1007/s11277-018-5772-8

Energy Harvesting Based Efficient Routing Scheme for Wireless Sensor Network

R. Srinivasan[1] · **E. Kannan**[1]

Published online: 28 April 2018

Abstract Wireless Sensor Network were deployed in a complex environment where the wide range of complex application is mandatory for the services. Such application includes military, agriculture, healthcare, defense, monitoring, surveillance etc. In general sensor nodes were spatially distributed and deployed in remote fashion, usually they are powered up by batteries. These battery powered sensor nodes are pruned to failure due to its power constrained nature. This led many researchers to explore energy efficient context aware routing for Wireless Sensor Networks. Hence a novel energy harvesting based efficient routing scheme is desirable to address the above stated problem. The key idea is to harvest the energy source from the deployed environment. The proposed routing scheme is tested and validated in MATLAB based simulation test bed. The experimental results shows that the proposed routing scheme is robust and meet all the requirements of routing and promising results for energy usage.

Keywords Energy harvesting · Energy efficient routing · Routing · WSN · Sensor · Swarm · Nature inspired

1 Introduction

Present day technologies leads sensor applications to wide range of usage and adaptability. These sensor technologies were tiny and widely used in complex situations [1]. Once these sensor were deployed on the field it is not possible to frequently access the node and manual configuration is still a risky factor [2]. Hence these senor nodes were more

✉ R. Srinivasan
Srinivasanrajkumar28@gmail.com

E. Kannan
ek081966@gmail.com

[1] Department of Computer Science and Engineering, Veltech Rangarajan Dr Sagunthala R&D Institute of Science and Technology, Chennai, Tamil Nadu 600062, India

precisely concentrated and worked on in order to avoid failure due to manual configuration. These sensor node requires energy and most of the senor nodes were battery backed up nodes. Hence power is an important issue in the sensor network [3–5].

Energy is the main issue which is directly oriented to network performance. Any deviation in the power could compromise the performance of the entire network [6]. Hence a optimal and realistic routing scheme is needed to route the data packets from source to destination. The present day sensor nodes were subjected to portable and constrained sources for energy and chance for energy dissipation is high and leakage is more. Some of the alternate energy sources like solar, wind based element can generate electric power frequently.

Hence in this paper such a technique is used to harvest the energy from the ambient environment and to harvest the energy source to the sensor network [7]. To address the problem stated above, a novel energy harvesting based routing scheme is proposed.

The organization of the paper is as follows: Sect. 2 deals with related work and basic knowledge about the energy harvesting schemes along with energy aware and energy efficient routing. Section 3 represents the proposed methodology. Section 4 discuss about the experimentation carried out to implement the proposed routing scheme. Section 5 finally concludes the paper.

2 Literature Review

Energy is the major part which plays a vital role in performing all the operations. The main goal of Wireless Sensor Network (WSN) is to design an optimal algorithm which should be energy efficient in routing. Enormous amount of protocols have been proposed by many researchers. Some of them were complex, reliable and benchmarked [8]. Low-energy adaptive clustering hierarchy (LEACH) is an efficient self organizing hierarchical protocol widely used for energy efficient routing. Later it has been modified for several versions in order to achieve better results. The successor of the LEACH protocol is Power-Efficient Gathering in Sensor Information Systems (PEGASIS). PEGASIS is a chain based protocol which works based on chain of neighbor communications. Some of the successors of PEGASIS [1, 4, 5] includes algorithms such as (Energy efficient PEGASIS) EEPB, MHRP etc [9].

Recently researchers proved the possibility of energy harvesting in WSN [10]. Here author claimed that TMG 127 series sensor module is an autonomous module widely used as standalone energy harvesting node to measure temperature [11]. Liqun Hou et al. also stated about the various sensor modules used for energy harvesting in the sensor network. Some of the researchers have also tried to design thermoelectric generators for physical surveillance [10]. Selvarathinam et al. stated about various energy harvesting techniques from the human bodies for biomedical application. Zhou et al. stated that Most of the researchers from north east countries work on Energy harvesting model in order to reduce downlink of sensor network, reducing network overhead, optimal energy scheduling strategy. Gündüz et al. stated in their paper about optimal offline transmission scheme for a multi-hop communication system [12].

From the literature it is seen that energy harvesting can be applied to any sensor network with proposer configuration [13–16]. The literature also reveals that there is no algorithm is available in hybrid fashion by combining energy harvesting technique along with nature

inspired algorithm. Hence there is a strong need for the proposed Energy harvesting based efficient routing scheme for Wireless Sensor Network [17–21].

The present day sensor nodes were subjected to portable and constrained sources for energy and chance for energy dissipation is high and leakage is more [22, 23].

Energy harvesting based efficient routing scheme is a novel scheme which uses harvesting mechanism to harvest energy using solar powered pane [24–26].

We consider a two step cluster head selection process for Energy harvesting based efficient routing scheme. In the first step, clustering to cluster energy harvesting nodes and its related nodes. In the second steps, nature inspired intelligence scheme in energy harvesting nodes for routing the data packets. Using K-means algorithm, the Centroid value is directly given among the clusters and harvesting node is performed by calculating transient probability distribution functions. After cluster, harvesting node is selected and nature intelligence scheme is applied to route the data packets within the clusters, using traditional Ant and Bee colony algorithm.

The main motivation of our research work is:

The proposed routing scheme is well works during the time of path loss effects, capable of reorder the nodes with novelty and robustness.

1. Uniform utilization of energy among all the nodes.
2. To increase the life time of the network.
3. Reduce packet drop ratio.

3 Energy Harvesting Based Efficient Routing Scheme

Energy harvesting based efficient routing scheme as shown in the Fig. 1 is a novel scheme which uses harvesting mechanism to harvest energy using solar powered pane (physical hardware attached to homogeneous sensor nodes).

Energy harvesting based efficient routing scheme has two main phases. (1) Clustering to cluster energy harvesting nodes and its related nodes. (2) Incorporating nature inspired intelligence scheme in energy harvesting nodes for routing the data packets.

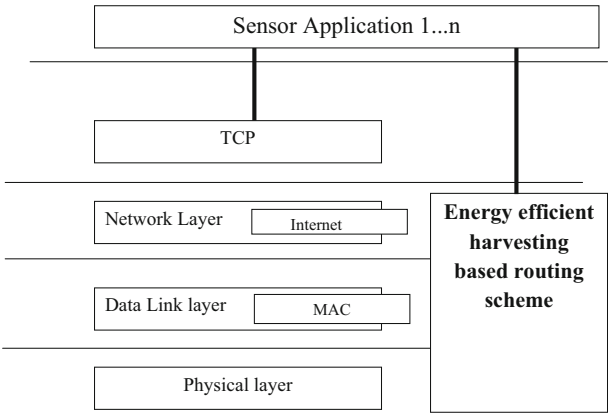

Fig. 1 Deployment architecture of proposed routing scheme

A. Clustering

Clustering is performed to cluster the nodes to connect the other nodes with the harvesting node. Here K-means algorithm [6] is used to cluster the nodes. The centroid value is directly given to the harvesting node where it is autonomous head among the clusters. This reduces the impact of node selection. Selection of harvesting node is performed by calculating transient probability distribution function by applying it to all the nodes.

B. Nature inspired intelligence scheme

Once the cluster is formed and harvesting node is selected. Nature inspired intelligence scheme is applied to route the data packets within the clusters. Here, traditional Ant and Bee colony algorithm [27, 28] is applied and performance measure were estimated. As stated in the Fig. 2. Route Request (RREQ) and Route Reply (RREP) are used to handle the request and response of the query message.

C. Experimentation and performance analysis

The experimental setup is carried out using 200 nodes in a MATLAB simulated environment with 5 harvesting nodes and 2 base stations. The simulation long lasts for more than 60 min with equal interval to process the data from the sensor and to transmit it using

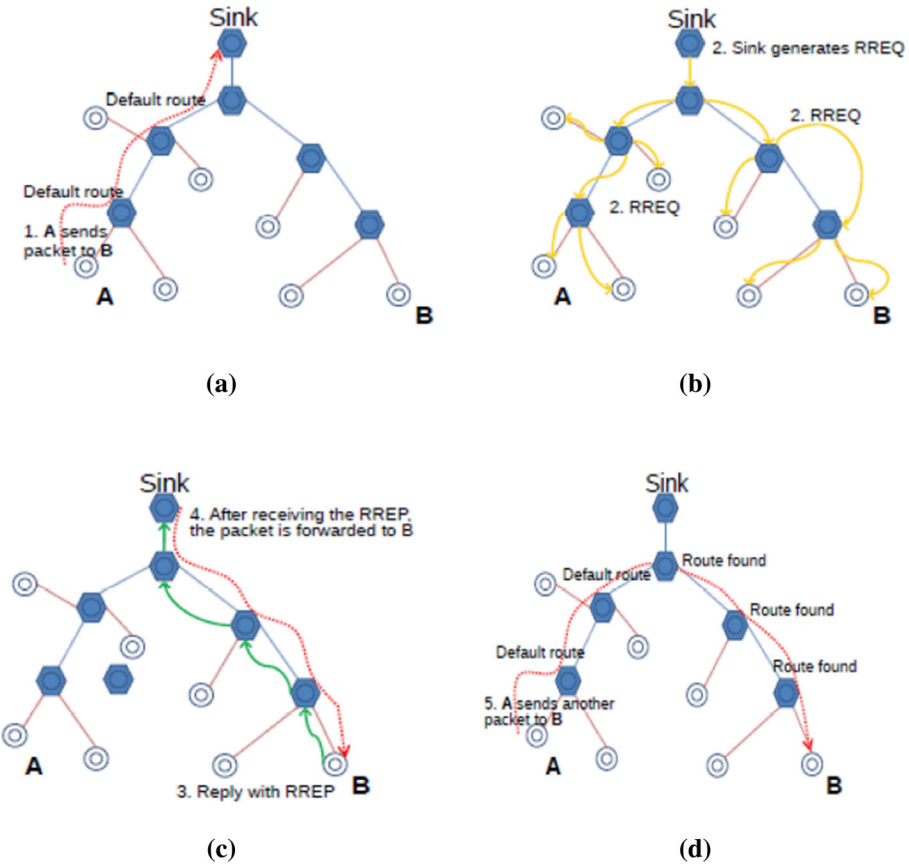

Fig. 2 Energy harvesting based efficient routing scheme

the proposed routing scheme. Some of the node were pre-assigned to perform energy harvesting in order to validate and harvest the energy. Figure 3 represents the network setup of the harvesting nodes.

Algorithm

```
For all the nodes in the network
     Calculate transient probability
     Select harvesting node
     Apply k-means
     cluster all the nodes
     Apply Ant Colony and Bee colony algorithm
     Route the packets
```

Figure 4 represents the bit usage of the harvesting nodes. The energy harvesting nodes are shown in different colors and layered. The average rate of the bit accessible by the harvesting node is 8 bit and maximum upto 32 bit chunk. Due to the limited constraints of sensor network, the sensor nodes were formed in the way of byte addressable. The transmission is carried out by calculating tag bits as stated in Eq. 2. Later these tag bits are converted to binary and forwarded finally.

Formulae to calculate tag bits be represented as follows

$$\text{exponent of address} = \text{exponent of index} - \text{exponent of offset} \tag{1}$$

$$\text{Tagbits} = \text{bit length address} - \text{exponent of address} \tag{2}$$

Case 1:

Consider the scenario, the bit usage rate during energy harvesting be 10 words. For each words it consists of 4 bytes. For an average of 8 words there is 32 bytes of chunk to be transmitted. The protocol uses context aware on demand wake scheduling by default. The offset address value be 10 and index value be 20. Then the Tagbit size is $40 - 20 - 10 = 10$.

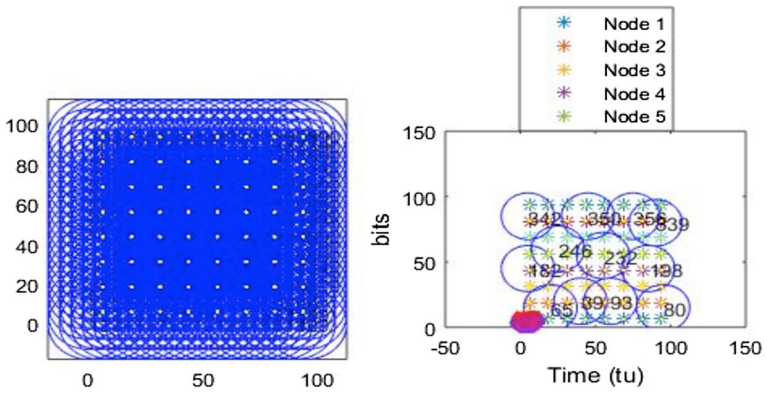

Fig. 3 Harvesting node

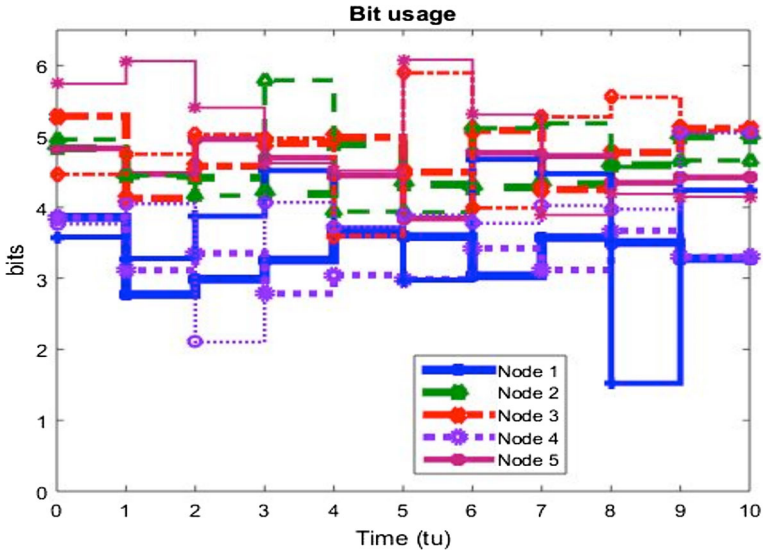

Fig. 4 Bit usage statistics for each harvesting node

Figure 5 explains the path loss and fading effect of the harvesting sensor nodes. Here, the sensor nodes were automatically simulated to perform the fade out effect in order to validate the situation of path loss. During simulation, the node 1 and node 2 is simulated to fade out its range between the communications nodes. When the situation is enabled and nodes starts to fading out its communication range, the other nodes collaboratively leaded the network to transmit the data by reordering and rescheduling the data transmitted from the failed nodes.

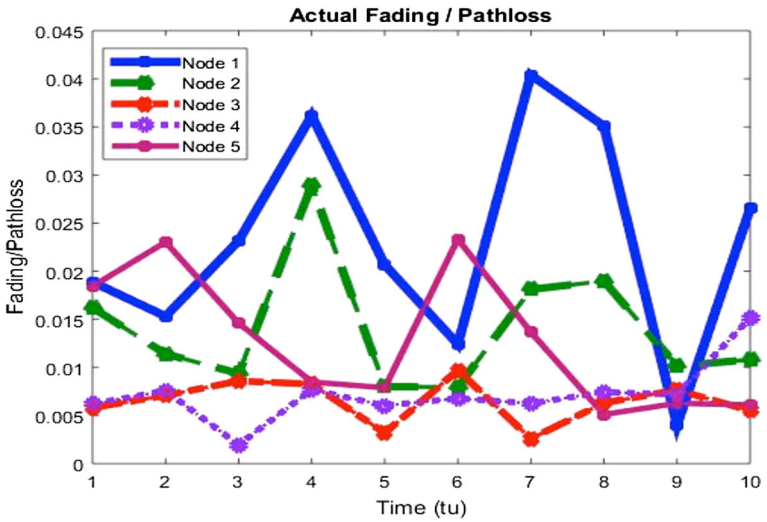

Fig. 5 Path loss and fading effect estimation in sensor network

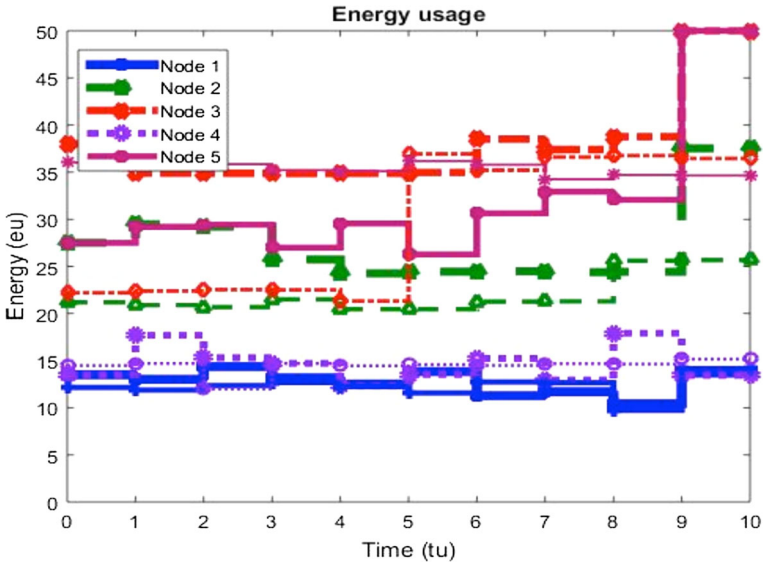

Fig. 6 Energy usage statistics for harvesting nodes

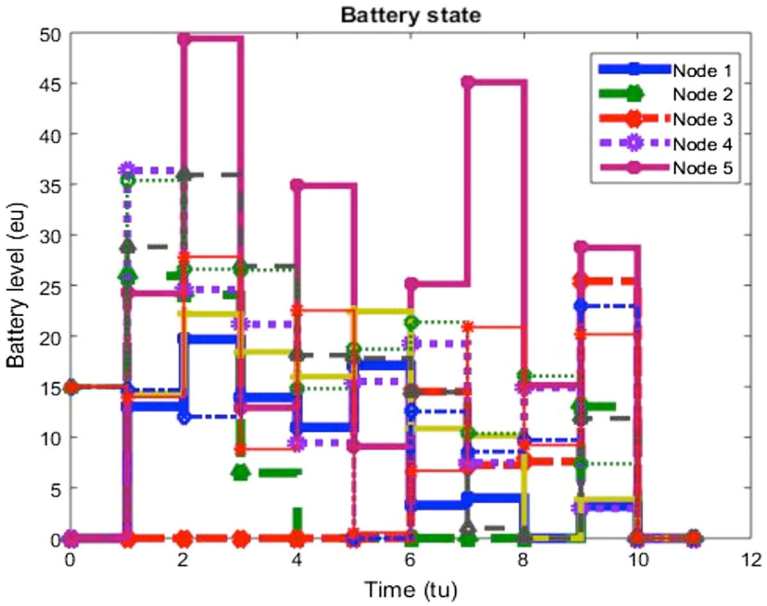

Fig. 7 Battery usage statistics for harvesting nodes

Figures 6 and 7 explains the energy usage of the energy harvesting nodes. From the observation it is clearly shown that the nodes harvesting the energy is also subjective to performance degradation due to some form factors like node replication, node path reordering etc.

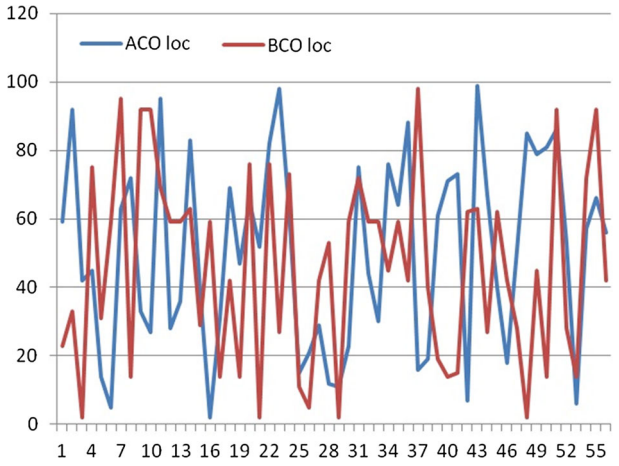

Fig. 8 ACO versus BCO performance results for localization of harvesting nodes

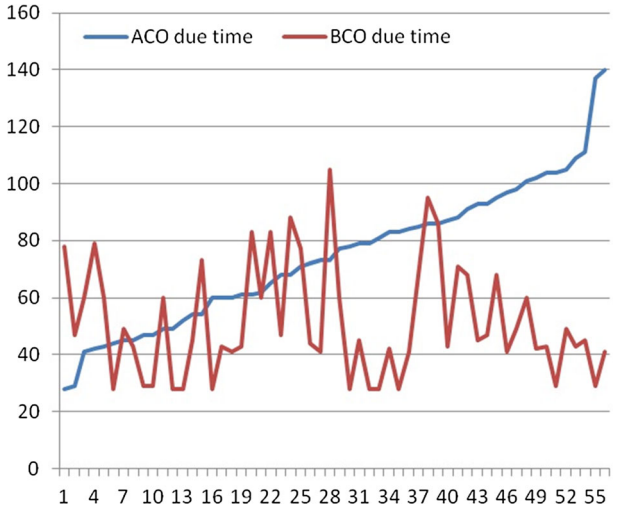

Fig. 9 ACO versus BCO performance results for network due time of harvesting nodes

Figures 8, 9 and 10 represents the performance analysis plot for various parameters such as node localization rate, network due time and dropped packet count etc. From the observation, both the protocol works similar for most of the cases.

4 Results

Energy harvesting routing method is used for efficient energy in WSN. Here traditional Ant and Bee colony algorithm is applied and performance measure was estimated. In this, analysis of result from this method, performance of the nodes is degradation due to issues like node replication, node path reordering.

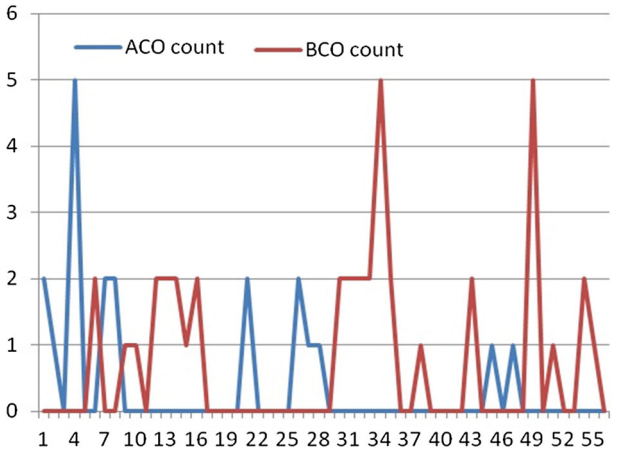

Fig. 10 ACO versus BCO performance results for packet loss count of harvesting nodes

At the same time performance of analysis are measured parameters like node localization rate, network due time, dropped packet count etc.

At the end of the performance analysis of the result, Ant colony algorithm and Bee Colony algorithm are similar in the performance for all the parameters in Tables 1, 2 and 3.

5 Conclusion

Finally this paper is concluded by proposing a robust Energy harvesting based efficient routing scheme for Wireless Sensor Network. Here the proposed routing scheme is optimal for well configure homogeneous network. The experimentation and performance analysis carried out over the proposed routing scheme gives the promising results and the accuracy of the proposed scheme is better and quantified in nature. The proposed routing scheme works well during path loss effects and capable to reorder the harvesting node which reveals the novelty and robustness of the proposed scheme. In future, the work can be extended along with overhead reduction and fault handling procedures.

Table 1 Localization of harvesting nodes

LACO		BCO	
Minutes	Nodes	Minutes	Nodes
1	55	1	22
4	42	4	20
7	20	7	18
40	22	40	60
55	42	55	42
57	41	57	41

Table 2 Network due time of harvesting nodes

NACO		BCO	
Minutes	Nodes	Minutes	Nodes
1	22	1	22
4	40	4	32
7	20	7	29
40	42	40	41
55	38	55	40
57	39	57	40

Table 3 Packet loss count of harvesting nodes

PACO		BCO	
Minutes	Nodes	Minutes	Nodes
1	2	1	0
4	0	4	0
7	0	7	0
40	0	40	1
55	2	55	2
57	2	57	2

References

1. Divya, P. & Shivkumar, S. (2016). Comparison of GSTEB, HEED and PEGASIS protocols. In *2016 International conference on wireless communications, signal processing and networking (WiSPNET), Chennai* (pp. 1935–1939).
2. Altinel, D., & Karabulut Kurt, G. (2016). Energy harvesting from multiple RF sources in wireless fading channels. *IEEE Transactions on Vehicular Technology, 65*(11), 8854–8864.
3. Kalantarian, H., & Sarrafzadeh, M. (2016). Pedometers without batteries: An energy harvesting shoe. *IEEE Sensors Journal, 16*(23), 8314–8321.
4. Angurala, M., & Bharti. (2016). A comparative study between leach and pegasis—A review. In *2016 3rd international conference on computing for sustainable global development (INDIACom), New Delhi* (pp. 3271–3274).
5. Khizar, M., et al. (2016) Enhanced energy efficient depth based routing protocol for underwater WSNs. In *2016 10th international conference on innovative mobile and internet services in ubiquitous computing (IMIS), Fukuoka, Japan* (pp. 70–77).
6. More, P. R., & Sankpal, S. V. (2016). Energy aware routing using energy efficient routing protocol in wireless Ad hoc network. In *2016 International conference on electrical, electronics, and optimization techniques (ICEEOT), Chennai* (pp. 1258–1261).
7. Nguyen, H. S., Bui, A. H., Do, D. T., & Voznak, M. (2016). Imperfect channel state information of AF and DF energy harvesting cooperative networks. *China Communications, 13*(10), 11–19.
8. Handa, P., Singh Sohi, B. & Kumar, N. (2016). Energy efficient hybrid routing protocol for underwater acoustic sensor network. In *2016 International conference on electrical, electronics, and optimization techniques (ICEEOT), Chennai* (pp. 2573–2578).
9. Warrier, M. M. & Kumar, A. (2016). Energy efficient routing in wireless sensor networks: A survey. In *2016 International conference on wireless communications, signal processing and networking (WiSPNET), Chennai* (pp. 1987–1992).
10. Hou, L., & Tan, S. (2016). A preliminary study of thermal energy harvesting for industrial wireless sensor networks. In *2016 10th international conference on sensing technology (ICST), Nanjing* (pp. 1–5).

11. Selvarathinam, J., & Anpalagan, A. (2016). Energy harvesting from the human body for biomedical applications. *IEEE Potentials, 35*(6), 6–12.
12. Gündüz, D., & Devillers, B. (2011). Two-hop communication with energy harvesting. In *2011 4th IEEE international workshop on computational advances in multi-sensor adaptive processing (CAMSAP), San Juan* (pp. 201–204).
13. Mantri, D. S., Prasad, N. R., & Prasad, R. (2017). Random mobility and heterogeneity-aware hybrid synchronization for wireless sensor network. *Wireless Personal Communications*, *100*(2), 1–16.
14. Kulkarni, N., Prasad, N. R., & Prasad, R. (2017). A novel sensor node deployment using low discrepancy sequences for WSN. *Wireless Personal Communications*, *100*(2), 1–14.
15. Kulkarni, N., Prasad, N. R., & Prasad, R. (2017). Q-MOHRA: QoS assured multi-objective hybrid routing algorithm for heterogeneous WSN. *Wireless Personal Communications*, *100*(2), 1–12.
16. Pawar, P. M., Nielsen, R. H., Prasad, N. R., & Prasad, R. (2017). GHMAC: Green and hybrid medium access control for wireless sensor networks. *Wireless Personal Communications, 94*(3), 1839–1868.
17. Zhou, H., Jiang, T., Gong, C., & Zhou, Y. (2016). Optimal estimation in wireless sensor networks with energy harvesting. *IEEE Transactions on Vehicular Technology, 65*(11), 9386–9396.
18. Sasikumar, P., & Khara, S. (2012). K-means clustering in wireless sensor networks. In *2012 Fourth international conference on computational intelligence and communication networks, Mathura* (pp. 140–144).
19. Mahima, V., & Chitra, A. (2017). Battery recovery based lifetime enhancement (BRLE) algorithm for wireless sensor network. *Wireless Personal Communications., 97*(4), 6541–6557.
20. Nageswari, D., Maheswar, R., & Kanagachidambaresan, G. R. (2018). Performance analysis of cluster based homogeneous sensor network using energy efficient N-policy (EENP) model. *Cluster Computing*. https://doi.org/10.1007/s10586-017-1603-z.
21. Jayarajan, P., MaheswarG, R., & Kanagachidambaresan, R. (2017). Modified energy minimization scheme using queue threshold based on priority queueing model. *Cluster Computing*. https://doi.org/10.1007/s10586-017-1564-2.
22. Kanagachidambaresan, G. R., & Chitra, A. (2016). TA-FSFT thermal aware fail safe fault tolerant algorithm for wireless body sensor network. *Wireless Personal Communications, 90*(4), 1935–1950.
23. Kanagachidambaresan, G. R., SarmaDhulipala, V. R., Vanusha, D., & Udhaya, M. S. (2011). Matlab based modeling of body sensor network using ZigBee protocol. In *CIIT 2011, CCIS 250* (pp. 773–776).
24. Kanagachidambaresan, G. R., & Chitra, A. (2015). Fail safe fault tolerant mechanism for wireless body sensor network (WBSN). *Wireless Personal Communications: An International Journal, 80*(1), 247–260. https://doi.org/10.1007/s11277-014-2006-6.
25. SarmaDhulipala, V. R., Kanagachidambaresan, G. R., & Chandrasekaran, R. M. (2012). Lack of power avoidance: A fault classification based fault tolerant framework solution for lifetime enhancement and reliable communication in wireless sensor network. *Information Technology Journal, 11*(6), 719.
26. Kanagachidambaresan, G. R., Sarma Dhulipalab, V. R., & Udhaya, M. S. (2011). Markovian model based trustworthy architecture. In *Procedia Engineering*, Elseiver, ICCTSD.
27. Lu, Y., Comsa, I. S., Kuonen, P., & Hirsbrunner, B. (2015). Probabilistic data aggregation protocol based on ACO-GA hybrid approach in wireless sensor networks. In *2015 8th IFIP wireless and mobile networking conference (WMNC), Munich* (pp. 235–238).
28. Xue, L. (2015). Data aggregation protocols for wireless sensor networks based on ACO. In *2015 International conference on intelligent transportation, big data and smart city, Halong Bay* (pp. 254–257).

R. Srinivasan Associate Professor of Veltech Rangarajan Dr Sagunthala R&D Institute of Science and Technology, Avadi, Chennai. He completed his Masters in Computer Science and Engineering in the year 2006. Completed his bachelor in computer science and engineering in 2002. His area of research includes energy managment in Wireless Networks.

E. Kannan Registrar of Veltech Rangarajan Dr Sagunthala R&D Institute of Science and Technology, Avadi, Chennai. He obtained his Ph.D. from NIT, Trichy in the year 2006. His research interest spans across computer networking and parallel computing. Much of his work has been on improvising the understanding, design and the performance of parallel and networked computer systems, mainly through the application of data mining, statistics and performance evaluation. He has published many journals in both international journals and conferences. He began his career in 1991 and has held various responsible positions in reputed institutions. He is also a member in many professional's society and a senior member in IEEE. He published 30 reputed journals.