FACTA UNIVERSITATIS
Series: **Electronics and Energetics** Vol. 31, N^o 2, June 2018, pp. 267 - 277
https://doi.org/10.2298/FUEE1802267B

IMPROVING NETWORK LIFETIME BY MINIMIZING ENERGY HOLE PROBLEM IN WSN FOR THE APPLICATION OF IoT

Trupti M. Behera, Sushanta K. Mohapatra

School of Electronics Engineering, KIIT University, Bhubaneswar, Odisha, India

Abstract. *The world today is at the Internet of Things (IoT) inflection point with more number of products adding to its intelligence system through a wide range of connectivity. Wireless sensor Networks (WSN) have been very useful in IoT application for gathering and processing of data to the end user. However, limited battery power and network lifetime are few of the major challenges in the designing process of any sensor network. One of those is the Energy Hole Problem (EHP) that arises when the nodes nearer to the sink or base station die out early due to excess load as compared to other nodes that are far away. This breaks the connection of the network from the sink which results in shortening the lifetime of the network. In this paper, a trade-off is maintained between network lifetime and power requirement by implementing a sleep-awake mechanism.With the help of MATLAB simulations, it is found that after applying the mechanism, the network lifetime was extended to almost 300 and 700 rounds for TEEN and LEACH protocol respectively. The results will be beneficial for the design process in WSN for IoT application.*

Key words: *IoT, WSN, Energy Hole Problem, Power consumption, Network lifetime.*

1. INTRODUCTION

The Internet of Things (IoT) is an integration of the existing and evolving Internet with future network developments, such as self-configuring capabilities and enhanced network lifetime with proper power management. The IoT cloud creates an intelligent network that can be sensed, controlled and programmed [1].

The basic elements of the future internet designed as IoT include three major components which enable seamless communication [2]. The first is the hardware which is made up of sensors, actuators and embedded communication hardware like Radio Frequency Identification (RFID), Wireless Sensor Network (WSN), etc. The second is a middleware which performs on-demand storage and computing tools for data analytics. And the last is a presentation of novel and easy to understand visualization and interpretation tools which can be widely accessed on different platforms and which can be designed for different applications [2].

Received May 25, 2017; received in revised form October 23, 2017
Corresponding author: Trupti M. Behera
School of Electronics Engineering, KIIT University, Bhubaneswar, Odisha, India
(E-mail: truptifet@kiit.ac.in)

The emerging IoT has a diversified application scenario equipped with a wide range of heterogeneous devices. As shown in Fig 1, WSN acts as a gateway to the IoT. WSN also has a wide range of applications in various working domains and is also well suited for long-term data acquisition, hence WSN will be the best sensor interfacing device in the IoT environment [3][4].

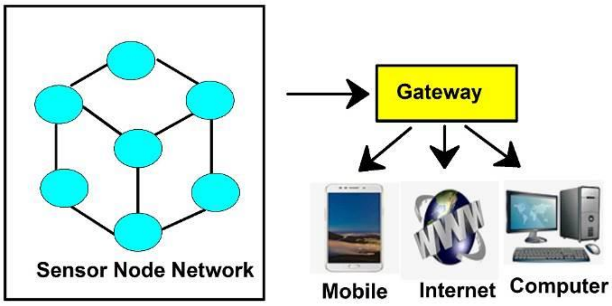


Fig. 1 WSN as a gateway for IoT

One of the major design criteria of WSN is communication of data in an IoT environment while trying to prolong the network lifetime. The design procedure should also prevent any connectivity degradation by employing efficient power management techniques. Further, the placement of the sink or the base station also plays a vital role in the process of power consumption as it is responsible to collect all the sensed data from the sensor nodes and process the information to the end user. The sink node is equipped with one or more receiving antenna and unlimited energy to carry out the communication process effectively. In a WSN, all the nodes are randomly deployed, but nodes nearer to the sink area consume more energy than those away from the sink (as they have a greater load). Hence these nodes die quickly creating a vacuum of energy called Energy Hole Problem (EHP)[5] around the sink. Under this scenario, the data transmission to the sink will be lost completely leading to an end of network lifetime[6]. As a result, optimizing the power consumption with enhancing the network lifetime becomes one of the most challenging tasks for researchers.

2. Related Work

Till date, a number of schemes have already been proposed to achieve the desired performance in terms of better power efficiency, network lifetime, throughput, etc. In [7], we have discussed a heterogeneous WSN where some of the nodes (called advanced nodes) are assigned more energy as compared to other nodes. With the simulation result we have shown that when all the normal nodes are dead, the network still continues transmission as the advances nodes are alive to transmit data from the sink, thus enhancing the network lifetime. An analytical modeling is proposed in [8] in order to reduce the EHP by analyzing the effectiveness of several existing approaches including traffic compression, deployment assistance, and aggregation.

In [9], the authors have prepared a model based on a calculation of Voronoi Polygon of each node to detect any energy hole in the network. Based on this, the node then moves to a better position to provide maximum coverage. They have also discussed optimizing the network lifetime and data collection simultaneously by adopting a rate allocation algorithm for data aggregation. A non-uniform node distribution strategy is proposed in [10], where the authors propose that if the number of nodes increases with geometric proportion from the outer parts of the network to the inner ones, then the energy wastage can be reduced to almost 10%.

In [11], the author proposed that instead of a single sink in a particular field, multiple sinks can be deployed. Each sink will be surrounded by normal nodes, thus dividing the network load to avoid the energy hole. This decision depends on the amount of data load in the network. A data gathering scheme is proposed in [12], where the network employs an optimum and fixed cluster radius intending to improve the network lifetime by avoiding the energy hole problem.

In [13], a new scheme WEMER is proposed that divides the whole network in too many small equiangular wedges that help in reducing energy hole formation. The authors in [14], proposed a non-uniform node distribution strategy to achieve nearly balanced energy depletion in the network with a distributed shortest path routing algorithm in order to reduce the energy hole problem.

A sensor network designed for IoT application need to perform various operations, such as sensing of data, aggregating and transferring the data to the end-user. To perform such operations with limited power becomes one of the major challenges in the design process. Hence, we need to maximize the network lifetime by conserving energy during the transmission phase. This is made possible if only a small percentage of nodes are allowed to transmit the data to Base station and the rest of the node becomes inactive and go to sleep condition.

3. Sleep-Awake Mechanism

From the above literature, it is clear that due to EHP, the network dies earlier [15] than its expected lifetime. The main reason behind EHP is that a large amount of data is given to the sink by nearby nodes as compared the nodes far away. In [16], the authors stated that due to the EHP, the network lifetime gets over even when 90% of the energy is left unused. Thus, avoiding EHP becomes an important research area nowadays.

We use the first-order radio model for energy consumption as used in [16] and shown in Fig. 2, where nodes are randomly deployed with equal energy level. The sink is centrally positioned with unlimited energy.

For each round, the sink has to search for the node with maximum distance in the region. It will then formulate the energy required to transmit the data to the sink. Let this energy be Reference energy (E_{Ref}). Only when the energy level of a particular node becomes greater than or equal to E_{Ref}, does it have the permission to transmit any data to the sink or else it is not allowed to transmit. When the energy level of any node [15] becomes less than E_{Ref}, it goes to sleep mode to save energy. This process continues for each round until the percentage of sleep nodes exceeds $1/10^{th}$ of the total nodes in the region. When the number of sleep nodes exceeds 10%, then the node which first went to

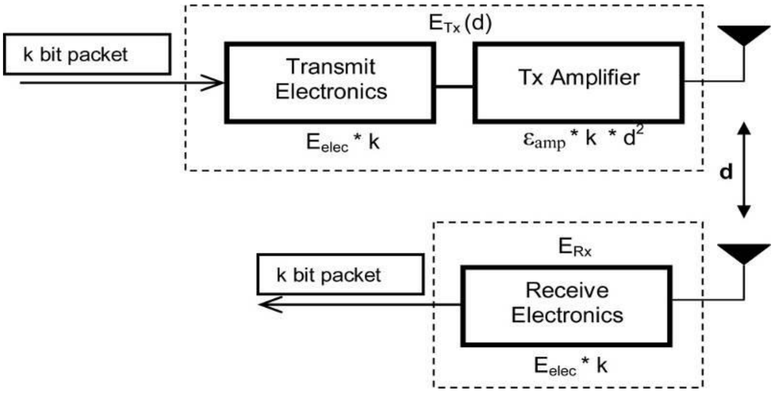


Fig. 2 First-order Radio Model

sleep mode moves to the awake mode. In consecutive rounds, when percentage again exceeds 10%, the nodes which went to sleep in the second position moves to the awake mode, and the mechanism continues. In such scenario, some $1/10^{th}$ of the total node will always remain in sleep position to save energy for extending network lifetime.

To calculate the Reference energy, we use the following formula as in [15],

$$E_{Ref} = ((E_{Tx} + E_{DA)} * D) + (E_{amp} * D * d^4) \quad (1)$$

Where
E_{Ref} is Reference energy
D is the length of the data packet
d is the distance between maximum distance node and sink
E_{Tx} is energy required for data transmission
E_{DA} is energy required for data aggregation
E_{amp} is energy required by power amplifier.

The next step will be Cluster head selection by nodes based on predefined probability [6]. Only after the Cluster heads broadcast their status, the nodes will be able to get associated with the cluster heads, thus consuming minimal energy while transmitting data. After formulation of clusters, each Cluster head creates a Time Division Multiple Access (TDMA) schedule for the nodes within the cluster. The TDMA slots are assigned by the sink to each node. Nodes can transmit their data to Cluster head only during their respective time slots. Once the Cluster head collects all the data, it performs data aggregation and transmits the data to the base station.

The energy consumption to transmit data from a node N to the Cluster head CH for the condition $d < d_0$ (reference distance) can be given as

$$E_N^{CH} = D_N^{CH}(E_{ele}) + D_N^{CH}(E_{fs})(d^2) \quad (2)$$

Where

$$d_0 = \frac{4\prod h_t h_r}{\lambda}$$

h_t and h_r are the height of transmitting and receiving antenna respectively.

Now considering the scenario where the distance between N to CH is $d > d_0$, the energy can be given as in [15]

$$E_N^{CH} = D_N^{CH}(E_{ele}) + D_N^{CH}(E_{amp})(d^4) \tag{3}$$

Energy consumed by CH to transmit data to the S when distance between them is $d < d_0$ is given as in [15]

$$E_{CH}^S = D_{CH}^S(E_{ele}) + E_{DA} + D_{CH}^S(E_{fs})(d^2) \tag{4}$$

When the distance between *CH* and *S*(sink) is $d > d_0$, the energy consumption can be written as in [15]

$$E_{CH}^S = D_{CH}^S(E_{ele}) + E_{DA} + D_{CH}^S(E_{amp})(d^4) \tag{5}$$

The total energy consumed in transmitting data from a particular node to sink will be the sum of both the energies in equation (2), (3) and (4), (5), i.e.

$$E_{TotalCH} = E_{CH} + E_N \tag{6}$$

The average of total energy can be found by

$$E_{Average\_CH} = \frac{E_{TotalCH}}{N} \tag{7}$$

Energy saving due to sleeping of normal nodes in each round

$$E_{Save\_N} = E_{ele} + E_{Tx} + E_{amp} \tag{8}$$

Where E_{ele} is radio energy dissipation
Energy saving for *CH* is

$$E_{Save\_CH} = E_{ele} + E_{DA} + E_{Tx} + E_{Rx} + E_{amp} \tag{9}$$

Energy saving for all sleep nodes can be written as

$$E_{Save\_Total} = \sum_{i=0}^{n} E_i \tag{10}$$

Where *n* is the total number of nodes that are in sleep mode, then the average energy saving can be written as

$$E_{Save\_Avg} = \frac{E_{Save\_Total}}{n} \tag{11}$$

4. SIMULATIONS AND RESULT

We have considered a sensor network where 100 nodes are deployed randomly. The sink is located at the center with unlimited energy. The normal sensor nodes have limited energy. For each round, some of the sensor nodes transmit data, while others are set to sleep mode to save energy. We implement this mechanism in some of the cluster-based protocols such as LEACH [17] [18], DEEC [19] and TEEN [20]. LEACH is a homogenous protocol, whereas DEEC and TEEN are heterogeneous protocols. However, the work can also be extended to other hierarchical routing protocols such as PEGASIS, EAMMH, and SEP. To generate MATLAB simulation, we consider these parameters as listed below.

Table 1 Parameters for Simulation

Symbol	Description	Value
X_m	Distance at X-axes	100 meters
Y_m	Distance at Y-axes	100 meters
N	Total number of nodes	100 nodes
E_0	Total energy of network	0.5J
P	Probability of cluster head	0.1
E_{Rx}	Energy dissipation: receiving	0.0013/pJ/bit/m^4
E_{fs}	Energy dissipation: free space model	10/pJ/bit/m^2
E_{amp}	Energy dissipation: power amplifier	100/pJ/bit/m^2
E_{ele}	Energy dissipation: electronics	50/nj/bit
E_{Tx}	Energy dissipation: transmission	50/nJ/bit
E_{DA}	Energy dissipation: aggregation	5/nJ/bit
d_0	Reference distance	87 meters
n	Number of sleep nodes	10 nodes

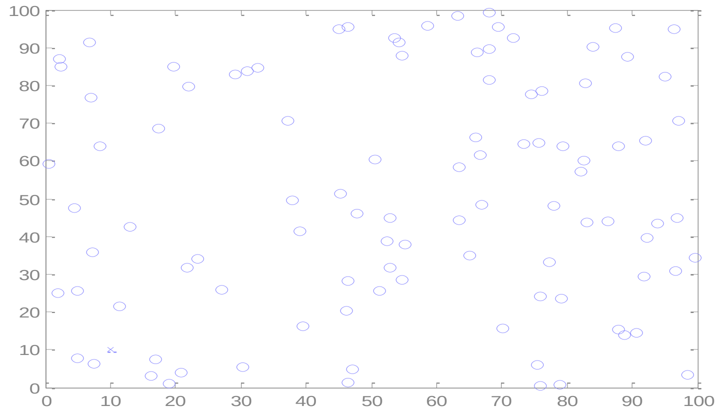
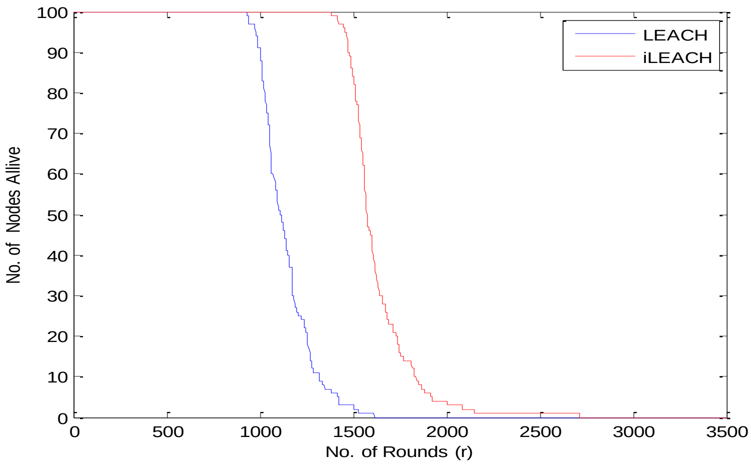
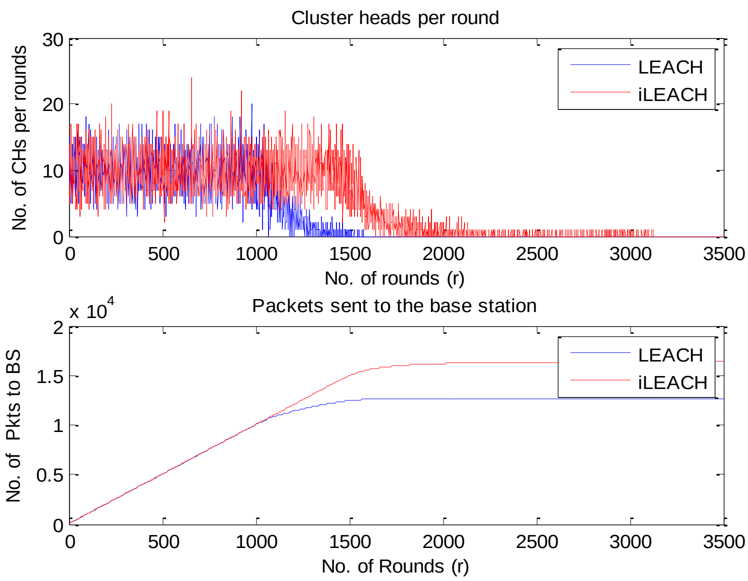


Fig. 3 Deployment of 100 sensor nodes randomly

LEACH is a homogenous protocol where all the sensor nodes are initially assigned the same energy level. According to our concept, the nodes that have the energy level less than the threshold are in the sleep mode. Following this method, we will be able to save the total energy of the network. Figure 4 shows the comparison of the above technique iLEACH (sleep-awake mechanism) with LEACH regarding the number of alive nodes, the number of dead nodes, the number of CHs per round and number of packets sends to BS. The above figure shows that in LEACH the last node alive around 1500 rounds and in iLEACH the last node is alive till 2200 rounds. This result shows that in the iLEACH utilization of energy is properly distributed among all the nodes in the networks, which results in increasing network lifetime.



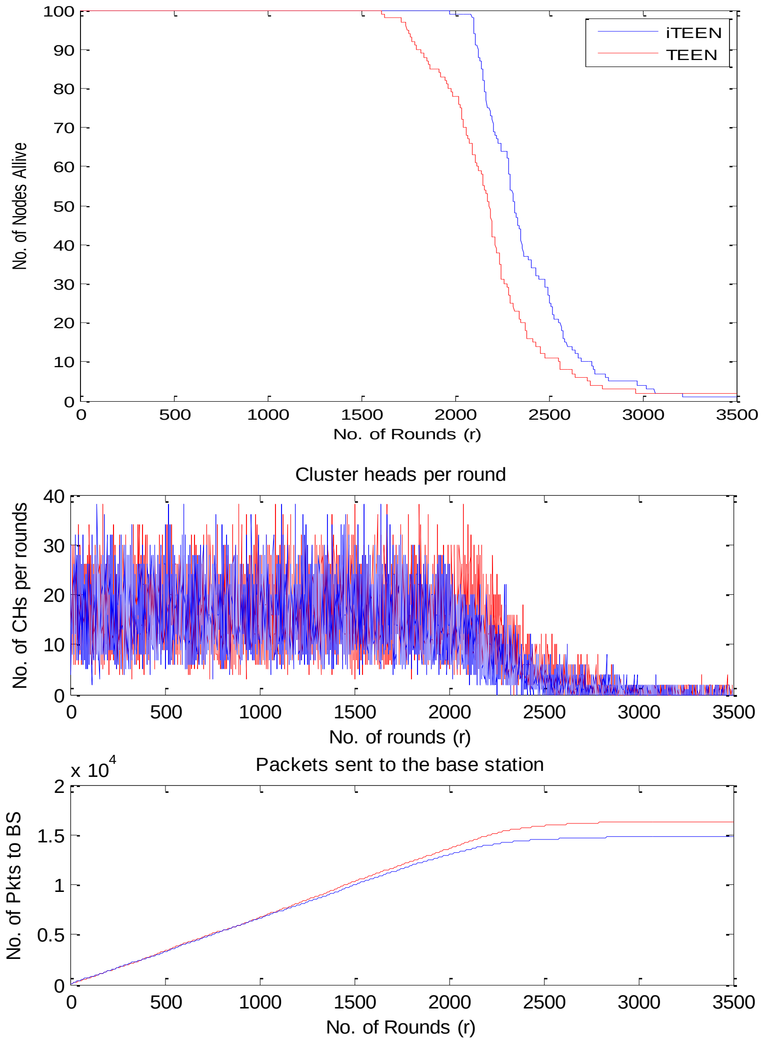
(a)



(b)

Fig. 4 Comparing the performance of LEACH and iLEACH:
(a) Number of alive nodes during rounds, (b) Number of data packets per rounds

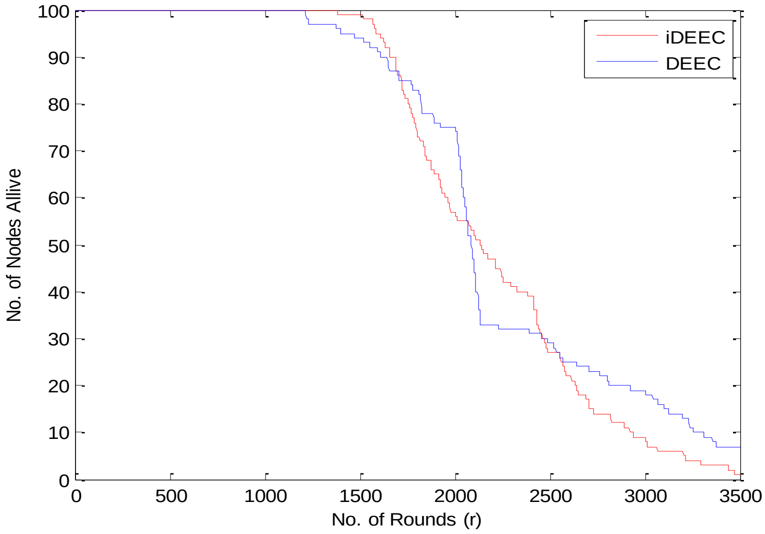
Hence, iLEACH has a prolonged stability period, and also the instability region starts much later as compared to LEACH. In LEACH, a random number of CHs is selected in every round, but iLEACH had some patterns and controlled CHs selection. In iLEACH efficient CHs selection algorithm helps it in better and constant data rate transmission to BS. With sleep-awake policy, iLEACH successfully delivers data to the Base station in a much better way than LEACH as the number of data packets sends much higher than LEACH to achieve higher data rate with longer network lifetime.



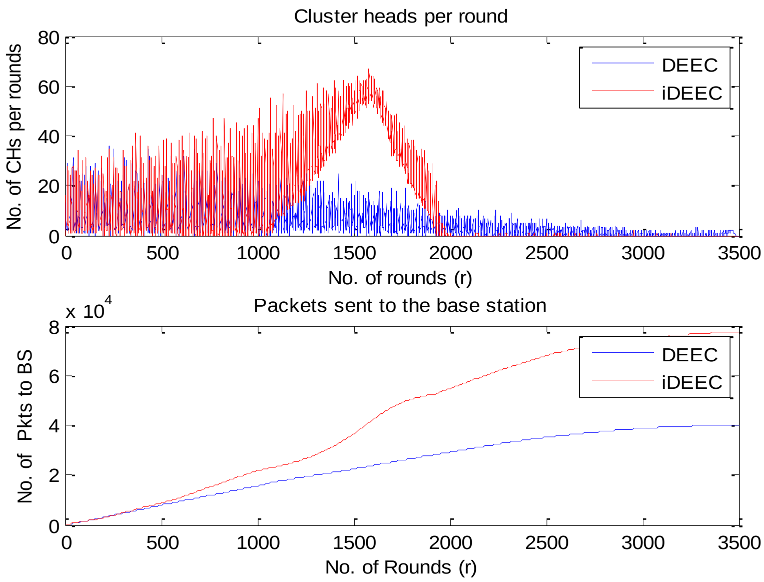
(a)

(b)

Fig. 5 Comparing the performance of TEEN and iTEEN: (a) Number of alive nodes during rounds, (b) Number of data packets per rounds(red-iTEEN and blue-TEEN)



(a)



(b)

Fig. 6 Comparing the performance of DEEC and iDEEC:
(a) Number of alive nodes during rounds, (b) Number of data packets per rounds

Figure 5 and 6 show the comparison of two existing heterogeneous protocols, i.e., TEEN and DEEC with the sleep-awake mechanism iTEEN and iDEEC respectively. The simulation result clearly shows that iTEEN and iDEEC outperform regarding the number of alive nodes, the number of CHs per round and number of packets sent to BS. For TEEN protocol, the nodes start to die out after 1600 rounds, wherein iTEEN goes till around 1900 rounds. In a similar manner, the data packets sent to the base station also increase for both protocols.

Rasheedl et al. in [6] did a similar experiment called EHORM to compare the number of alive nodes for protocols, such as LEACH, DEEC, TEEN, and SEP. Our approach, however, gives better results with more valid comparisons by taking different parameters into consideration. For LEACH protocol, the number of alive nodes extend to 2750 rounds as compared to almost only 1700 rounds using EHORM technique in [6]. Similarly, for TEEN and DEEC protocol it extends beyond 3500 rounds, wherein EHORM the nodes becomes dead by 3200 and 3000 rounds respectively. Hence, we can say that the network lifetime is enhanced after the implementation of our proposed mechanism for both heterogeneous and homogenous protocols.

5. CONCLUSION

In this article, we discussed an important issue in Wireless Sensor Network for the application in IoT which is Energy Hole Problem. EHP is created since the nodes near the sink consume more energy, and as a result, die quickly, which in turn shortens the network lifetime. EHP in both heterogeneous and homogeneous routing protocols is studied. The sleep–awake mechanism was implemented in LEACH, DEEC and TEEN protocols to study the behavior of the network under the different scenarios in order to remove any energy hole problem within the network. From the simulation result, it was found that less energy is consumed and nodes live longer in iLEACH, iTEEN and iDEEC, as compared to LEACH, TEEN, and DEEC respectively. This clearly indicates that the sensor network lifetime will be enhanced or increased after implementation of the sleep-awake mechanism. Simulation result also shows a better stability period and increased data packets sent to the sink in the network. This technique of enhancing the network lifetime while also optimizing energy consumption can be implemented in IoT to achieve better performance. To extend the work in future direction, performance analysis of IoT based applications can be done for other routing protocols such as PEGASIS, EAMMH, SEP, etc.

REFERENCES

[1] J. Chase, “The evolution of the internet of things,” *Texas Instruments*, 2013.

[2] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, “Internet of Things (IoT): A vision, architectural elements, and future directions,” *Futur. Gener. Comput. Syst.*, vol. 29, no. 7, pp. 1645–1660, 2013.

[3] P. Bellavista, G. Cardone, A. Corradi, and L. Foschini, “Convergence of MANET and WSN in IoT urban scenarios,” *IEEE Sens. J.*, vol. 13, no. 10, pp. 3558–3567, 2013.

[4] M. T. Lazarescu, “Design of a WSN platform for long-term environmental monitoring for IoT applications,” *IEEE J. Emerg. Sel. Top. Circuits Syst.*, vol. 3, no. 1, pp. 45–54, 2013.

[5] J. Jia, X. Wu, J. Chen, and X. Wang, “Exploiting sensor redistribution for eliminating the energy hole problem in mobile sensor networks,” *EURASIP J. Wirel. Commun. Netw.*, vol. 2012, no. 1, p. 68, 2012.

[6] M. B. Rasheedl, N. Javaid, A. Javaid, M. A. Khan, S. H. Bouk, and Z. A. Khan, “Improving Network Efficiency by Removing Energy Holes in WSNs,” *arXiv Prepr. arXiv1303.5365*, 2013.

[7] T. M. Behera and S. S. Singh, “A Novel Energy Efficient Network Management Scheme of Heterogeneous WSN with MIMO Techniques,” *Int. J. Comput. Appl.*, vol. 93, no. 7, 2014.

[8] J. Li and P. Mohapatra, “Analytical modeling and mitigation techniques for the energy hole problem in sensor networks,” *Pervasive Mob. Comput.*, vol. 3, no. 3, pp. 233–254, 2007.

[9] X. Tang and J. Xu, “Optimizing lifetime for continuous data aggregation with precision guarantees in wireless sensor networks,” *IEEE/ACM Trans. Netw.*, vol. 16, no. 4, pp. 904–917, 2008.

[10] X. Wu, G. Chen, and S. K. Das, "On the energy hole problem of nonuniform node distribution in wireless sensor networks," in Proceedings of the IEEE International Conference on Mobile Adhoc and Sensor Systems (MASS), 2006, pp. 180–187.

[11] M. Ahadi and A. M. Bidgoli, "A multiple-sink model for decreasing the energy hole problem in large-scale wireless sensor networks," *Int. J. Comput. Theory Eng.*, vol. 4, no. 5, p. 843, 2012.

[12] A.-F. Liu, X.-Y. Wu, Z.-G. Chen, and W.-H. Gui, "Research on the energy hole problem based on unequal cluster-radius for wireless sensor networks," *Comput. Commun.*, vol. 33, no. 3, pp. 302–321, 2010.

[13] N. Sharmin, M. S. Alam, and S. S. Moni, "WEMER: An energy hole mitigation scheme in Wireless Sensor Networks," in Proceedings of the 2016 IEEE International WIE Conference on Electrical and Computer Engineering (WIECON-ECE), 2016, pp. 229–232.

[14] X. Wu, G. Chen, and S. K. Das, "Avoiding energy holes in wireless sensor networks with nonuniform node distribution," *IEEE Trans. parallel Distrib. Syst.*, vol. 19, no. 5, pp. 710–720, 2008.

[15] M. B. Rasheed, N. Javaid, Z. A. Khan, U. Qasim, and M. Ishfaq, "E-HORM: An energy-efficient hole removing mechanism in Wireless Sensor Networks," in Proceedings of the 26th Annual IEEE Canadian Conference on Electrical and Computer Engineering (CCECE), 2013, pp. 1–4.

[16] J. Li and P. Mohapatra, "An analytical model for the energy hole problem in many-to-one sensor networks," in Proceedings of the IEEE vehicular technology conference, 2005, vol. 62, no. 4, p. 2721.

[17] S. K. Singh, P. Kumar, and J. P. Singh, "A Survey on Successors of LEACH Protocol," *IEEE Access*, vol. 5, pp. 4298–4328, 2017.

[18] L. Yadav and C. Sunitha, "Low Energy Adaptive Clustering Hierarchy in Wireless Sensor Network (LEACH)," *Int. J. Comput. Sci. Inf. Technol.*, vol. 5, no. 3, pp. 4661–4664, 2014.

[19] L. Qing, Q. Zhu, and M. Wang, "Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks," *Comput. Commun.*, vol. 29, no. 12, pp. 2230–2237, 2006.

[20] A. Manjeshwar and D. P. Agrawal, "TEEN: A Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks.," in *ipdps*, 2001, vol. 1, p. 189.