Gaussian Functional Shapes-Based Type-II Fuzzy Membership-Based Cluster Protocol for Energy Harvesting IoT Networks

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***Abstract*:**With the advancements in Internet of Things (IoT) technologies, energy harvesting IoT devices are becoming significantly important. These tiny IoT devices can harvest bounded energy, thus need an efficient protocol to conserve the energy in more efficient manner. From the review, it is found that the development of an efficient energy efficient protocol for energy harvesting IoT is still an open area of research. It is found that fuzzy based energy harvesting IoTs has shown significant improvement over the existing protocols. However, the fuzzy logic suffers from the data uncertainty issue. Therefore, in this paper, Gaussian functional shapes-based type-II fuzzy membership function is used to elect the cluster heads among the IoT devices to reduce the energy consumption of energy harvest IoTs. Thereafter, inter-cluster data aggregation is used. Finally, the communication between the elected cluster heads and the cloud servers or sink. Extensive experiments are drawn by considering the existing and the proposed protocolsfor energy harvesting IoTs. Comparative analysis reveals that the proposed type-II fuzzy membership function-based protocol outperforms the existing protocols in terms of bandwidth analysis, throughput, conserve energy, network lifetime, and average consumed energy.

***Keywords*:** Energy harvesting, Internet of things, Gaussian membership, Type-II fuzzy logic.

1. Introduction

With advancement in various artificial intelligence (AI) applications, the internet of things (IoT) networks are widely accepted to provide high availability of services to the users. The IoT makes people's lives simpler, easier and more comfortable; where tasks could be accomplished without the need for human cooperation and where activities could be carried out without a human being's need for cooperation. What makes the IoT stand out is that it helps people to be free from the place. [2]The energy harvesting tiny IoT devices are recently being utilized in various applications to improve the service experience of various users. Energy harvesting IoT devices ensure that nodes can be charged for high availability of IoT networks. The energy harvesting nodes can recharge via some source of energy such as electricity. Figure 1 shows the basic flow of the energy harvesting flow of IoT devices. It shows that there are multiple energy sources from where we can obtain the energy to recharge the energy harvesting IoT devices. From the energy sources, there might be a conversion circuit which converts the external energy to chargeable form. Finally, depending upon the remaining energy of IoT device, it can be recharged to its maximum threshold. The power management controls the maximum threshold limit to prevent the overcharging of IoT batteries.

Although, energy harvesting IoT devices can charged, but using these devices in energy efficient manner is desirable. Therefore, to utilize the IoT networks in energy efficient manner many protocols have been designed in the literature. Among the existing protocols, the clustering-based energy aware protocols are found to be more efficient to provide better lifetime of IoT networks.

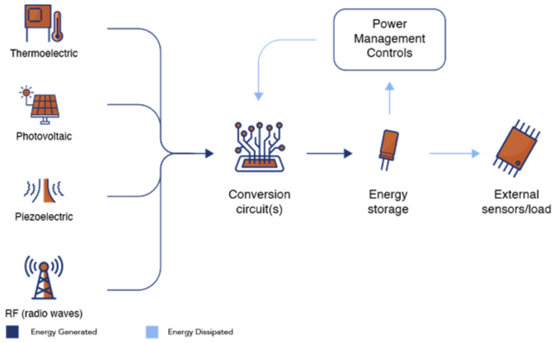

Figure 1. Energy harvesting flow of IoT devices

Figure 2 shows the basic clustering-based energy harvesting IoT networks. In cluster based IoT networks, initially, cluster heads are formed on the basis of specific threshold function. Thereafter, remaining IoT devices are associated to the nearest cluster head using Euclidean distance. Intra-cluster data aggregation is then utilized by the cluster heads to collect the data from its respective member IoT devices. Thereafter, inter-cluster data aggregation is then used to transmit the data to the base station (sink) or cloud server. Finally, users can utilize the collected information through application layer of IoT networks.

However, still there is a room of improvement in the clustering-based energy harvesting IoT networks. Therefore, in this paper, we will try to design a novel type-II fuzzy membership-based clustering protocol to elect the optimal number of cluster heads in IoT networks.

The main contributions of this paper are as: Gaussian functional shapes-based type-II fuzzy membership function is used to elect the cluster heads among the IoT devices to reduce the energy consumption of energy harvest IoTs. Comparative analysis reveals are also drawn among the existing and the proposed type-II fuzzy membership function-based protocols in terms of bandwidth analysis, throughput, conserve energy, network lifetime, and average consumed energy.

The remaining paper is organized as: Section 2 discusses the related work. Proposed methodology is presented in Section 3. Comparative analysis is presented in Section 4. Section 5 concludes the paper.

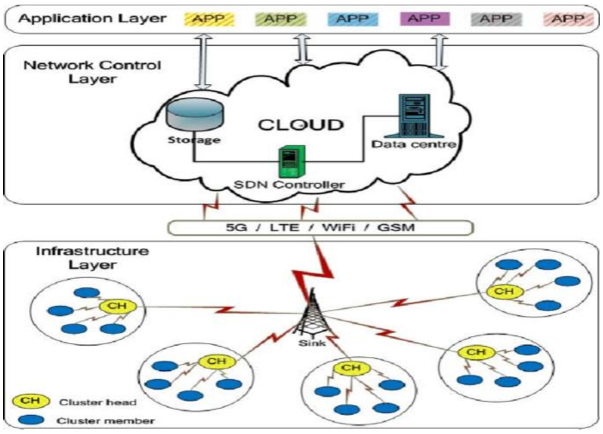

Figure 2. Cluster based energy harvesting IoT network

2. Related work

Ercanet al. (2018) designed a spectrum and energy aware IoT model. The spectrum was distributed with the cellular system to achieve efficient energy harvesting. Initially, clusters were formed, then these cluster heads utilize random scheduling and spectrum sensing of the energy harvesting devices [3].

Altineland Kurt (2019) designed a Gaussian mixture models to achieve the energy harvesting IoT devices. The generalized expression was utilized for both correlated and independent energy harvesting devices. The energy levels distributions can be computed by using the joint densities. Clustering was achieved by using an accurate probabilistic and single form to form the clusters [4].

Dong et al. (2016) proposed a clustering-based protocols for energy harvesting IoT networks. It has been shown that the cluster head IoT nodes suffer from energy shortages issues. An energy and distance-based cluster head selection was done to form the clusters. It has shown remarkable good energy reservation as compared to the competitive protocols [5].

Bahbahani and Alsusa (2018)designed a cooperative clustering protocol by using a low energy dynamic clustering (LEDC) to improve the energy conservation for energy harvesting IoT clusters. Cluster heads were dynamically computed to enhance the energy conservation of energy harvesting IoT networks [6].

Elmagidet al. (2019) has considered joint signal-to-interference-plus-noise and energy coverage to obtain better energy convergence. A realistic spatial model was used to compute the spatial coupling between IoT nodes and locations. Poisson cluster process and IoT gateways were utilized [7].

Ara et al.(2018) proposed energy-efficient secured cluster-based distributed fault diagnosis protocol for IoT in WSN by adopting concise cipher block to organize secured and trusted communication in IoT environment[16] .

Moraes and Har (2017)designed an energy harvesting IoT networks by using the distributed sensors nodes. IoT devices can be charged either by mobile charger or by charging undercharged devices by overcharged ones. Center based clustering was utilized to form the cluster heads [8].

Aslam et al. (2018) utilized cognitive radios and energy harvesting to enhance the energy conservation and spectral efficiency. Energy harvest IoT devices can access the spectrum efficiently and also IoT devices can be charged from ambient radio-frequency sources. Energy-aware mode switching was also used. Current and mean of past energy levels were used to form the cluster heads to enhance the network lifetime [9].

Baroudi (2017) proposed a wirelessly energy-charged protocols to conserve the energy of energy harvest IoT networks. Adaptive clustering was used to select the optimal number of cluster heads. Compared to the existing protocols the proposed model comes up with lesser overheads [10].

Han and Huang (2017) implemented a network architecture which provides D2D intercommunication between passive IoT devices by integrating wireless power transfer and backscatter communication. The standalone power beacons were utilized for wirelessly powering nodes by beaming unmodulated transporter signals to destination devices [11].

Song et al. (2019) implemented a cooperative multiple-input-multiple-output (CMIMO)approach to extend the lifetime of cluster heads in cluster-based capillary networks in IoT networks. However, this model consumes additional energy overhead to cooperative nodes and further minimizes the lifetime of these nodes [12].

Collotta et al. (2014) used Type-1 fuzzy logic system (TI-FUZZY) to enhance the energy efficiency of IoT devices. This paper proposes a fuzzy logic-based mechanism to determine the sleeping time of field devices in an environment based on Bluetooth Low Energy (BLE). The proposed Fuzzy Logic Controller (FLC) determines the sleeping time field devices according to the battery level and to the ratio of Throughput to Workload (Th/Wl). The simulation results show significant increase in lifetime of devices [13].

Kaur et al. (2015) implemented the Quality energy efficient (QEE) framework for IoT devices. This framework comprises of three layers such as sensing and control, information processing, and presentation. The sleep interval of sensors based upon its remaining battery level is predicted and is re-provisioning is done when the other sensory nodes are in sleep mode. This concept allows the energy-efficient utilization of all the IoT resources. The results show a significant amount of energy saving in the case of sensor nodes and improved resource utilization of cloud resources [14].

Toklu et al. (2014) studied the use of Base Station Controlled MAC (BSC-MAC) in the field of IoT to increase the energy efficiency. It is an adaptive approach which determines and manages a sleep schedule of nodes on the network based on the structures. It determines the nodes on the network as root and source nodes and manages a sleep schedule according to these structures. The simulation of the BSC-MAC protocol was performed with ns-2 and compared to similar protocols., such as adaptive energy efficient MAC (AEEMAC), pattern MAC (P-MAC), and sensor MAC (S-MAC)[15].

3. Proposed model

This section discusses the proposed type-II fuzzy system in which IOT devices are deployed randomly using cluster head selection that further shows significant improvement over the existing energy efficient techniques.

3.1 Type-II fuzzy logic

From the existing review, it has been found that the type-I fuzzy logic does not support uncertainty. It is unable to support the uncertainty related to the problem. Therefore, type-II fuzzy logic was introduced. The type-II fuzzy membership can be computed as:

$$\gamma(B) = \frac{1}{N}\sum_{G=0}^{l-1} k(G) * [\mu_w(G) - \mu_l(G)] \quad (1)$$

$$\mu_w(G) = [\mu_B(G)^{1\backslash\alpha}] \quad (2)$$

$$\mu_l(G) = [\mu_B(G)^{\alpha}] \quad (3$$

Here, $\alpha \in (0, 2]$ such that $\mu_w(G)$defines upper bound fuzzy membership. $\mu_l(G)$ shows the lower bound of fuzzy membership. $\mu_B(G)$defines Gaussian membership function.$k(G)$ Represents the remaining energy of IoT devices. N Defines number of energy harvesting IoT devices. The index of vagueness of the energy harvesting IoT devices with various values. The optimal threshold for cluster head selection can be computed as:

$$D^* = argmax\,\{\gamma(B_a)\} \quad (4)$$

Here, $a = a, \dots\dots, .m$.

3.2 Cluster head selection

It is assumed that in an average of total IoT devices $(N)/\ epochs\ (k)$, every IoT device become a cluster head exactly once. Each IoT device probability to be elected as a cluster head can be computed as:

$$P_s(\mathrm{t}) = \begin{cases} \frac{k*\hat{B}}{N-k*(rmod\frac{N}{k})} : H_s(t) = 1 \\ 0 : H_s(t) = 0 \end{cases} \quad (5)$$

Here, $\hat{B}$defines computed type-II fuzzy membership value. If $H_s(t)$=1, then IoT deviceis not a cluster head in latest $rmod(N/k)$ rounds. IoT device elected as a cluster head (CH), If $H_s(t) = 0$.

In the initial 'r' rounds, $(N - k * r)$represent the estimated count of IoT devices which were not cluster heads. After N/k rounds, all IoT devices once are considered as a cluster head and they perform task in coming series of rounds. $\sum_{s=1}^{N} H_s(t)$represents the eligible IoT devices to be elected as a cluster head at time t.

$$E[\sum_{s=1}^{N} H_s(t)] = \left(N - k * \left(rmod\,\frac{N}{k}\right)\right)(6)$$

The energy all IoT devices become equivalent to one another after every N/k rounds. By using Eqs. (5) and (6), the expected amount of cluster heads per round can be computed as:

$$\mathrm{E}\,[\#\mathrm{CH}] = \sum_{s=1}^{N} P_s(\mathrm{t}) * 1 = \left(N - k * (rmod\,\frac{N}{k})\right) * (k * B\hat{})/(N - k * (rmod\,\frac{N}{k})) = k(7)$$

3.3 Proposed inter-cluster data aggregation for energy harvesting IoT devices

Algorithm 1 shows the proposed algorithm. Initially, gaussian functional shapes-based type-II fuzzy membership function is used to elect the cluster heads among the IoT devices to reduce the energy consumption of energy harvest IoTs. Thereafter, inter-cluster data aggregation is used. Finally, the communication between the elected cluster heads and the cloud servers or sink.

Algorithm 1: Proposed inter-cluster data aggregation for energy harvesting IoT devices.
Step i. Deploy energy harvesting IoT devices randomly.
Step ii. Elect cluster heads using type-II fuzzy based thresholding by using Eq. (5).
Step iii. Associate member energy harvesting IoT devices to their respective nearest cluster heads using Euclidean distance.
Step iv.Elected cluster heads collect the data from energy harvesting IoT devices.
Step v. Cluster heads communicates the collected data with the base station or cloud server using Dijkstra algorithm.
Step vi.Finally, IoT's end users can communicate with the base station or cloud server to process the obtained dataset.
Step vii. Finally, various performance metrics can be computed by considering various parameters.

4. Performance analysis

This section discusses the parameter settings for simulation environment. Thereafter, experimental results are also discussed. The required number of initial parameters tosimulate the energy harvesting IoT network is described Table 1.

Table 1. Simulation parameters for energy harvesting IoT

Parameter	Value
Base station(x,y)	200,200
Area(x,y)	200,200
Probability(p)	0.1
IoTs(N)	200
Transmitter energy	$50 * 10^{-9}$J/bit
Initial Energy	0.25 Joules (J)
Receiver energy	$50 * 10^{-9}$J/bit
Free space(amplifier)	$10 * 10^{-13}$J/bit/m^2
Effective Data aggregation	$5 * 10^{-9}$J/bit/signal
Multipath(amplifier)	$0.0013 * 10^{-13}$ J/bit/m^2
Data packet Size	4000 KB
Maximum lifetime	5000

Figure 3 shows the packets sent to cluster head analysis of the proposed model over the competitive models. It clearly shows that the proposed model significantly sent more packets to cluster head as it has more lifetime.

Figure 4 shows the packets sent to base station analysis of the proposed model over the competitive models. It clearly shows that the proposed model significantly sent more packets to base station or cloud server as it has more lifetime.

Figure5 demonstrates the remaining energy analysis (in joules) of the proposed model over the competitive models. It clearly shows that the proposed model can significantly conserve more energy than the existing models, thus the proposed model is more energy efficient manner.

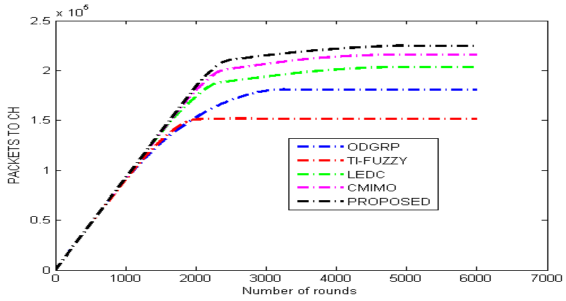

Figure 3. Packets sent to cluster head analysis

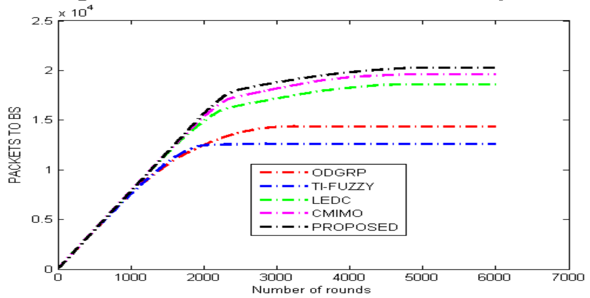

Figure 4. Packets sent to base station analysis

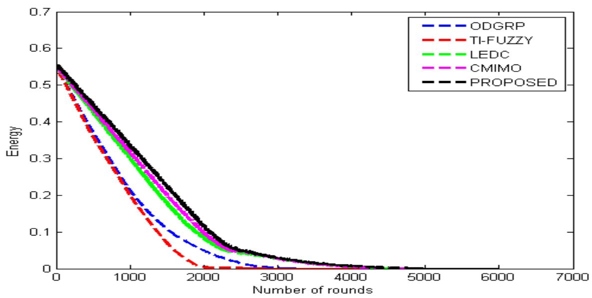

Figure 5. Remaining energy analysis

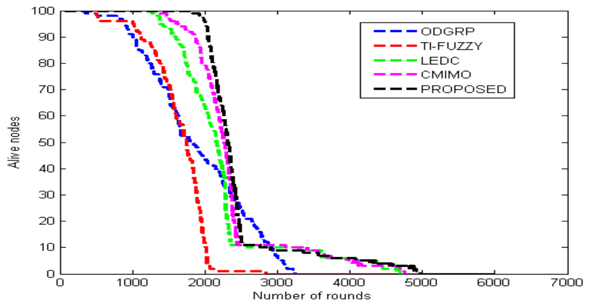

Figure 6. Network lifetime analysis

Figure 6 shows the network lifetime analysis of the proposed model over the competitive models. It clearly shows that the proposed model has significantly better lifetime as compared to the existing models

From Figures 3 to 6, it is found that the proposed model achieves significantly better results in terms of packets sent to base station, packets sent to cluster head, remaining energy and network lifetime by 2.2732%, 2.1638%, 1.9345%, and 2.1374%, respectively. Thus, the proposed model is more energy efficient compared to the existing protocols.

5. Conclusions

A Gaussian functional shapes-based type-II fuzzy membership function was designed to elect the cluster heads among the IoT devices to minimize the energy consumption of energy harvest IoTs. Inter-cluster data aggregation was then used to communicate the sensed data to the base station or cloud server. Extensive experiments were drawn by considering the existing and the proposed protocols for energy harvesting IoTs. Comparative analysis has shown that the proposed type-II fuzzy membership function-based protocol outperforms the existing protocols in terms of bandwidth analysis, throughput, conserve energy, network lifetime, and average consumed energy. From Figures 3 to 6, it has been observed that the proposed model achieves significantly better results in terms of packets sent to base station, packets sent to cluster head, remaining energy and network lifetime by 2.2732%, 2.1638%, 1.9345%, and 2.1374%, respectively. Thus, the proposed model is more energy efficient compared to the existing protocols.

In this paper, we have not considered any metaheuristics based inter-cluster data aggregation approach to enhance the results further. Therefore, in near future, we will apply various metaheuristics techniques to obtain more energy efficient inter-cluster path selection techniques to obtain more better results.

References

[1] S. Khan, K. K.. Loo, “Real time cross layer flood detection mechanism,” Elsevier Journal of Network Security, Vol. 16, No. 5, pp. 2-12, 2009.

[2] N. Almrezeq,L. Almadhoor, T. Alrasheed, A.A El-Aziz and S.Nashwan, ”Design a secure IoT Architecture using Smart Wireless Networks” ,International Journal of Communication Networks and Information Security,vol. 12, no.3, pp. 401-410,2020

[3] A.Ö. Ercan, M. O. Sunay and I. F. Akyildiz, "RF Energy Harvesting and Transfer for Spectrum Sharing Cellular IoT Communications in 5G Systems," in IEEE Transactions on Mobile Computing, vol. 17, no. 7, pp. 1680-1694, 1 July 2018.

[4] D. Altinel and G. Karabulut Kurt, "Modeling of Multiple Energy Sources for Hybrid Energy Harvesting IoT Systems," in IEEE Internet of Things Journal, vol. 6, no. 6, pp. 10846-10854, Dec. 2019.

[5] Y. Dong, J. Wang, B. Shim and D. I. Kim, "DEARER: A Distance-and-Energy-Aware Routing With Energy Reservation for Energy Harvesting Wireless Sensor Networks," in IEEE Journal on Selected Areas in Communications, vol. 34, no. 12, pp. 3798-3813, Dec. 2016.

[6] M. S. Bahbahani and E. Alsusa, "A Cooperative Clustering Protocol With Duty Cycling for Energy Harvesting Enabled Wireless Sensor Networks," in IEEE Transactions on Wireless Communications, vol. 17, no. 1, pp. 101-111, Jan. 2018.

[7] M. A. Abd-Elmagid, M. A. Kishk and H. S. Dhillon, "Joint Energy and SINR Coverage in Spatially Clustered RF-Powered IoT Network," in IEEE Transactions on Green Communications and Networking, vol. 3, no. 1, pp. 132-146, March 2019.

[8] C. Moraes and D. Har, "Charging Distributed Sensor Nodes Exploiting Clustering and Energy Trading," in IEEE Sensors Journal, vol. 17, no. 2, pp. 546-555, 15 Jan.15, 2017.

[9] S. Aslam, W. Ejaz and M. Ibnkahla, "Energy and Spectral Efficient Cognitive Radio Sensor Networks for Internet of Things," in IEEE Internet of Things Journal, vol. 5, no. 4, pp. 3220-3233, Aug. 2018.

[10] U. Baroudi, "Robot-Assisted Maintenance of Wireless Sensor Networks Using Wireless Energy Transfer," in IEEE Sensors Journal, vol. 17, no. 14, pp. 4661-4671, 15 July15, 2017.

[11] K. Han and K. Huang, "Wirelessly Powered Backscatter Communication Networks: Modeling, Coverage, and Capacity," in IEEE Transactions on Wireless Communications, vol. 16, no. 4, pp. 2548-2561, April 2017.

[12] L. Song, K. Chai, Y. Chen, J. Loo, S. Jimaa, and Y.Iraqi. "Energy efficient cooperative coalition selection in cluster-based capillary networks for CMIMO IoT systems." Computer Networks 153 (2019): 92-102.
[13] M. Collotta and G. Pau, "Bluetooth for Internet of Things: A fuzzy approach to improve power management in smart homes", Computers & Electrical Engineering, vol. 44, pp.137-152, 2015.
[14] N. Kaur and S.K Sood, "An energy-efficient architecture for the Internet of Things (IoT)", IEEE Systems Journal, vol.11, no. 2, pp.796-805, 2015.
[15] S. Toklu and O.A. Erdem, "BSC-MAC: Energy efficiency in wireless sensor networks with base station control", Computer Networks, vol. 59, pp.91-100, 2014.
[16] T.Ara, M.Prabhkar and P.G Shah," Energy efficient secured cluster based distributed fault diagnosis protocol for IoT." International Journal of Communication Networks and Information Security, vol 10,no.3, 539,2018