University of Ibadan
Journal of Science and Logics in ICT Research

Extending the Lifetime of a Wireless Sensor Network Using Fuzzy-Chinese Remainder Theorem

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Abstract

Improvements in wireless communication and hardware miniaturization have fostered increased utilization of Wireless Sensor Networks (WSN) in hazardous, low-human presence environments. Unfortunately, energy constraints prevented application of other adhoc networks' protocols to improving WSN nodes, which are designed to operate continuously on a single charge, constantly communicate with the network Base Station (BS) and forward data. This makes battery life crucial. Existing WSN algorithms do not consider battery charge levels, which determine affordable data packet sizes. Therefore, insufficient battery charge levels poses a significant constraint to the general performance of the WSN. Hence, to prolong battery life, this study implemented data-centric Fuzzy Chinese Remainder Theorem (CRT) to save energy and used Fuzzy logic for WSN data collection, node location, and battery charge monitoring with Python. Results show that the Fuzzy-CRT algorithm extended WSN battery life, reduced the number of dead nodes by 40% over 8000 rounds, and thus, surpassed Low Energy Adaptive Clustering Hierarchy (LEACH) and CRT-LEACH algorithms in overall performance. Data-centric Fuzzy-CRT is therefore recommended for prolonged WSN battery life, improved network service, extended data collection and packet transfer durations.

Keywords: *Wireless Sensor Network, Data-centric Fuzzy Chinese Remainder Theorem, Low Energy Adaptive Clustering Hierarchy (LEACH), Lifetime, Base Station*

1.0 Introduction

Environmental data collection and monitoring has increased over the years, even in hazardous environments where little human presence is required, and sensor networks play a very important role in providing such human-free service. Sensor networks are quite different from traditional networks in different ways: Sensor networks have severe energy concerns, redundant low-rate data, and many-to-one flows. Routing protocols [1] developed for other ad-hoc networks cannot be applied directly in Wireless Sensor Network (WSN) because of the energy constraint of the sensor nodes. Data-centric technologies are needed to perform in-network aggregation of data to yield energy-efficient dissemination. Sensor networks are used in many applications like environment monitoring, health, industrial control units, military applications and in the various computing environments. Since sensor nodes are usually battery powered devices, energy consumption of such nodes during transmission or reception of data packets affects the life-time of the entire network.

The WSN node is designed to operate for very long periods of time and this makes it cumbersome to regularly replace WSN node batteries that may run down from unforeseen circumstances. This research utilised data-centric routing protocols to optimise WSN node energy consumption, and improve WSN

Odulaja, G. O., Ifeta , A. T., Ayeni, A. G., Solanke, O. O. (2023). Extending the Lifetime of a Wireless Sensor Network Using Fuzzy-Chinese Remainder Theorem, *University of Ibadan Journal of Science and Logics in ICT Research (UIJSLICTR),* Vol. 10 No. 1, pp. 53 – 68.

lifetime, and its performance would be compared with traditional end-to-end routing schemes. For better understanding of this study, the following keywords and terms are contextual:

$E_{Tx}(k,d)$: Energy consumed when sending k bit data by sensor nodes from d distance

$E_{Tx-elec}(k)$: Energy consumed by transmitter distributor

$E_{Tx-amp}(k)$: Energy consumed by transmitter power amplifier

k: The length of data package sent
d: Data transmission distance

E_{elect}: Energy consumed by radiating circuit when processing 1 bit data

ε_{fs}: Energy consumed by transmitter power amplifier when sending 1 bit data to unit area in free space channel model

ε_{amp}: Energy consumed by transmitter power amplifier when sending 1 bit data to unit area in multipath fading channel model

$E_{Rx-elec}(k)$: Energy consumed by the interface circuit

E_{elec}: Energy consumed by the interface circuit when processing 1 bit data

E: energy consumed for transmission
h_R: height of receiving antenna
h_r: height of transmitting antenna
γ: wavelength

$\sim N(0,1)$ represents normally distributed random number with a mean of zero and a unity variance

$f(RE, NC, DBS)$ represents fuzzy map
E_0 represents Node initial energy

NC represents Node Centrality
DBS represents distance from base station
WSN: Wireless Sensor Network
CRT: Chinese Remainder Theorem

2.0 Related Works

Most often, data collected by wireless sensor network node is considered an important factor in determining the lifetime of the wireless sensor network and therefore**,** Kumar, Thiyagarajan, and Sripriya looked at this constraint and saw that sensor networks are quite different from traditional networks in different ways: sensor networks have severe energy concerns, redundant low-rate data, and many-to-one flows. Routing protocols developed for other ad-hoc networks cannot be applied directly in WSN because of the energy constraint of the sensor nodes. Data-centric technologies are needed to perform in-network aggregation of data to yield energy-efficient dissemination. Since sensor networks are used in many applications like environment monitoring, health, industrial control units, military applications and in the various computing environments, and the entire sensor node are battery powered devices, energy consumption of nodes during transmission or reception of packets directly affects the life-time of the entire network. In that paper they modelled data-centric routing protocol and compared its performance with traditional end-to-end routing schemes [2].

According to **Yadav and Rana**, there has been recent improvements in the design of micro-electro-mechanical systems, digital electronics and wireless communication, and this is responsible for the development in applications of wireless sensor networks. Wireless sensor networks (WSNs) consist of large number of cheap and tiny devices known as sensor nodes. In WSNs, sensor nodes communicate with each other via the many communication routing approaches and these routing approaches are governed by routing protocols. These routing protocols are indispensable for the performance of wireless sensor networks. On the basis of these, their work contains the survey on wireless sensor networks, and based on the network architecture, routing protocols in wireless sensor networks are categorized into three main types: data centric, cluster based or hierarchical routing and location-based routing. Because of these advantages clustering is becoming an active root in routing technology [3].

Following this, Marhoon *et. al.,* [4] proposed a chain-based as one approach (from Hierarchical routing protocols) for reducing the energy consumption in WSN. However, they saw a problem when the chain has a long link (LL) from the base station (BS).

Considering Wireless Communication Standards, Labeau *et. al.,* [5] in their paper considered that power utilities around the world are modernizing their grid by adding layers of communication capabilities to allow for more advanced control, monitoring and preventive maintenance. Wireless Sensor Networks (WSNs), due to their ease of deployment, low cost and flexibility, are considered as a solution to provide diagnostics information about the health of the connected devices and equipment in the electrical grid. However, in specific environments such as high voltage substations, the equipment in the grid produces a strong and specific radio noise, which is impulsive in nature.

The robustness of off-the-shelf equipment to this type of noise is not guaranteed; it is therefore important to analyse the characteristics of devices, algorithms and protocols to understand whether they are suited to such harsh environments. In this paper, they reviewed several WSN standards: 6LoWPAN, Zigbee, WirelessHART, ISA100.11a and OCARI. Physical layer specifications (IEEE 802.15.4) are similar for all standards, with considerable architectural differences present in the higher layers. The purpose of this paper was to determine the appropriate WSN standard that could support reliable communication in the impulsive noise environment, in electrical substations. The review concluded that the WirelessHART sensor network was one of the most suitable to be implemented in a harsh impulsive noise environment.

A survey was performed by Al Rasbi *et. al.,* [6], in which they had great concern for energy that grew with the technological advances in the field of networks and especially in sensor networks which had triggered various approaches and protocols that relate to sensor networks. In this context, the routing protocols were of great interest. The aim of the paper was to discuss routing protocols for sensor networks. The paper focused mainly on the discussion of the data-centric approach (COUGAR, rumor, SPIN, flooding and Gossiping), while shedding light on the other approaches occasionally. The functions of the nodes were discussed as well. The methodology selected was a close description and discussion of the protocol. As a conclusion, open research questions and limitations were proposed to the reader at the end of the paper.

Also, in Kharb and Singhrova [7], Wireless Sensor Networks was seen as the most exciting and interesting area of research and is seen as a very important tool in most major application domains and industrial planning. It has also been noted that since there are different WSN applications, there must therefore be various WSN standards for specific applications with their limitations. They also discussed the various challenges faced using the IEEE 802.15.4e industrial standard, carried out a comparative analysis of the standards provided, and revealed the associated research gap.

Haque *et. al.,* [8] have seen a tremendous advancement in wireless communication technology in the area of wireless sensor networks (WSNs) for use in a broad array of real-life applications as remotely deployed autonomous sensors gather data from their vicinity and communicate it to the base station after processing. Realising that sensor communication strategy are governed by routing protocols, which impact greatly on the performance of sensor networks, they extensively surveyed routing protocols for WSNs. This in turn led to the broad classification of WSNs' protocols into three foremost classes: flat, hierarchical, and location-based routing. In their work, they also provided a detailed survey of famous hierarchical routing protocols, and a taxonomy of hierarchical routing protocols along with the design challenges and also present a comparative analysis based on their traits and limitations.

Furthermore, Hosen and Cho [9] looked also at data-centric protocols in line with control messages overhead incurred by the nodes, formulating an energy-centric cluster routing protocol. According to the paper, Clustering is an effective way to prolong the lifetime of a wireless sensor network (WSN). The common approach is to elect cluster heads to take routing and controlling duty, and to periodically rotate each cluster head's role to distribute energy consumption among nodes. However, a significant amount of energy dissipates due to control messages overhead, which results in a shorter network lifetime. Their paper proposed an energy-centric cluster-based routing mechanism in WSNs. To begin with, cluster heads are elected based on the higher ranks of the nodes. The rank is defined by residual energy and the average distance from the member nodes. With the role of data aggregation and data forwarding, a cluster head acts as a caretaker for cluster-head election in the next round, where the ranks' information are piggybacked along with the local data sending during intra-cluster communication. This reduces the number of control messages for the cluster-head election as well as the cluster formation in detail. Simulation results showed that their proposed protocol saved energy consumption among nodes and achieved a significant improvement in the network lifetime.

Additionally, in Yoo and Kim [10], their paper saw that WSN as seen as penetrating people's lives and even seen as being ever more deployed in the industrial environment. The research on such industrial wireless sensor networks (IWSNs) was considered as a more stringent requirement of robustness, reliability, and timeliness in each network layer. Also, wireless sensor networks play a crucial role in modern communication by utilizing cost-effective sensor devices with various environmental and physical parameters. Establishing an efficient communication path between the base station and sensor nodes relies on routing protocols. However, previous protocols faced challenges like computational complexity, subpar cluster head selection, high energy consumption, and scalability issues. In response, this paper introduces the BMBWFL-HEED protocol, combining the BM-BWO algorithm with HEED. BM-BWO improves the Black Widow Optimization (BWO) mutation phase with the direction average strategy, while fuzzy logic aids in selecting optimal cluster heads. Extensive experimental analyses and benchmarking against ICFL-HEED, HEED, and ICHB-HEED demonstrate BMBWFL-HEED's superior performance, particularly in residual energy, energy consumption, and cluster head formation across homogeneous and heterogeneous environments [11].

From an environmental point of view, recent advancements in communication technology, driven in part by the strategic deployment of sensor nodes, have greatly improved. These wireless sensor networks (WSNs) enable real-time data collection in various environments. However, due to limited power in sensor nodes, especially when placed in remote areas, their lifespan is compromised. This review focuses on energy-efficient protocols for environmental monitoring applications and energy-harvesting WSNs. It addresses challenges in dynamic deployment, communication, and security within the WSN protocol stack, emphasizing the physical layer, network layer (routing), and medium access control (MAC). The paper also discusses scientific approaches for enhancing environmental monitoring applications [12].

Finally, data aggregation in WSN and IoT networks integrates data from various sensors and devices, optimizing resource usage and addressing network challenges like latency, energy efficiency, and security. This paper offers insights into data aggregation protocols and identifies research gaps in this field [13].

2.1 Problem Formulation

The lifetime of every WSN node commonly involves constantly communicating with the network Base Station (BS) and forwarding collected data. Unfortunately, this WSN lifetime is fully dependent on WSN node battery charge and cannot be regularly charged, as they are designed to operate regularly on a single charge. Present WSN algorithms do not take into consideration the state of the WSN node as regards data packet size in terms of data collection and transmission, location in the network relative to the network Base Station and the state of the battery charge level. Ignoring these negatively affects the smooth operation of all WSN. Continuous collection of data and transmission of same to the BS would eventually consume battery energy over time, as this is the major objective of its design. Furthermore, the WSN node's location that is of great importance also involves distance which determines the amount of energy needed for transmission; thus shorter transmission distances are preferred. Finally, as energy is constantly being consumed as a result of the WSN node collecting and transmitting data regularly, the state of the battery charge level becomes important in deciding whether data packets should be transmitted, as high battery charge levels do guarantee successful transmission and a low battery charge level does not. These constraints continue to inhibit the lifespan of WSN node in the network.

3.0 Methodology

3.1 The Low Energy Adaptive Clustering Hierarchy (LEACH) protocol

The most utilized Wireless Sensor Network (WSN) model is based on the novel Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [14], which is a basic energy efficient routing protocol of hierarchical routing protocol's family, where the sensor nodes remain static. Generally speaking, there are three steps in cluster routing protocol: the generation of cluster heads, the formation of clusters and the communication among clusters. Hence, LEACH algorithm also includes these three steps, just merging the first two steps into one that is the establishment of clusters and the communication among clusters. Thus, LEACH protocol algorithm contains the set-up of clusters and stable data transmission.

As for the selection of cluster heads, LEACH adopts equal probability method, selecting cluster heads in a circle and random manner and distributing the energy of the whole network evenly on each node. During the set-up stage of clusters, nodes will generate a number randomly between 0 and 1 (including 0 and 1). If the random number is smaller than the threshold T(n), then the node will be a cluster head in this round. The calculation method of T(n) is based on the following formula in Eq 1:

$$T(n) = \begin{cases} \dfrac{P}{1 - P\left(r \bmod (1/P)\right)} & N \in G \\ 0 & otherwise \end{cases} \quad -------1$$

In the above formula, p represents the percentage of cluster nodes accounting in the total number of nodes, that is probability of nodes becoming cluster heads; r refers to the current number of rounds (periods), and N is the total number of nodes; G is the set of nodes that did not become cluster heads in the $1/P$ round.

3.2 The Wireless Sensor Network Energy Model

The radio communication energy consumption model used is defined in Eq 2:

$$E_{total} = E_{send} + E_{received} -----------2$$

According to the radio communication energy consumption model, we know that when sending k bit data, sensor nodes will consume the below energy as defined in Eq 3:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k) -------3$$

Such that:

$$E_{Tx}(k,d) = \begin{cases} k \times E_{elect} + k \times \varepsilon_{fs} \times d^2, \ d < d_0 \\ k \times E_{elect} + k \times \varepsilon_{amp} \times d^4, \ d \gg d_0 \end{cases} --------4$$

On the flipside, when receiving k bit data, the sensor node will acquire energy as defined in Eq 5:

$$E_{Rx}(k) = E_{Rx-elec}(k) = k \times E_{elec} --------5$$

The definition of d_0 is given by Eq 6:

$$d_0 = \frac{4\pi h_R h_r \sqrt{E}}{\gamma} --------6$$

This distance formula can be re-written as:

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}} ---------7$$

3.3. Data Compression using Chinese Remainder Theorem (CRT)

Minimising the amount of data consumed by a node involves data compression using Chinese Remainder Theorem. The Chinese Remainder Theorem (CRT) is considered a splitting technique which can transform an integer Z

into a vector of smaller numbers named CRT components, $\{z_i\}$. The CRT components are obtained from Z using modular arithmetic as:

$$z_i = Z \left(mod\ p_i\right) - - - - - - - - 8$$

Where $p_i \quad \left(with\, i \in [1, \cdots, N_{CRT}]\right)$ are prime numbers (or at lease pairwise coprime integer numbers).

CRT states that ever integer number Z can be exactly recovered from its CRT components if the product of the prime numbers

$P = \prod_{j=1}^{N_{CRT}} p_j$ satisfies the condition:
$P > Z - - - - - - - - - - 9$

The CRT always states that Z can be recovered through a simple linear combination as:

$$Z = \sum_{j=1}^{N_{CRT}} c_j z_j \left(mod\ P\right) - - - - - - - - 10$$

Coefficient c_j are given as:

$$c_j = Q_j \cdot q_j - - - - - - - - 11$$

With

$$Q_j = \frac{P}{p_j} - - - - - - - - - 12$$

and q_j is its modular inverse obtained by solving:

$$q_j Q_j = 1 \left(mod\ p_j\right) - - - - - - - - - 13$$

3.4 The LEACH-Fuzzy-CRT Algorithm

The Fuzzy-CRT algorithm targets a non-uniform WSN to ensure proper rotation of cluster heads (CHs) among eligible nodes in the network, and targets three important factors to determine the selection of CHs. These factors include residual energy, node centrality and distance to BSs, and fuzzy logic was used to map these factors to the chance of a node becoming a Cluster Head (CH). These factors are further explained:

i. Residual Energy: It is an important factor for electing a node as CH since a CH node has to spend more energy than a member node. A CH node collects data from members, aggregates the collected data, and communicates it to BS. So, sufficient energy level is required for a CH for executing the above-mentioned activities.

ii. Node Centrality (NC): Total number of one-hop adjacent nodes within radium *R* of a node is called node degree. Node centrality is a factor which determines how a node is located in the middle among its neighbours. Lower NC value gives more chance of electing a node as CH:

$$NC = \frac{\sqrt{\sum_{i=1}^{ND} dist_i^2 / ND}}{Ntk\_Dimension} - - - - - - 14$$

Where ND (node degree) corresponds to the number of neighbours within the communication radius R of a node, and Ntk_Dimension is “M” in an $M \times M$ field area, and $dist_i$ represents distance of the ith neighbour node.

iii. Distance to BS: The energy consumption for transmitting data increases with the increase in distance between transmitter and receiver nodes. From an energy conservation perspective, the distance between CH and BS should be minimized:

$$Distance\ to\ BS = \frac{d_i}{d_{max}} - - - - - - - - 15$$

Where d_i is the distance between node i and the BS, and d_{max} is the maximum distance between a node in the network and the BS.

These factors are used as input to the fuzzy logic model, mapping these factors to the chance of the node becoming a cluster head. Chance serves as the output of the fuzzy logic model. The higher the chance value, the higher it is being elected as a CH. To utilize fuzzy logic, these inputs are fuzzified using fuzzy logic membership and each input has a set of memberships that maps the inputs from the input space to the fuzzy space (values between 0 and 1). The mapping to fuzzy space uses a set of linguist variables such that Low, Medium, and High as the fuzzy linguistic variables for residual energy, Close, Reachable, and Distant for node centrality; Nearby, Average, and Far for distance to BS. The output variable chance has nine output linguistic variables and they are very low, low, rather low, low medium, medium, high medium, rather high, high, and very high. In this, very low and very high, which are the two extremes follow trapezoidal membership function. Table 1, shows the mapping rules that determine how each WSN node input variable maps to a chance of being elected to a CH:

Using the Fuzzy map, the chance of a node becoming a cluster head is now reviewed in Eq.16 from Eq.1 as:

$$Node = \left(\sim N(0,1) > T(n)\right) \& f(RE, NC, DBS) - - - - - - - 16$$

$$RE = E_0 - E_{total} - - - - - - - - - - - - 17$$

Table 1: Fuzzy input-output mapping rules [15]

Rule Number	Residual Energy	Node Centrality	Distance to BS	Chance
1	Low	Close	Nearby	Rather Low
2	Low	Reachable	Nearby	Low
3	Low	Distant	Nearby	Very Low
4	Low	Close	Average	Rather Low
5	Low	Reachable	Average	Low
6	Low	Distant	Average	Very Low
7	Low	Close	Far	Rather Low
8	Low	Reachable	Far	Low
9	Low	Distant	Far	Very Low
10	Medium	Close	Nearby	Rather Medium
11	Medium	Reachable	Nearby	Medium
12	Medium	Distant	Nearby	Low Medium
13	Medium	Close	Average	Rather Medium
14	Medium	Reachable	Average	Medium
15	Medium	Distant	Average	Low Medium
16	Medium	Close	Far	Rather Medium
17	Medium	Reachable	Far	Medium
18	Medium	Distant	Far	Low Medium
19	High	Close	Near	Very High
20	High	Reachable	Near	High
21	High	Distant	Near	Rather High
22	High	Close	Average	Very High
23	High	Reachable	Average	High
24	High	Distant	Average	Rather High
25	High	Close	Far	High
26	High	Reachable	Far	High
27	High	Distant	Far	Rather High

4.0 Results and Discussion

The analysis utilized WSN model parameters for the model and is given in table 2:

Table 2: Wireless Sensor Network (WSN) Model Parameters [16]

Parameter Name	**Parameter Value**
Network Length (km)	100
Network Width (km)	100
Base Station X position (m)	50
Base Station Y Position (m)	50
Initial WSN node Energy, E_0 (J)	0.5
Energy consumed by WSN node to transmit x packets, E_{TX} (J)	50×10^{-9}
Energy consumed by WSN node to receive x packets, E_{RX} (J)	50×10^{-9}
Energy consumed by WSN node in free-space,E_{FS} (J)	10×10^{-12}
Energy consumed by WSN node in the transmit power amplifier, E_{MP} (J)	0.0013×10^{-12}
Energy consumed by WSN node internal components, E_{AGGR} (J)	5×10^{-9}
Number of Rounds	8000
Number of Clusters	5
Percentage of Cluster Nodes (P) in percent	20
Data Packet to be transmitted by WSN	[20,60,300,2000,4000,500]
Control Packet to be transmitted by WSN	[30,140,100,60]
Total number of nodes in WSN	100

The WSN Low Energy Adaptive Clustering Hierarchy (LEACH) protocol was modelled in python (Python 3.7), and was used to analyse the WSN node model. The proof of improvement on using CRT on the LEACH algorithm was in how many WSN nodes die after a set number of rounds as it relates to extending the lifetime of the WSN. The WSN parameters provided the working area of the WSN given by its length and breadth, the number of nodes in the network, the parameter settings of each WSN node, and the size of data/control packets transmitted by each WSN node. The WSN parameters were applied to the LEACH protocol and result is as shown for WSN Energy dissipation and number of dead nodes in Figures 1 and 2 respectively.

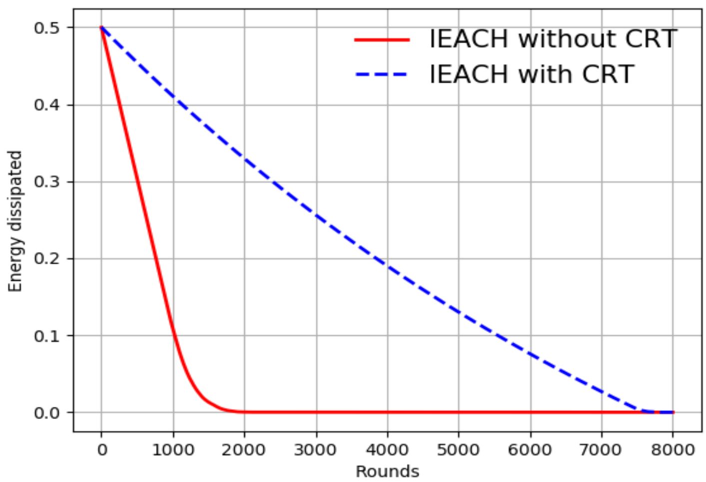

Figure 1: Energy dissipated for 8000 rounds

Figure 1 shows the energy dissipation of a WSN with and without using LEACH. An energy dissipating WSN is an indication of an active network, which showed that WSN nodes are still alive, with results indicating energy being dissipated for a WSN using LEACH with CRT compared to that without CRT, indicating that around 2000 rounds the LEACH without CRT goes to zero compared to that with CRT and this related to the number of dead nodes as shown in Figure 2.

Using LEACH only, energy dissipation was seen to drop drastically to 0.0 after 2000 rounds, but combined with CRT reduces this drastic drop which compared to the without CRT is seen to drop to 0.0 after 7500 rounds. As the number of rounds increase, the number of dead nodes increase as well and the energy dissipation reduces indicating that around 2000 rounds the WSN using LEACH without CRT completely die off compared to that using CRT with no node dead at this round.

The number of clusters was also investigated to see its effect on the lifetime of the network for both LEACH without CRT and that with CRT. The following results were obtained for 2, 5 and 10 clusters in Figures 3 and 4:

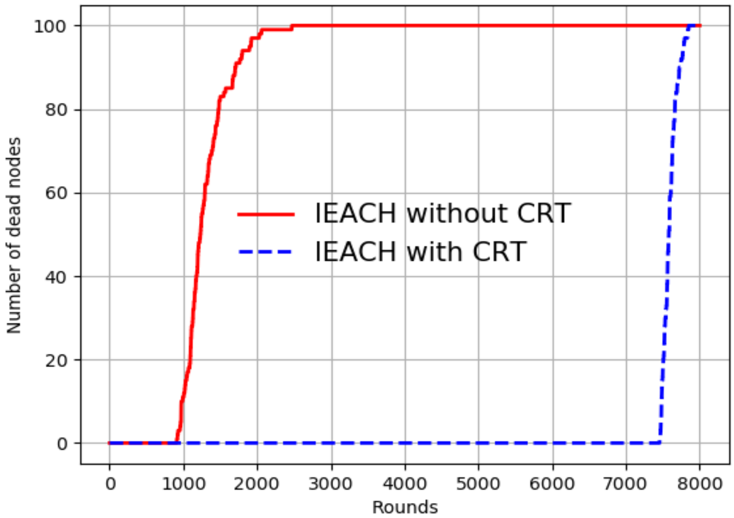

Figure 2: Number of dead nodes for 8000 rounds

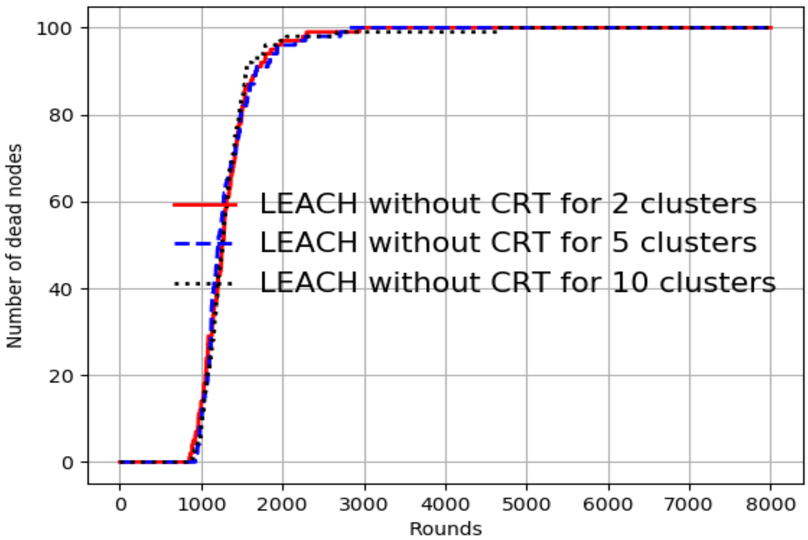

Figure 3: Number of dead nodes for different clusters for LEACH without CRT

It was obvious from Figure 3 that the number of clusters had no significant effect on the number of dead nodes after each round with an increase in cluster size.

The addition of CRT on the other hand was seen to reduce the number of dead nodes per round compared to that without CRT, but the effect of cluster size increase was seen to have no effect on number of dead nodes as seen in Figure 4. Figure 5 is an expansion of Figure 4 for clarity.

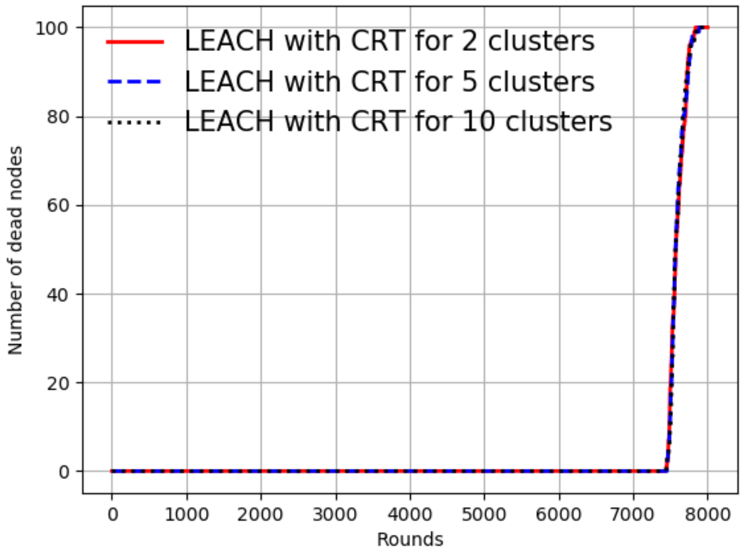

Figure 4: Number of dead nodes for different clusters sizes for LEACH with CRT algorithm

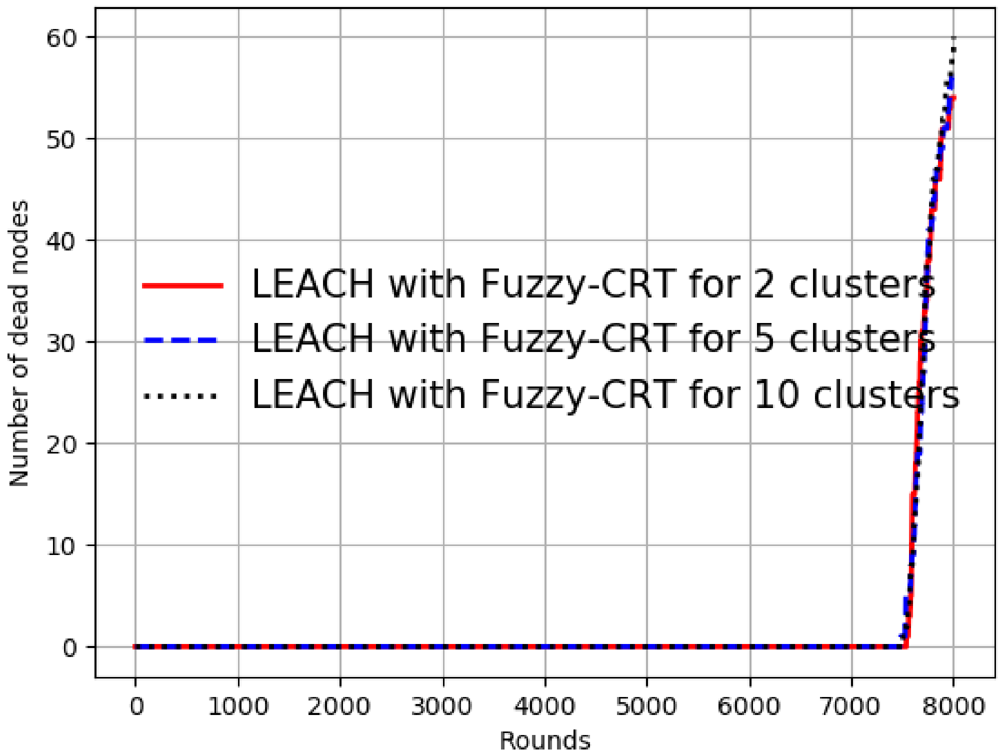

Figure 5: Number of dead nodes for different clusters for LEACH with Fuzzy-CRT algorithm

The Fuzzy-CRT algorithm was seen to further reduce the number of dead nodes per round as seen in Figure 5, but the cluster size is seen to have no effect also on the number of dead nodes.
The effect of base station location was also investigated on the lifetime of the network as the results shows in Figure.6 and Figure7:

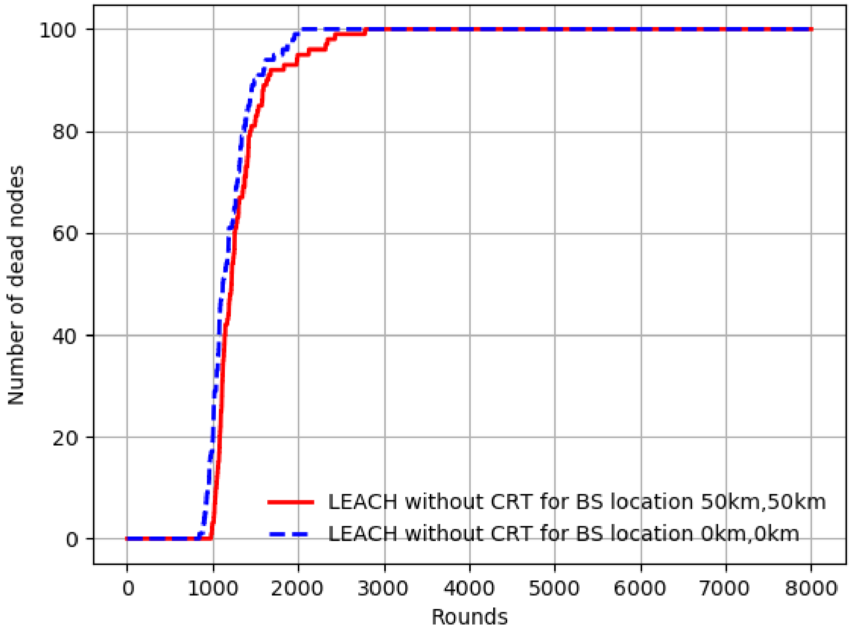

Figure 6: Number of dead nodes for LEACH without CRT with BS as (50km,50km) and (0km,0km) position

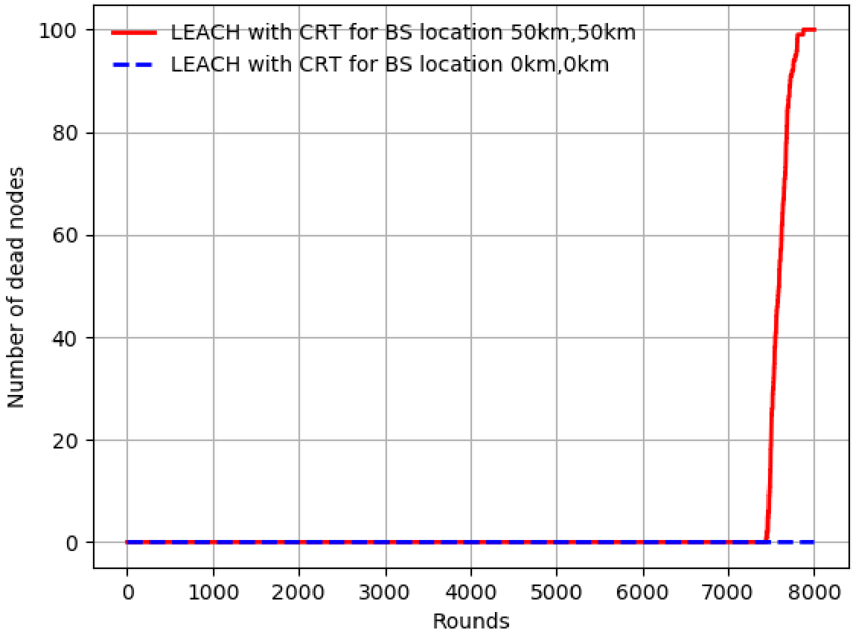

Figure 7: Number of dead nodes for LEACH with CRT with BS as (50km, 50km) and (0km,0km) position

For an overall area size of 10,000 sq km, two locations were investigated with a placement at the center (50km, 50kn) of the WSN, and and edge (0km, 0km). The location of the BS within the WSN was seen to have a very little effect on the lifetime of the WSN nodes for the

LEACH protocol, but a CRT algorithm on the LEACH protocol had very drastic effects. The analysis was done for 8000 rounds, but since it does not show the full result for both BS placements, it was then extended to 10,000 rounds to see the overall effect of the CRT on BS location, as seen in Figure 8.

Data packet size on the lifetime of the network was also investigated, and this was done by increasing the original packet size by 0%, 25%, 50% and 100% respectively, as seen in Figures 9 to 12.

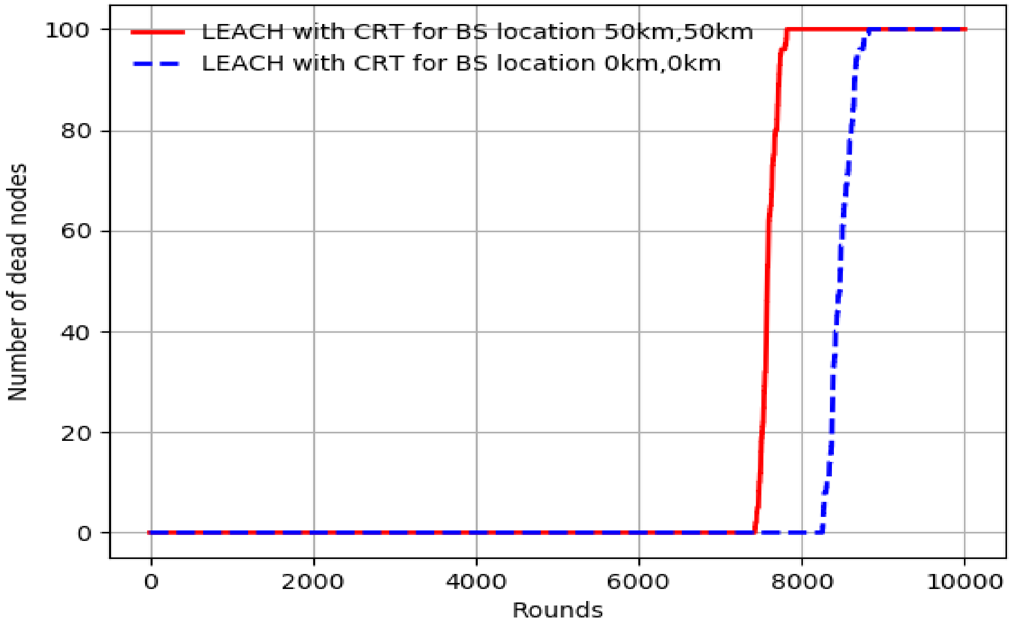

Figure 8: Number of dead nodes for LEACH with CRT with BS as (50km,50km) and (0km,0km) position with extended number of rounds of 10,000

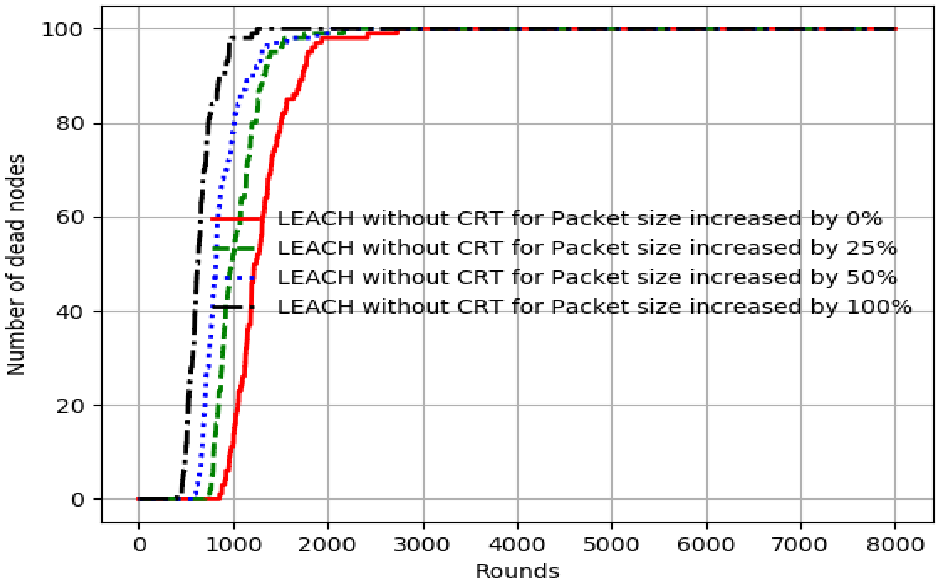

Figure 9: Number of dead nodes for LEACH without CRT for varied Packet Size increase

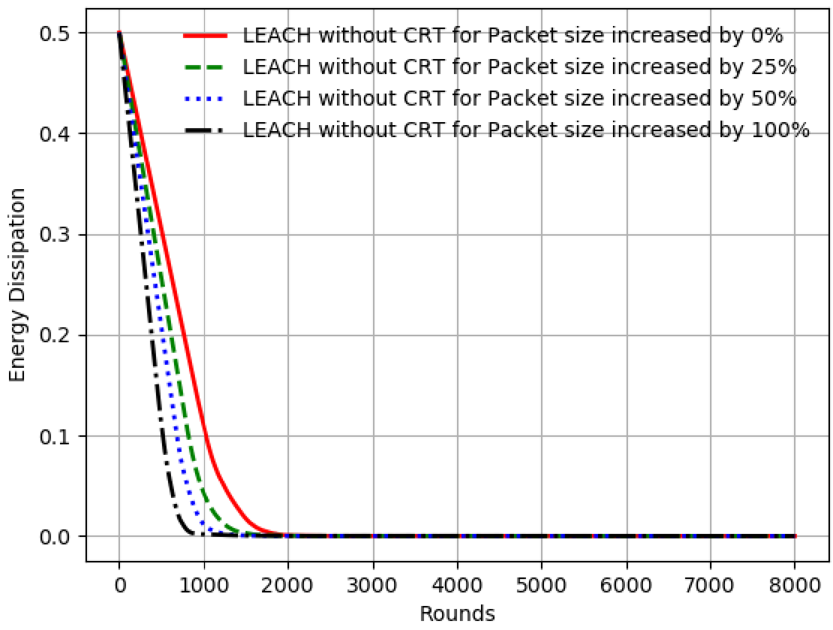

Figure 10: Energy Dissipation for LEACH without CRT for varied Packet Size increase

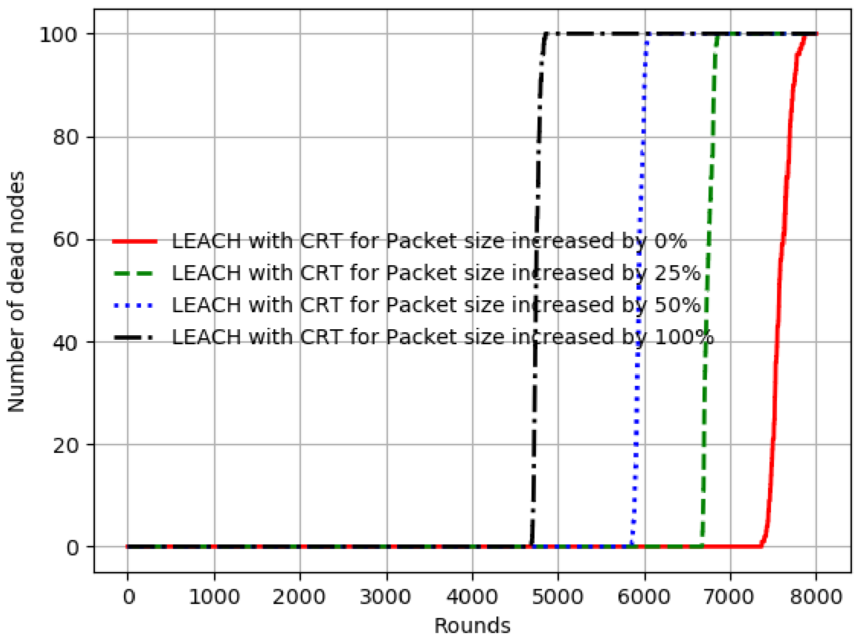

Figure 11: Number of dead nodes for LEACH with CRT for varied Packet Size increase

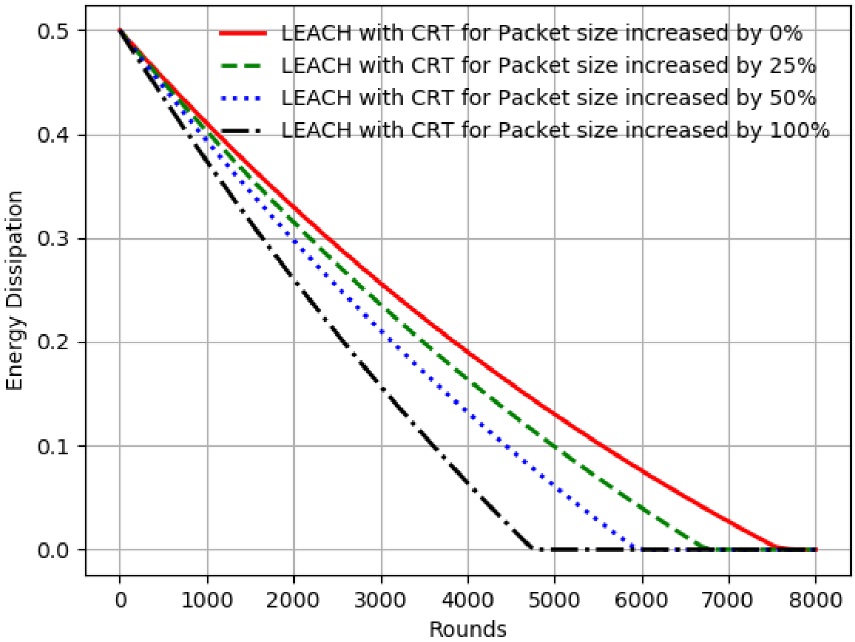

Figure 12: Energy Dissipation for LEACH with CRT for varied Packet Size increase

The LEACH protocol alone showed a moderate increase in number of WSN dead nodes and a decrease in energy dissipation (Figure 9 and Figure 10 respectively), but with the inclusion of the CRT algorithm, a further extension of the WSN lifetime, and a large change in the number of dead nodes and energy dissipation (Figures 11 and 12 respectively).

The CRT algorithm in the LEACH protocol improved the lifetime of the WSN, but by incorporating fuzzy logic demonstrated the effectiveness of considering node factors in electing cluster heads and the result obtained were compared to the LEACH-CRT algorithm and results are show in Figure 13 for WSN energy dissipation, Figure.14 for WSN number of dead nodes.

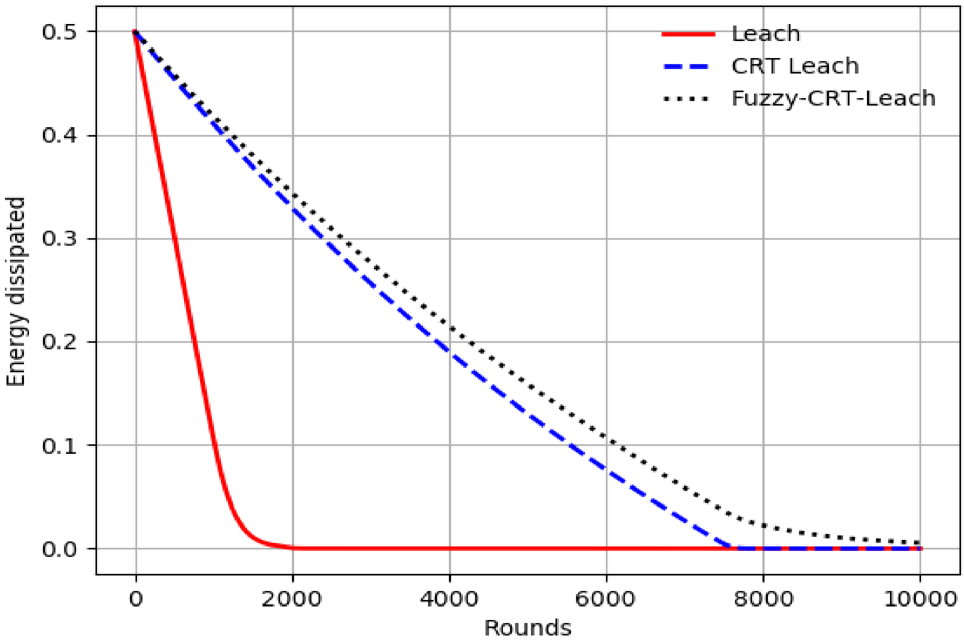

Figure 13: Energy dissipated comparison between LEACH, CRT LEACH and Fuzzy-CRT LEACH

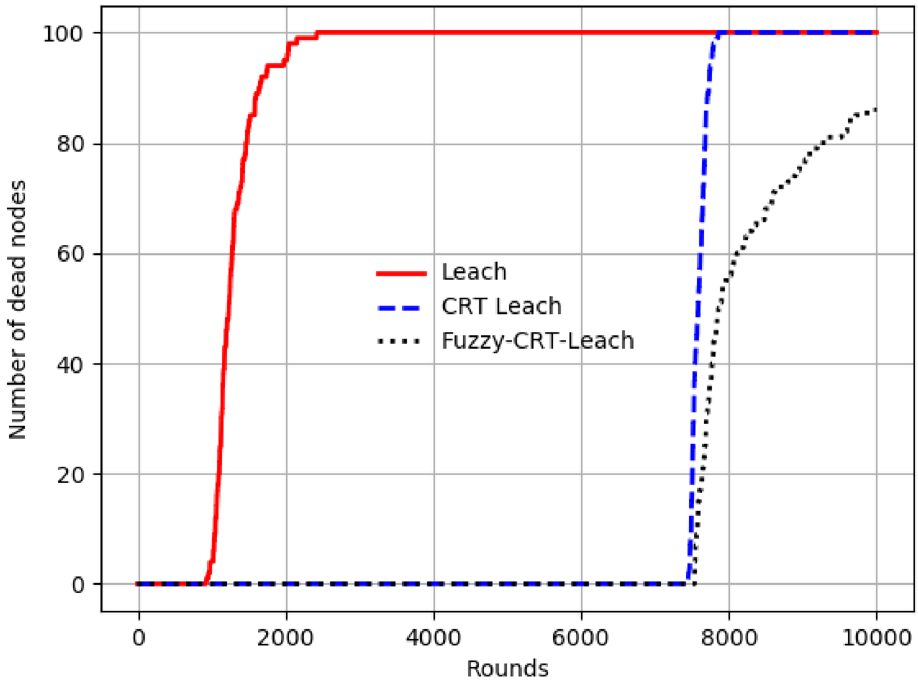

Figure 14: Number of dead nodes comparison between LEACH, CRT LEACH and Fuzzy-CRT LEACH

5.0 Conclusion and Further Research

The results from the research showed that LEACH-Fuzzy-CRT was able to extend the lifetime of a WSN compared to the novel LEACH algorithm. Therefore, this implies that energy consumption per WSN node is reduced, and a battery power depletion is also reduced as a consequence.

Overall, CRT showed improvements in the lifetime of a WSN. It also showed it has the ability to extend the number of rounds of all the nodes in the network. It further also showed that incorporating fuzzy logic node characteristics mapped to chances of electing CHs improved network performance. Further research can be done by incorporating optimization routines into the Fuzzy-CRT model for parameter tuning, especially in the parameters of the membership functions used in fuzzifying the inputs to the Fuzzy-CRT algorithm.

5.0 References

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