Effect of Energy-Efficient Routing for Packet Splitting using Chinese Remainder Theorem (CRT) for Wireless Sensor Networks (WSNS)

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Abstract: - The most popular Wireless Sensor Network (WSN) protocol utilized for energy optimization of WSN nodes is the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol, which is a basic energy-efficient routing protocol of hierarchical routing protocol's family, where the sensor nodes remain static. There is a need to extend the lifetime with respect to reducing the energy consumption of nodes, and this was accomplished using the Chinese Remainder Theorem (CRT. In this research large data packets are broken into smaller packets. The focus of the study is to develop an energy routing for splitting packets in Wireless Sensor Networks (WSNs) using Chinese Remainder Theorem (CRT) techniques. A further improvement in WSN lifetime is by utilizing fuzzy logic. Factoring node parameters such as residual energy of nodes, their centrality within clusters, and their distance to the base station and improving upon the selection of nodes as cluster heads are required. The developed application can be used to reduce the communication cost of Energy efficiency of WSN. The forwarding technique for this research is to split the packet sent by the source node of a WSN so that the maximum number of bits per packet that a node has to transmit is significantly minimized.

Key-Words: - Energy consumption, Adaptability, Localization, Routing, Chinese Remainder Theorem (CRT), Wireless Sensor Networks (WSNS).

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1 Introduction

A Wireless Sensor Network (WSN) is an ad-hoc network that consists of a set of sensor nodes that are either randomly fixed or spread out in a given geographical area and usually communicate through a wireless link. The area in which these sensor nodes operate is usually called the area of interest and where information is collected. Most often, to save data, a special sensor node is chosen to collect data from the various other nodes, and this node is called the sink node. Most often, the transmission of the collected data is done periodically or may be event-based, usually dependent on the application. The sink node usually acts as a bridge between the WSN and the end-user network, allowing the user to communicate with the WSN through this node. Individual sensor nodes have their own characteristics and energy autonomy, and this resource is essential to the survival of a WSN because, in most cases, the sensor's battery is irreplaceable. Energy in Wireless Sensor Networks is controlled with limited power thereby making the revitalization of resources difficult. Therefore, it is important to plan WSNs in an energy-efficient manner because it affects the network lifetime.WSN energy saving is highly dependent on how long a sensor node takes to process data packets. WSN technologies utilize Network coding to achieve this objective, but can only be efficiently applied to sensor nodes for data dissemination, and cannot be applied to data collection, which is the most important traffic in WSN.

The main features of WSN are: Energy consumption: Sensors have energy autonomy, and they usually use tiny batteries as energy resources. In most cases, WSNs are deployed in hard-to-reach areas. This makes it difficult or almost impossible to recharge or replace the batteries. This difficulty leads us to deduce that the life time of a sensor is essentially dependent on the battery. Therefore, energy-consumption management is a major constraint in this type of network. An intrinsic characteristic of these sensors is their low storage capacity. Although they also have a processor, the sensors cannot perform very large operations due to their relatively low processing power. For example, “mote”-type sensor nodes are composed of an 8-bit 4 MHz microcontroller, 40 KB of memory, and a radio with a bit rate of about 10 Kbps.

These remain true even for midrange nodes, such as “UCLA/ROCKWELL’S WINS”, which have a strong ARM 1100 processor with 1 MB flash memory, 128 KB of RAM, and a 100 Kbps radio. Quality is defined by the ability to interpret the information collected by the sink. Even though the QoS requirements vary according to the different WSN applications, the two main measures of QoS are data reliability and latency. Usually, a successful data-exchange rate between the sensor nodes and the sink must be above a certain threshold to ensure network reliability and functionality. Reliability can be further maximized, but this could be at the cost of increased energy consumption. It is therefore necessary to design robust and lightweight algorithms for data encryption, authentication mechanisms for privacy protection, and secure routing for data relays to protect the entire network against passive and active attacks, and denials of external service providers.

2 Theoretical Foundation

The Architecture used in WSNs is commonly based on five layers of the OSI Model. However, Transmission Control Protocol (TCP) is not suitable for WSNs because of multi-hop communication. Different layers used in WSNs are application, transport, network, data link, and physical. Additionally, the special functions of a WSN such as power management, mobility management, and task scheduling, to improve the effectiveness of the network are generally managed by three cross layers which are: ***Application layer*:** it supervises movement and offers software for several usages which transfer queries to obtain information. ***Transport layer*:** this layer is usually essential for internetwork communication. There have been numerous protocols designed to offer consistency and avoid congestion. Generally, because of multi-hop communication, TCP is not appropriate for WSNs. ***Network Layer*:** this layer provides a function for routing which is a difficult mission in WSNs. As a result of low energy and inadequate memory, routing protocol has to provide consistent and redundant paths, for which many protocols are available according to the desired metric. To guarantee consistency in case of hub failure, redundant hubs are deployed which results in the production of a lot of redundant information. The information can be processed as a processing unit that utilizes less energy co ***Data link layer*:** this layer guarantees consistency from point-to-point or point-to-multipoint. Error control and multiplexing of information streams are also achieved in this layer. In WSN, Medium Access Control (MAC) has a significant part to play. It offers higher efficiency, consistency, low delay, and higher rates of transmission. ***Physical layer*:** this layer makes available an interface to convey streams of information over a physical medium. It also deals with the choice of frequency, generation of a carrier frequency for modulation, signal detection, and security, [1]. Also the research in, [2], The correctness of information has incredible impact on the performance of the network.

2.1 Wireless Sensor Network Operating Systems

LiteOS is a newly developed OS for wireless sensor networks, which provides UNIX-like abstraction and support for the C programming language. Contiki is an OS that uses a simpler programming style in C while providing advances such as 6LoWPAN and proto-threads, [3]. Clustering Routing schemes are expected to make efforts to be scalable given the vast collection of motes in WSNs. WSNs should be able to talk back to the events taking place in the environment effectively, [4]. The number of sensor nodes deployed in the sensing area may be on the order of hundreds, thousands, or more. Any routing scheme must be able to work with this huge number of sensor nodes. Because there is no global addressing scheme like IP IP-based network, the location of a sensor node in WSN is estimated by calculating the signal strength between two specific nodes. This technique will not realize the coordinates of the neighboring node. The realistic alternative is to use GPS (Global Positioning System). Also, there is a need for scalable and energy-efficient routing, data gathering, and aggregation protocols in these WSN environments, [5]. However, using GPS will add significant power consumption to the sensor node which is already energy-constrained, [6].

A number of redundant data are sent to the BS, this is not desirable in WSN because such unnecessary data add a significant burden to the network thus reducing the lifespan of the network. This drawback is evident in the flat routing protocols as all nodes send data to the BS directly. Reducing redundant data is part of the requirements of WSN; it is desirable to divide sensors into groups (clusters) so that not only cluster heads (CH) are allowed to send data out of the network.

2.2 Classification of WSN Routing Protocol According to Network Operations

These are protocols based on the overall goal or kind of operation performed by the network. Several paths are discovered between the source and the destination and are used to provide a backup route. When the primary path fails, the backup is used and this increases the network performance at the expense of increasing the cost of energy consumption and traffic generation. E.g. Ad hoc On-demand Multipath Distance Vector routing (AOMDV), [7], the Destination node sends queries requesting certain data from the nodes in the network. If a node has the data that matches the query, it sends it back to the requested node. This process is known as Directed Diffusion. The main idea is to suppress duplicate information and prevent redundant data from being sent to the next sensor or the base station by conducting a series of negotiation messages before the real data transmission begins.

2.3 Development of Chinese Remainder Theorem

This is an ancient theorem that gives the conditions necessary for multiple equations to have a unique simultaneous integer solution. It states that if one knows the remainders of the Euclidean division of an integer n by several integers, then one can determine uniquely the remainder of the division of n by the product of these integers, under the condition that the divisors are pairwise coprime or relatively prime. The theorem can be widely used for computing with large integers, as it allows replacing a computation for which one knows a bound on the size of the result by several similar computations on small integers.

CRT can be formulated as follows: Let $m_1, \ldots\ldots\ldots m_k$ be integers greater than 1, which are often referred to as moduli or divisors. Let M denote the product of the m_i. The theorem asserts that if the m_i are pairwise coprime, and if $a_i, \ldots\ldots. a_k$ are integers such that $0 \leq a_i < m_i \; for \; every \; i$, then there is one and only one integer X, such that $0 \leq X < M$ and the remainder of the Euclidean division of X by n is a_i for every i.

This may be restated as follows in terms of congruences. If the m_i are pairwise coprime, and if $a_1, \ldots, a_k$ are any integers, then there exist integer X such that

$$X \equiv a_1 (mod m_1)$$

.
.
.

$$X \equiv \mathrm{a}_k (mod m_k),$$

STEP 1: $M = m_1 * m_2 * \ldots\ldots\ldots * m_k$

STEP 2: $M_1 = \frac{M}{m_1}$,

$$M_2 = \frac{M}{m_2}$$

$$M_k = \frac{M}{m_k}$$

STEP 3: Find the inverse using Euler's or Fermat's theorem

$$M_1^{-1} mod m_1$$

$$M_2^{-1} mod m_2$$

.
.

$$M_k^{-1} mod m_k$$

STEP 4: $X = \left(a_1 * M_1 * M_1^{-1} + a_2 * M_2 * M_2^{-1} + \ldots\ldots\ldots. + a_k * M_k * M_k^{-1}\right) mod M$

For instance, consider the system below:

$$X \equiv 2 \; (mod \; 3)$$
$$X \equiv 3 \; (mod \; 5)$$
$$X \equiv 2 \; (mod \; 7)$$

Using the methods and equations above, X = 23.

The review in [8], presents a new energy-aware algorithm named Minimum Residual Hop Capacity (MRHC). The algorithm is incorporated into the most commonly used protocol called Low Energy Adaptive Clustering Hierarchy (LEACH) in the transmission process within clusters. This reduces energy utilization in the transmission process, extends network lifetime, and improves the amount of data delivered to the base station, [9], investigating an application of the Chinese Remainder Theorem (CRT) for novel privacy-preserving routing in Wireless Sensor Networks (WSNs). The distinctive nature of their proposed technique is to gather data, aggregate, and then slice the aggregate. t-out-of –n secret sharing scheme (based on CRT) and then route the final aggregate with just t shares using CRT. The multi-objective of their proposed technique is to provide data privacy, identity privacy, source location privacy, and route privacy. Their proposed approach can be modified to cover Energy saving in Wireless Sensor Networks (WSNs). Different methods have been employed to secure and protect the shared and sensitive data. However, the significant roles of encryption algorithms are numerous and essential in information security, [10], in the Comparative Study of Symmetric Cryptography Mechanisms. The prediction of incoming attacks is achieved promptly which enables security professionals to install defense systems to reduce the possibility of such attacks in Zero-Day Attack Prediction with Parameter Setting Using Bi Direction Recurrent Neural Network in Cyber Security, [11]. Applying the Chinese remainder theorem to data aggregation in wireless sensor networks in, [12], provides data aggregation. Work on comparison of Modified LEACH (MODLEACH) and Mobile sink improved energy-efficient PEGASIS-based routing protocol (MIEEPB). Simulation results of the two protocols using MATLAB showed that MIEEPB performs better than MODLEACH. They noted with interest that wireless sensors that are powered by ambient energy are promising technology for many wireless sensor applications. Immune Inspired Concepts Using Neural Networks for Intrusion Detection in Cybersecurity will detect and prevent such intrusive attacks, [13].

3 Methodology

The Wireless Sensor Network (WSN) model utilized in the methodology is based on the novel Low Energy Adaptive Clustering Hierarchy (LEACH) protocol, which is a basic energy-efficient routing protocol of the hierarchical routing protocol's family, where the sensor nodes remain static. LEACH protocol algorithm contains the set-up of clusters and stable data transmission. As for the selection of cluster heads, LEACH adopts an 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:

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

In the above formula, p represents the percentage of cluster nodes accounting for 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.
The radio communication energy consumption model used is defined as:

$$E_{total} = E_{send} + E_{received} \quad (2)$$

According to the radio communication energy consumption model, we know that when sending kbit data, sensor nodes will consume the following energy:

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

Such that:

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

where:
$E_{Tx}(k,d)$: Energy consumed when sending kbit data by sensor nodes from d distance
$E_{Tx-elec}(k)$: Energy consumed by the transmitter distributor
$E_{Tx-amp}(k)$: Energy consumed by the transmit power amplifier
k: The length of the data package sent
d: Data transmission distance
E_{elect}: Energy consumed by radiating circuit when processing 1-bit data
ε_{fs}: Energy consumed by the transmit power amplifier when sending 1-bit data to the unit area in the free space channel model
ε_{amp}: Energy consumed by transmit power amplifier when sending 1-bit data to the unit area in multipath fading channel model

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

Where
$E_{Rx-elec}(k)$: Energy consumed by the interface circuit
E_{elec}: Energy consumed by the interface circuit when processing 1-bit data

The definition of d_0 is given by:

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

Where
E: energy consumed by transmission
h_R: height of receiving antenna
h_r: height of transmit antenna
γ: wavelength

Refined formula for d_0 is established as:

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

The results obtained are compared with LEACH and based on the equation:

$$E_{Tx}(k,d) = \begin{cases} k \times E_{elect} + k \times \varepsilon_{fs} \times d^2,\ d < d_0 \\ k \times E_{elect} + k \times \varepsilon_{amp} \times d^4,\ d \gg d_0 \end{cases} \tag{8}$$

And

$$E_{Rx}(k) = E_{Rx-elec}(k) = k \times E_{elec} \tag{9}$$

It can be seen that the length of the data packet, k, ultimately affects the amount of energy consumed and ultimately the lifetime of sensor nodes. Their CRT helps to reduce k , and hence energy consumption.

Using the Fuzzy map, the chance of a node becoming a cluster head is now reviewed in the below procedure.

Where
$\sim N(0,1)$ represents normally distributed random number
$f(RE, NC, DBS)$ represents fuzzy map
RE represents node residual energy
NC represents Node Centrality
DBS represents distance from base station

The flowchart in Figure 1 show shows the LEACH protocol:

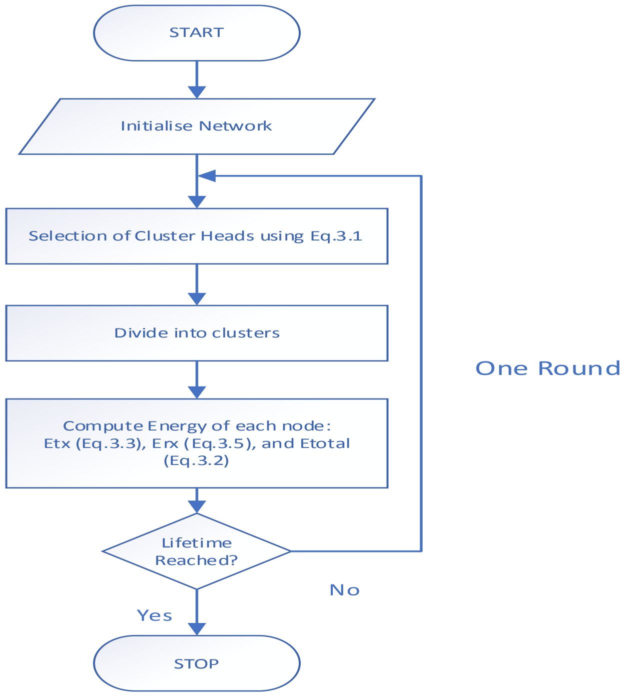

Fig. 1: LEACH Protocol

The flowchart also is depicted for LEACH-CRT and is shown in Figure 2:

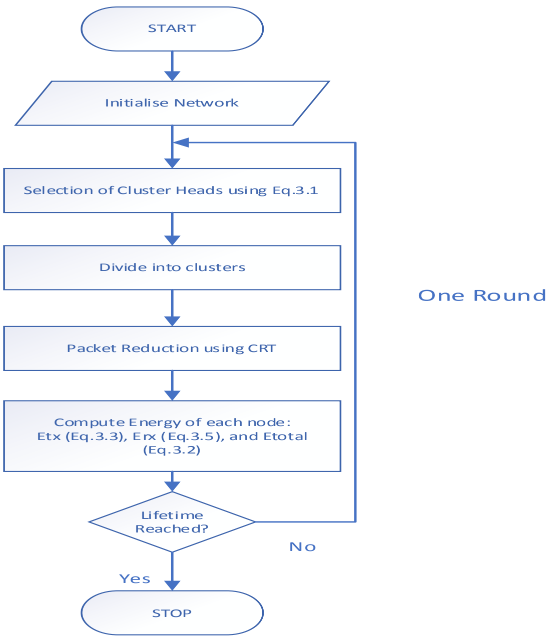

Fig. 2: LEACH-CRT Protocol

The WSN LEACH protocol with and without CRT were all modeled in Python. The data utilized for modeling is given in Table 1 below:

Table 1. WSN Model Parameter

Parameter Name	Parameter Value
Network Length (m)	100
Network Width (m)	100
Base Station X position	50
Base Station Y Position	50
E_0 (W)	0.5
E_{TX} (W)	50×10^{-9}
E_{RX} (W)	50×10^{-9}
E_{FS} (W)	10×10^{-12}
E_{MP} (W)	0.0013×10^{-12}
E_{AGGR} (W)	5×10^{-9}
Number of Rounds	3000
Number of Clusters	5
R	1
P	0.1
Packet	[20,60,300,2000,4000,500]
Control Packet	[30,140,100,60]
Number of Nodes	100

4 Discussion of Results

This data in the model parameter was applied to the LEACH protocol with and without CRT and the result is shown below: Table 2 shows the status of the network at the beginning of LEACH with and without CRT.

Table 2. LEACH vs LEACH-CRT for Energy Dissipated

Number of Rounds	LEACH	LEACH-CRT
10	0	0
1000	9	0
2000	97	0
3000	99	0
4000	99	0
5000	100	0
6000	100	0
7000	100	0
7500	100	14
7900	100	99
8000	100	100

This data when simulated and applied to the LEACH protocol. This data when simulated and applied to the LEACH protocol with and without CRT, the result in Figure 3 shows that without CRT the number of rounds was 2800 while with CRT the number of rounds was 3000 with both energy dissipation stable. When some of the nodes on the network are dead i.e. exhausted their residual energy.

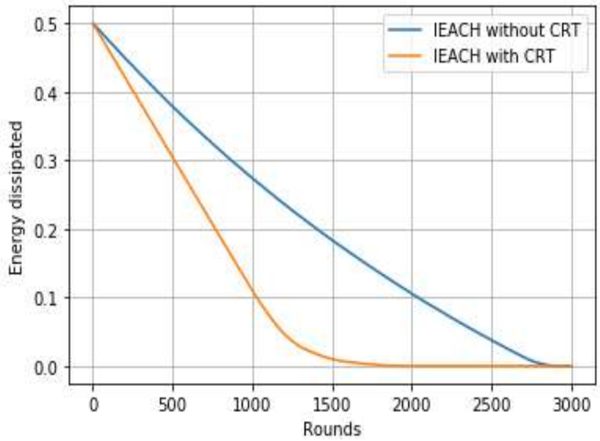

Fig. 3: Energy dissipated

However, another result in Figure 4 shows that without CRT the number of rounds was 900 while with CRT the number of rounds was 0 with both numbers of dead nodes stable.

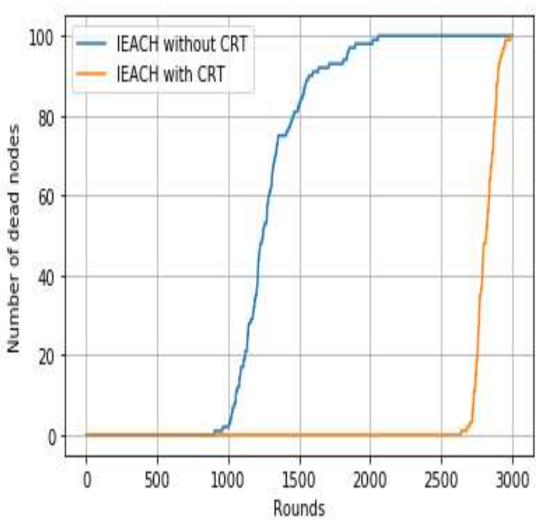

Fig. 4: Number of dead nodes

The number of clusters was also investigated to see its effect on the lifetime of the network. The following results were obtained for 2, 5, 10, 30, 60. Number of dead nodes for different clusters for LEACH without CRT and Number of dead nodes for different clusters for LEACH with CRT are provided in Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, Figure 11, Figure 12, Figure 13, Figure 14 and Figure 15.

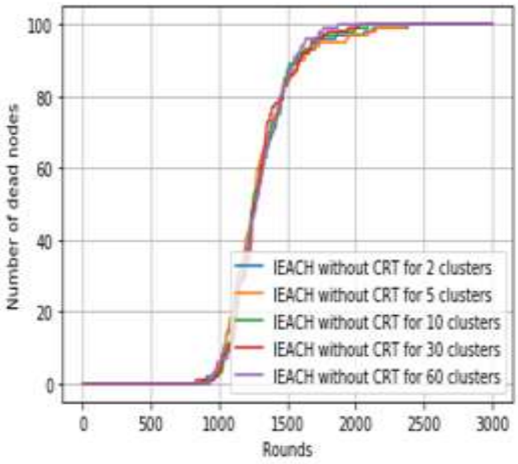

Fig. 5: Number of dead nodes for different clusters for LEACH without CRT

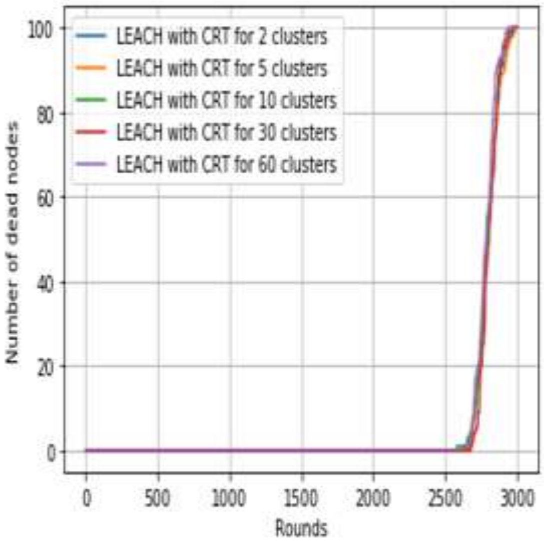

Fig. 6: Number of dead nodes for different clusters for LEACH with CRT

The effect of base station location was also investigated on the lifetime of the network as the results are shown below. *The effect of* ***the*** *Number of dead nodes for LEACH without CRT with BS as (50km,50km) and (0km,0km) position was investigated.*

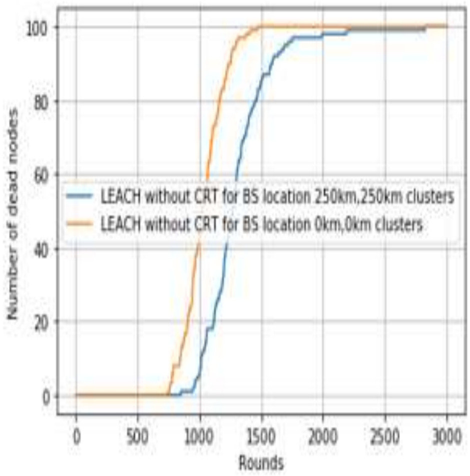

Fig. 7: Number of dead nodes for LEACH without CRT with BS at (50km,50km) and (0km,0km) positions.

Several dead nodes for LEACH with CRT with BS as (50km,50km) and (0km,0km) position are shown below.

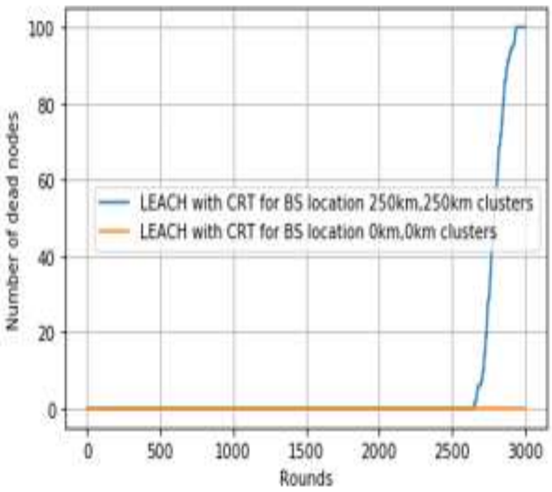

Fig. 8: Number of dead nodes for LEACH with CRT with BS BS at (50km,50km) and (0km,0km) positions.

Another experiment was conducted for the Number of dead nodes for LEACH with CRT with BS as (50km,50km) and (0km,0km) position with an extended number of rounds of 5000. The result of the simulation is presented below.

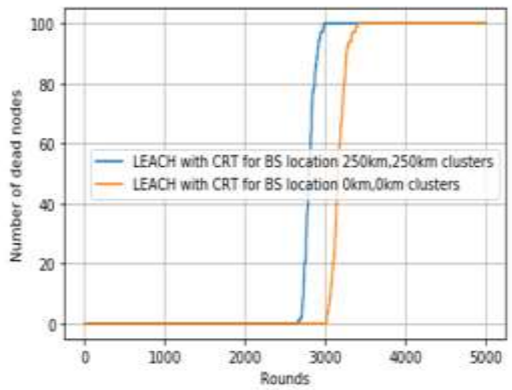

Fig. 9: Number of dead nodes for LEACH with CRT with BS as (50km,50km) and (0km,0km) position extended number of rounds of 5000.

The effect of packet size on the lifetime of the network was also investigated by increasing the original packet size by 25%, 50%, 75%, and 100%. The results gathered after the simulation were presented as follows.

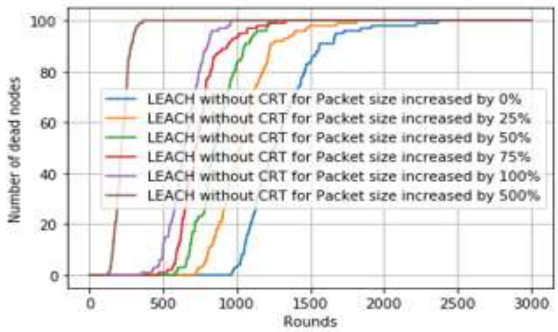

Fig. 10: Number of dead nodes for LEACH without CRT for varied Packet Size Increase

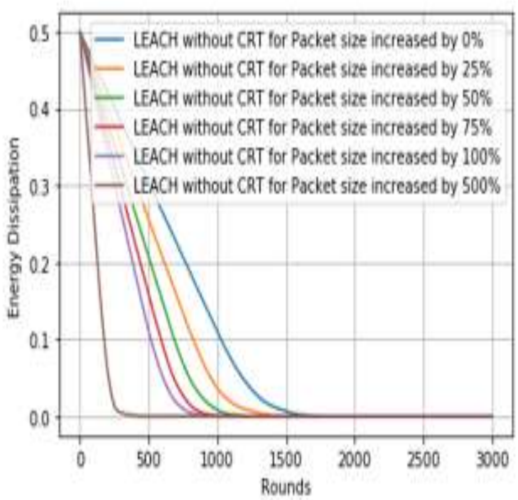

Fig. 11: Energy Dissipation for LEACH without CRT for varied Packet Size Increase

The Number of dead nodes for LEACH with CRT for varied Packet Size increase was simulated and the figure below presents the result.

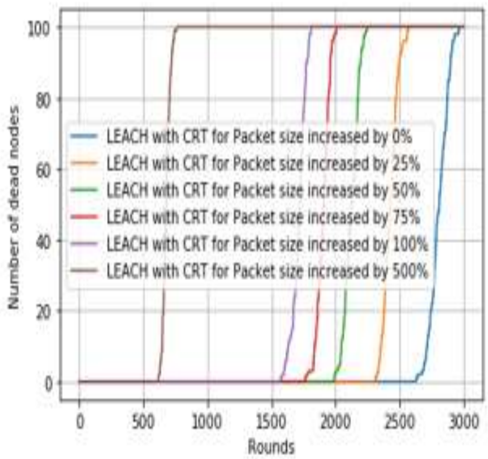

Fig. 12: Number of dead nodes for LEACH with CRT for varied Packet Size Increase

The result of Energy Dissipation for LEACH with CRT for varied Packet Size increase is presented below.

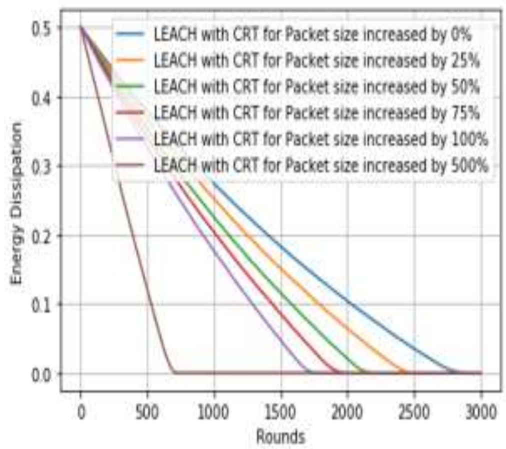

Fig. 13: Energy Dissipation for LEACH with CRT for varied Packet Size Increase

The improved LEACH-CRT algorithm incorporating fuzzy demonstrates the effectiveness of considering node factors in electing cluster heads and the results obtained from the mathlab simulation are compared to the LEACH-CRT algorithm without incorporating fuzzy in Table 3 and Table 4 provide the WSN energy dissipation, and the WSN number of dead nodes.

Table 3. LEACH-CRT vs. LEACH-CRT-Fuzzy for Energy Dissipated

Rounds	LEACH-CRT	LEACH-CRT-Fuzzy
10	0.496	0.499
1000	0.108	0.418
2000	0.002	0.344
3000	0	0.277
4000	0	0.215
5000	0	0.159
6000	0	0.108
7000	0	0.059
7500	0	0.037
7700	0	0.029
8000	0	0.023

Table 4. LEACH-CRT vs LEACH-CRT-FUZZY for the number of dead nodes

Rounds	LEACH-CRT	LEACH-CRT-FUZZY
10	0	0
1000	7	0
2000	96	0
3000	100	0
4000	100	0
5000	100	0
6000	100	0
7000	100	0
7500	100	1
7700	100	27
8000	100	60

The simulated Energy Dissipated Comparison between LEACH-CRT with and without Fuzzy results is presented below.

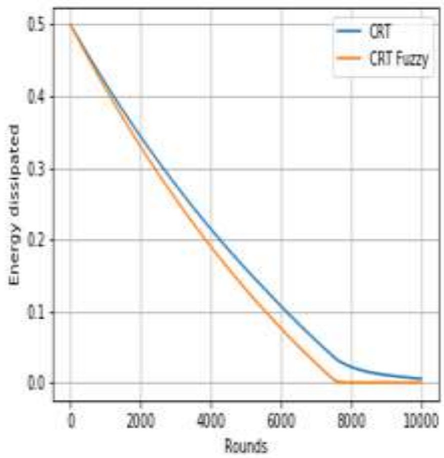

Fig. 14: Energy Dissipated Comparison between LEACH-CRT with and without Fuzzy

The Number of dead nodes comparison between LEACH-CRT with and without Fuzzy is presented below.

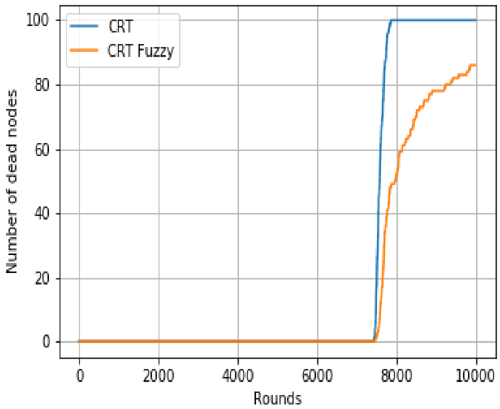

Fig. 15: Number of dead nodes comparison between LEACH-CRT with and without Fuzzy

5 Contributions to the Research

It was observed that including CRT increases the Wireless Sensor Network lifespan, and at the same time reduces the overall energy dissipation of the nodes in the network, and this also shows the relationship between the life of a node and its energy consumption. Though the LEACH and LEACH-CRT show similar sensitivity to parameter changes, the LEACH-CRT showed an extended number of rounds for each parameter change. Finally, it was observed that factoring node factors in the election of cluster heads using fuzzy logic showed further improvement in network performance.

6 Conclusion

In this research work, Wireless Sensor Network (WSN) was modeled using LEACH protocol and CRT was incorporated into the WSN model using Python to improve on network lifespan. The performance of the improved model was tested over the number of network node clusters, the location of the Base Station (BS), and the size of packets used in the network. The LEACH-CRT showed improved performance across all parameter changes (Number of Clusters, location of Base Station, and Packet Size). It was further shown that utilizing fuzzy logic to map node networks to elect CHs showed further network performance.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Adeniji oluwashola david, Azeez, bukola akeem carried out the simulation and the optimization.
- Azeez, Bukola Akeem has implemented the Algorithm on mathlab.
- Adeniji oluwashola david, Azeez, bukola akeem and Samuel Oladele Adeyemi organized and were responsible for the Statistics.

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