International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Research Article)

Enhancement of an energy efficient wireless sensor network using position responsive routing protocol

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International Journal of Science and Research Archive, 2025, 16(01), 2359-2368

Publication history: Received on 02 June 2025; revised on 19 July 2025; accepted on 27 July 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.16.1.2124

Abstract

A protocol for position-responsive routing (PRRP) was developed dynamically to minimize the maximum distance between nodes and gateways/cluster heads, for maximum energy utilization of a deployed wireless sensor node. A tree routing technique was employed to display notable gains in key performance metrics. Network Simulator (NS3) software was utilized to evaluate and compare the effectiveness of the suggested technique using two selected conventional techniques: LEACH (Low Energy Adaptive Clustering Hierarchy) and PEGASIS (Power Efficient Gathering in Sensor Information System). The node energy efficiency of the proposed PRRP was obtained as 0.3881J, LEACH as 0.2249J and PEGASIS as 0.2755J. The total energy remaining after 100 second iteration process was evaluated as 19.4060J, 11.2490J and 13.7745J for PPRP, LEACH and PEGASIS respectively. The result obtained showed that PRRP achieved a 63% energy efficiency improvement over LEACH and 41% over PEGASIS, demonstrating superior energy conservation capabilities.

Keywords: Wireless Sensor Network; Pegasis; Position Responsive Routing Protocol; Throughput; Leach

1. Introduction

The development of sensor techniques which are very effective in data sensing, transmitting and receiving information has made Wireless Sensor Networks (WSNs) become among the newest and fastest-growing areas of research. Wireless sensors (WSs) are configured in small size, low-cost and battery operated devices which is deployed in a remote area to sense and detect various types of physical and environmental conditions with minimal manpower in the form of video, audio, seismic etc. and co-operatively transmits the gathered data via the network to a central point called the sink, from which the information could be viewed as well examined (Abidi et al., 2020). A WSN is made up of hundreds of sensors which are dispersed geographically over a large area in order to accomplish complicated tasks (Kulkarni et al., 2020). These sensor nodes coordinate with each other to obtain, process, and disseminate easily accessible, high-quality data concerning the physical environment.

As the applications of wireless sensor networks increase rapidly, energy efficiency in wireless sensor networks become an issue that needs serious consideration in order to ensure extension of the network's lifespan and the sensor nodes' overall effectiveness. The energy of the battery does not last long due to energy shortage. It is expected to operate for a considerable amount of time. The energy is mostly drained during data transmission, reception, idle, standby, or sleeps states in relation to additional components like sensing and computing units (Singh et al., 2020). The replacement of battery in some certain circumstances during data transmission operation is extremely difficult after it had been fully deployed. Once the battery drains, the performance of the nodes are adversely affected, the connectivity decreases and the network will no longer perform as expected. Therefore, understanding the sources of energy drainage in WSNs is very essential towards adopting a suitable technique to limit energy consumption and increase network longevity in WSNs (Adu-Manu et al., 2019; Engmann et al., 2018). As a result, many scholars had deployed various solutions in the

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past in order to increase energy efficiency, performance as well as WSNs network lifespan, such as Energy Harvesting (Adu-Manu, et al., 2018), Wireless Energy Transfer (Olatinwo and Joubert 2019), Clustering techniques (Nezha et al., 2021), Routing Algorithms (Shah et al., 2017). Despite the techniques deployed, the issue has not been adequately addressed. This paper therefore proposes the implementation of Protocol for Position Responsive Routing (PRRP) as a measure to improve WSN's energy efficiency.

2. Literature review

In the works of Kiran et al., (2020), the authors developed a blurry-based method that uses distance and energy as blurry descriptors to choose the best cluster Head (CH). However, blurry-based clustering technique is often seen as ineffective in heterogeneous WSN scenarios. In Liu et al., (2019), a low-energy adaptive clustering hierarchy (LEACH) tailored to a particular application in WSNs was designed. The authors affirmed that the LEACH protocol would raise the energy consumption of the network if the cluster heads (CHs) distributed is not considered based on rotation. Karthick and Palanisamy (2019), introduced an algorithm for clustering that was derived from the Krill herd algorithm. This overcomes challenges like energy-sensitive clustering and node distribution to identify the best cluster head. Vancin and Erdem (2018), established a three-level heterogeneous energy-efficient Distributed Energy-Efficient Clustering protocol (DEEC) using criteria such as the quantity of packets that the base station receives, energy consumption, average latency, alive nodes during the network life, and sensor network throughput. They examined the performance of the developed protocol with two different convectional techniques. The factors in convectional clustering and the impact of the measured threshold balance were taken into account. The modeling results improved the network longevity and energy efficiency. Gupta and Jha (2018), presented an advanced routing algorithms based on harmony search and cuckoo search clustering algorithms for the distribution of cluster heads and for transferring of data between cluster heads and the sink respectively. The issue of clustering and routing nodes with energy balance between cluster heads and the sink was resolved by the strategies that were provided. Alnawafa and Marghescu (2018), presented a strategy that entails segmenting the entire sensor network into several tiers and every node in the network behaves in accordance with its state and location. Darabkh et al., (2019) established an algorithm for clustering and routing that is density-oriented altitude and energy sensitivity to gather data in wireless sensor networks. The strategy had an empirical expression that explained how to effectively divide equal-sized layers and sub-layers within the network field. This approach essentially balanced energy usage and increases network longevity by distributing the load among the available sensor nodes.

An Energy-Aware Path Creation algorithm (EAPC) with mobile sink was presented by Wen et al. (2018). The process involved establishing a data collection route, choosing an appropriate representative data collection cluster, building a data gathering route, and collecting data from data-burdened sites. This method lowered the sensor nodes' energy expenditure by allowing movable sinks to visit certain sensor nodes and collect information from them while traveling along a predetermined path. Orumwense and Abo-Al-Ez (2022), presented a strategy to arrange sensor nodes for charging to enhance existing systems and increase lifespan. Elshrkawey et al., (2018) presented an enhanced method to limit energy dissipation and increase the network's lifespan by scaling clustered energy balancing among all sensor nodes while communicating via a network. The revised technique is supported by a CH selection process. The simulation results demonstrated that WSN has a lower energy usage and outlived LEACH regarding the longevity of the network. Yalcin et al., (2022) introduced Thermal Exchange Optimization based Clustering Routing Protocol (TEOMCRP). The strategy aimed to increase energy efficiency and network longevity by optimizing the use of thermal exchange for both clustering formation and routing decisions.

3. Methodology

Simulation analysis with hybrid routing approach that incorporates both position responsive routing and tree routing were deployed in the study. The hierarchical approach deployed minimized energy loss by enabling efficient data transfer pathways. The simulator was deployed to analyze and compare the effectiveness of the technique with the two convectional protocols: PEGASIS and LEACH using a number of key performance metrics which are the cluster head, remaining energy after 100 seconds, node energy efficiency and network transmission throughput.

3.1. PRRP WSN System Model Development

The Wireless Sensor Network (WSN) is separated into cells and a grid, followed by other tiers while it's thought that the sink is positioned in the middle of the topology. Presuming that the nodes are cognizant of their geographical location as well as position via a global positioning system (GPS), they are dispersed at random. The nodes near the sink, typically with tier-0, are the gateways. In addition, the gateways are chosen alongside with other tiers based on the energy level of the node, distance to the sink, and neighboring node count. Depending on the network size, the tiers are often established at radii within the sink, beginning at tier Q_0 through tier Q_1 and so on. First, the sink sends a signal into the network with energy level E_0. Nodes situated nearer the sink are the only ones that will receive the signal with energy E_0. Following the signal's reception, these nodes will react to the sink and become tier Q_0 nodes. When $E_1 > E_0$, after then, the sink will promote a signal with a transmitted energy of E_1. In response to this signal, the nodes that are not Q_0 will become tier Q_0 nodes as shown in Figure 1. A predetermined number of tiers will be created before this process is repeated.

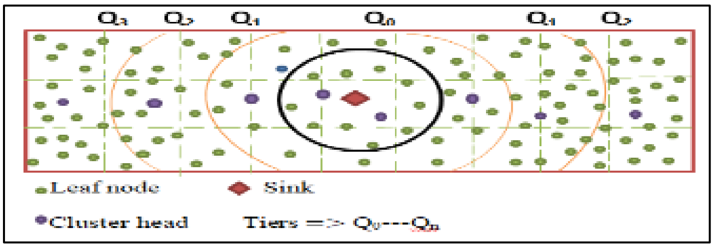

Figure 1 The PRRP network model

The idea that energy consumption is directly related to transmission distance forms the basis of the model for power control employed within this study. The energy consumed by the node for sending k bits of data across a distance of d meters that provides the energy used to receive k bits is given as:

$$E_{TX} = kE_{elect} + kE_{amp}d^2 \text{ and } E_{RX} = kE_{elect}. \qquad (1)$$

Where E_{elect} is the electronics energy per bit, E_{amp} is the amplifier energy and k are a constant.

The minimal energy required so that a node will be eligible to take part in the subsequent round is given as

$$E_{thmin} = kE_{elect} + kE_{amp}d^2 + 8kE_{elect}. \qquad (2)$$

Assume the WSN consists of N wireless sensor nodes evenly spaced throughout a grid of size m × m, where a node serves as the cluster head (CH) for each lifetime; broadcasting its own data, obtaining samples of data from participant nodes, and sleeping. For one data sample, let E_{in}, E_{th}, E_r, and E_t represents initial energy, energy dissipated while receipt, threshold energy, and dissipated energy during transmission respectively.

Moreover, every sample of the data is presumed to be fixed; as a result, T_s, the sending and receiving times for each data sample are equal. Throughout every interval of sampling, a CH with k member nodes transmits for T_t, receives samples for KT_t, and sleeps for the remaining $T_s - (K+1)T_t$. When its remaining energy drops below the threshold (E_{th}) required for a node to operate, the CH is considered to have died. As a result, CH's life is given as:

$$N_s = \frac{E_{in} - E_{th}}{E_t + KE_r + T_s - (K+1)T_t)P_s} \qquad (3)$$

3.2. Proposed PRRP Description

Every node is cognizant of its location as well the distance to the sink and nearby node. Appropriate gateways are found from each cluster after system modelling. The gateway is chosen depending on factors including the energy threshold level, neighboring node count near a specific node as well the node distance. The proposed PRRP aims to reduce the distance of the gateway from the nodes in order to conserve energy while transmitting information. The proposed PRRP functions in several stages, beginning with the gateway selection and ending with data transfer. Information is gathered with the use of TDMA scheduling mechanism once a tree with roots at the sink is created. PRRP makes the assumption that a node can only join a neighbor on the same tier that is accessible. Each node would choose a parent from its nearest neighbors in order to prevent a long-distance data transfer, maintaining minimal distance and saving energy during data transfer. As such, nodes' broadcast range is constantly limited. Every node has the ability to listen to each other's transmission nearby or in the same tier. This strategy saves energy by ensuring that there is as little distance between communication nodes as possible during data transfer. The proposed WSN routing protocol (PRRP) is simulated under the following assumptions: (a) that the Cluster Head (CH) selection depends on several factors like distance to the sink, the residual energy as well the average distance of the neighboring nodes. (b) Grid-Based division ensures the approach uses a central sink, and the network is partitioned into grids, cells, and tiers. (c) Gateway selection was done based on the gateway's closeness to the central sink, the energy level also the number of neighboring nodes. (d) Tree routing structure was built from the sink. This approach was to ensure that the closest neighbor nodes are chosen for data transmission. (e) Energy efficiency is achieved by utilizing Distributed TDMA scheduling to conserve energy, while the nodes that are not currently transmitting would be in sleep mode.

3.3. The proposed protocol algorithm

The proposed protocol (PRRP) comprises four stages; (a) Gateway Selection (GS), (b) Tree Building (TB), (c) Scheduling Building (SB), (d) The Transmission of Data (TD) as shown in Figure 2.

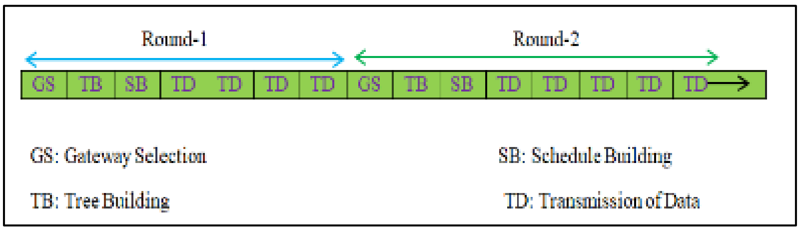

Figure 2 PRRP phases

3.3.1. (a). Gateway Selection (GS)

The GS is the first stage which its selection depends on the residual energy's level, number of nearby modes, and modes position in order to reduce the wireless sensor's network overall energy usage. The network is separated on both sides of the sink into various grid cells, each of which is further subdivided into a number of tiers, say n. The nodes in tierQ_0 will initially be regarded as possible gateway candidates according to their energy level (e), distance to the sink (d), and the quantity of surrounding nodes (n). Certain nodes are being permitted to promote that they operate as gateways. Nonetheless, a node's remaining energy will determine its priority. Until the remaining energy decreases below the threshold value E_{th} , a prospective gateway will continue to function as $Q_n$such. After that, more gateways will be chosen among the tier nodes. Until their remaining energy falls belowE_{th}, the newly chosen nodes will once more function as gateways, and so on. The sensor and sink nodes will communicate with one another through the use of the Carrier Sense Multiple Access (CSMA) technique.

3.3.2. (b). Tree Building (TB)

After the gateway selection process is over, the tree building phase begins. A routing tree with the sink as its root is constructed. This tree was constructed based on two types; the leaf mode and the non-leaf mode. Once a message is received by a node from another node, it automatically turns into a leaf node then detects the communication link until the link is unresponsive, and then waits for the period allocated for the next node. Should the link remain unresponsive, the node will then transfer the message then turns into a non-leaf node after that. The node that has the highest energy level and the nearest distance will be chosen as the parent node as the node gets several messages from other nodes prior to transmitting its message. The node will pick one node at random if their energy and distance are equal.

3.3.3. (c). Scheduling Building (SB)

This is the third stage were an efficient distributed scheduling system which uses the TDMA concept for data transfer is constructed in distributed manner. The schedule is based on the supposition that every node linked to the same gateway would provide data at the same frequency. Since nodes linked to the various gateways are presumably using distinct frequencies for data transmission, it is permitted for data to be transmitted simultaneously between the various trees. Time Ready to Transmit (TRT) (i.e. the node's readiness to broadcast to its parent towards the sink) and Time Ready to Receive (TRR) (i.e. the node's readiness to receive from its children's nodes) are the two-time constants that are recognized. The values of TRT and TRR can be used to determine the node wakeup time, which is the amount of time that the transceiver will remain in the ON state. The leaf node's transmission time (TRT_m) is equal to the width of a single time slot (t) while its reception time (TRR_m) is zero because it has no offspring. Conversely, for the non-leaf node TRR_m = max (TRT_i). where $i = 1, 2, \ldots n_m^c$ and $TRT_m = TRR_m + n_m^c T_t$. Where m = a node and TRT_m= leaf node's transmission time, TRR_m = leaf node's reception time, i = index for the offspring of m node. n_m^c = number of offspring of m corresponds to one data packet transmission time.

3.3.4. (d). The Transmission of data (TD)

At this phase, the data is sent from the nodes to the sink according to the distributed TDMA scheduling that was created in the third phase. One period of data transmission is the amount of time needed to transfer every packet in a single round. There may be more than one TD in a data transmission time depending on the gateways' energy level. Figure 3 illustrates the flow of the PRRP procedure. When a tree is rebuilt, various sensor nodes will always participate, serving as a source of evenly distributed energy throughout the network. Each node will receive an equitable share of the network's overall energy consumption.

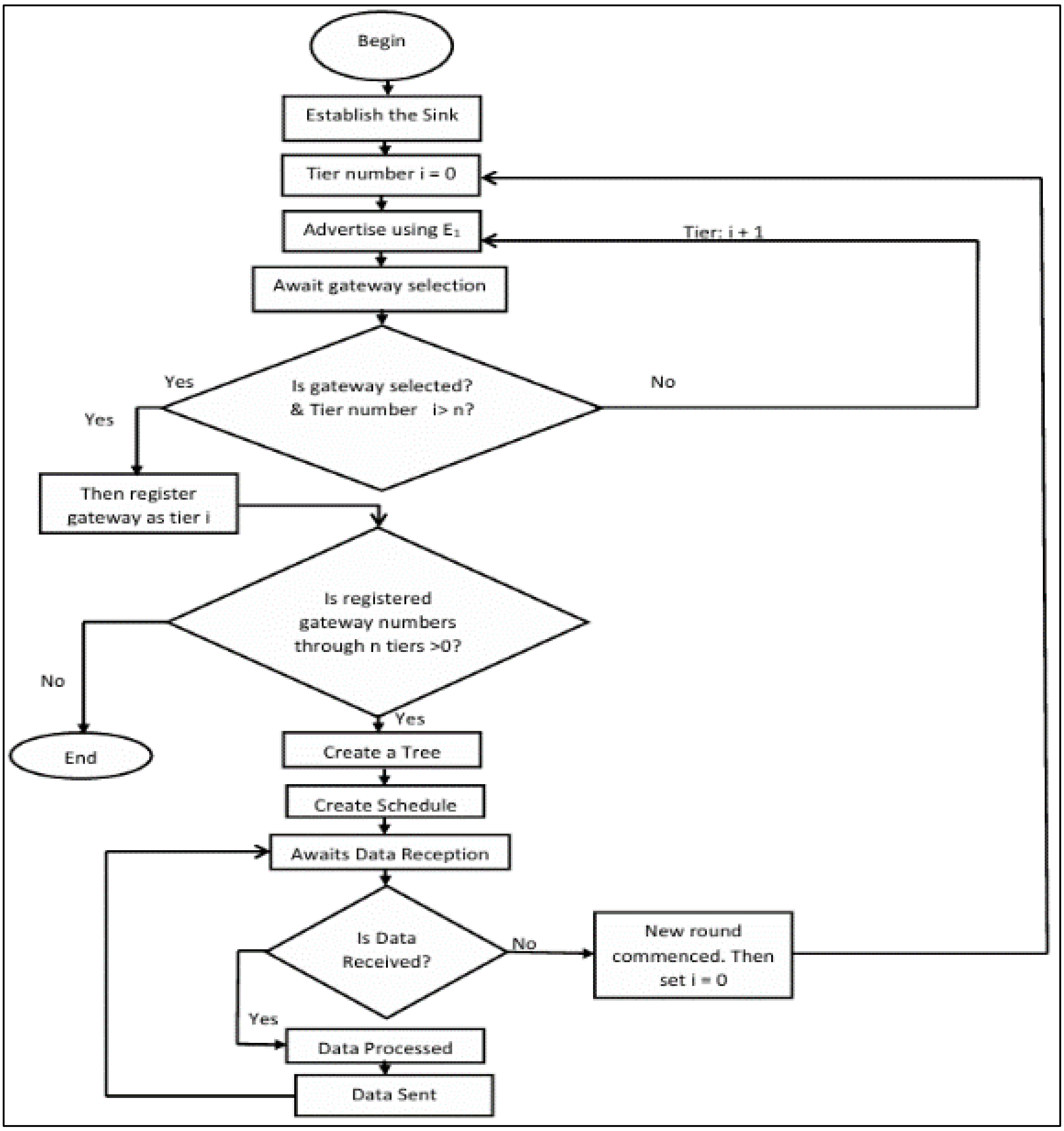

Figure 3 PRRP process flow

3.4. Simulation of the Proposed Protocol Using NS-3 Software

The performances of the proposed model and the existing protocols were analyzed, evaluated, and compared using Network Simulator3 (NS3).

Table 1 Simulation Parameters

Parameters	Values
Simulation Area	50m × 50m
Sensor Deployment	Uniform Random
Number of nodes	50
Sink Location	Center
Sensing Range	6m
Packet size	100 bits
Initial Energy E_0	0.4joules
Energy consumed in the electronics circuit (E_{elec})	40nj/bit
Energy consumed by the amplifier (E_{amp})	80pj/bit/m^2
Energy Threshold (initial) E_{th}	4×10^{-4}j
Total Simulation time (sec)	100sec

4. Result and discussion

Following the simulation setup and parameters, the Position Responsive Routing Protocol (PRRP), as well as LEACH and PEGASIS were run for a duration of 100 seconds, after which the Cluster Heads were observed with respect to the remaining energy, i.e. the residual energy after transmission has occurred. Figures 4, 5 and 6 show the energy levels for the Cluster Heads (CH).

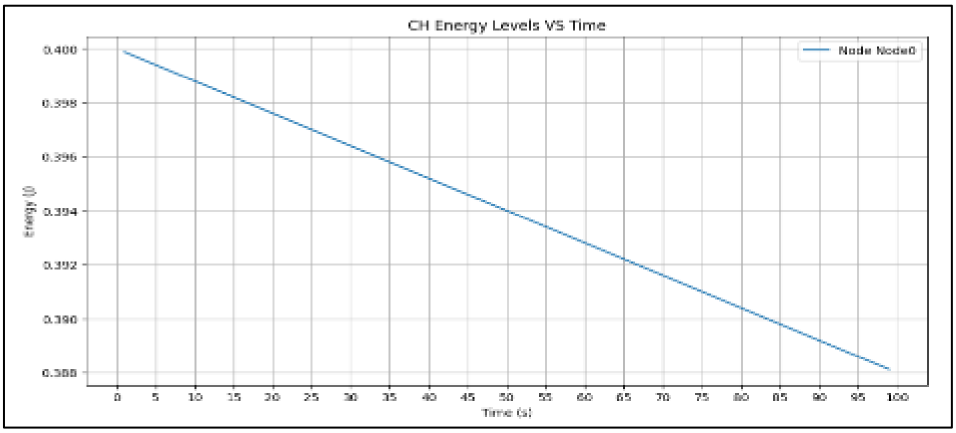

Figure 4 PRRP CH energy level after 100 seconds

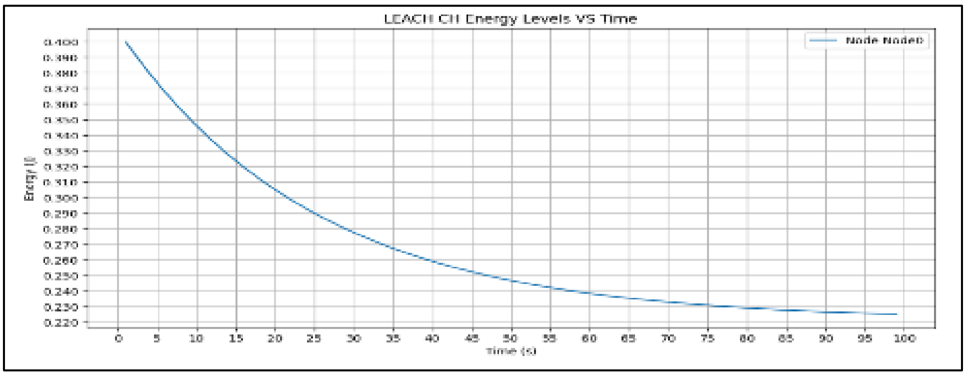

Figure 5 LEACH CH energy level after 100 seconds

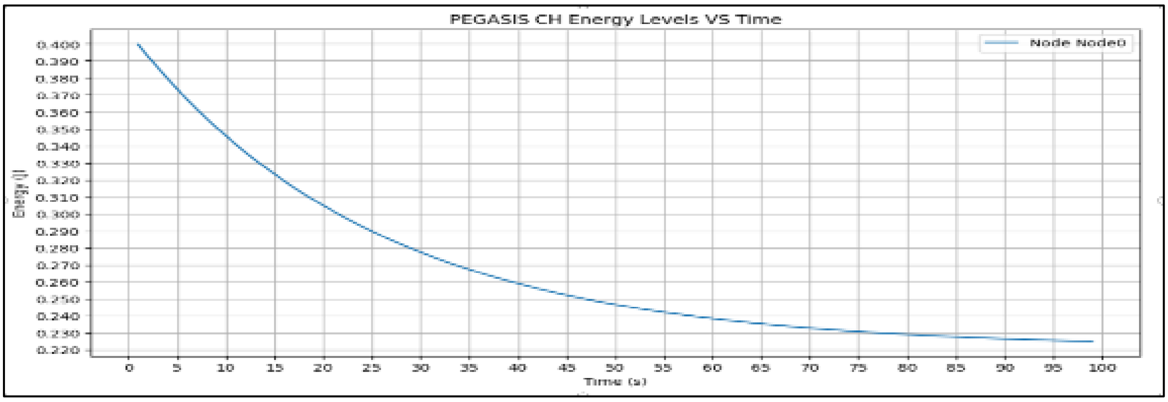

Figure 6 PEGASIS CH energy level after 100 seconds

Among the three routing protocols, PRRP proves to be the most stable in terms of energy consumption with a steady and balanced power usage ending at 0.3881j after 100 seconds as shown in Figure 4. Next is the curved line depicting PEGASIS power consumption, with a moderate energy usage and shows a steep energy decline at about the 30th second, and finally ending at 0.2755j after 100 seconds of the simulation as seen in Figure 5. Finally, LEACH shows the most significant energy depletion and imbalance, with total remaining energy after 100 seconds being 0.2248j as shown in Figure 6. The energy balance approach used in PRRP's CHs contributes to overall efficiency and durability, which makes it outperform other protocols like LEACH and PEGASIS.

Throughout the entire time of the simulation, and after node transmissions, the remaining energy is logged for the total nodes in the network after 100 seconds. The average of the energy remaining per node and the total energy remaining in the network were calculated using $E_{navg} = \frac{\sum(E_{fi})}{N_t}$ and $E_{ntotal} = \sum(E_{fi})$ respectively. Where: E_{navg} is average energy remaining in nodes after 100sec, Efi is the final energy remaining in each node after 100sec, E_{ntotal} is the total energy remaining in the network after 100sec, and Nt is the total number of nodes in the network. The simulation outcome is summarized in Table 2.

Table 2 Energy comparison after 100 Seconds

Protocol	Avg. Energy/Node (J)	Total Energy Remaining in Network (J)
PRRP	0.3881	19.4060
LEACH	0.2250	11.2490
PEGASIS	0.2755	13.7745

The PRRP showed efficient energy management with a total residual energy of 19.4060J in network nodes and an average node energy of 0.3881J after 100 seconds. PEGASIS showed moderate energy efficiency with a total remaining energy of 13.7745J and an average node energy of 0.2755J. The least efficient of the three protocols in power management was LEACH with a total remaining energy of 11.2490J and node average of 0.2250J. Additionally, the energy efficiency in PRRP performed better than LEACH and PEGASIS protocols, which confirms its superiority in potential in energy efficiency. Following the computation obtained from Table 2, PRRP showed an energy efficiency level of 63% and 41% improvements over the LEACH and PEGASIS techniques respectively.

The respective individual node throughputs for PRRP, LEACH and PEGASIS were extracted into an Excel sheet for further processing. The resulting transmission throughput is calculated using $T_n = \frac{\sum(t_i)}{N_t}$ Where T_n is the total throughput of the network, t_i is the individual throughput of the nodes, and N_t is the total number of nodes in the network. This is shown in Figures 7, 8, and 9.

G13

	A	B	C	D	E
1	Node	Throughput			
2	0	714.1330092		PRRP THROUGHPUT	
3	1	1312.988619		1112.746327	
4	10	1094.506508		(Average of B2 to B51)	
5	11	1152.773993			
6	12	998.6795498			
7	13	954.9998952			
8	14	1318.354258			

Figure 7 PRRP transmission throughput

D12

	A	B	C	D	E
1	Node	Throughput			
2	0	733.5190344		LEACH THROUGHPU (MEAN)	
3	1	1145.775302		1074.424017	
4	2	1059.486227		(Average of the sum of B2 to B51)	
5	3	1084.865367			
6	4	934.0761374			
7	5	1298.050139			
8	6	1059.486227			

Figure 8 LEACH transmission throughput

J20

A	B	C	D	E
Node	Throughput			
0	791.4962802		PEGASIS THROUGPUT	
1	1085.628418		944.8145046	
2	1001.379514		(Average of B2 to B51)	
3	952.6038331			
4	825.4914519			
5	1094.496724			
6	965.9062916			
7	926.7379416			

Figure 9 PEGASIS transmission throughput

Based on the data obtained from the simulation, PRRP has the highest throughput of 1112.75kbps of all the three protocols which makes it more efficient. Closer to PRRP in data delivery efficiency is the LEACH protocol with throughput of 1074.42kbps. The least throughput efficiency is that of PEGASIS with 944.81kbps. Conclusively, the high throughput of PRRP means that it manages high data delivery efficiently, and that it is more suitable for applications that require high data delivery rates.

5. Conclusion

This paper examines the need for a new energy-efficient routing protocol for enhancing energy efficiency of a wireless sensor network using position responsive routing protocol, specifically by applying a tree routing method that shows notable gains in key performance metrics like throughput, energy consumption, and network lifetime. The simulation results produced by NS-3 software confirm the efficacy of this strategy, demonstrating how strategically routing data according to node placements can maximize communication pathways and cut down on wasteful energy use. Through the use of a tree-based structure, the routing protocol reduces the distance that data must travel, saving transmission energy while preserving high throughput. According to the results, this technique successfully distributes the load throughout the network, preventing individual nodes' batteries from running out too soon and increasing the lifespan of the entire system. Additionally, the analysis shows that the suggested position responsive routing technique improves the network's resilience and flexibility to changing node densities and mobility patterns in comparison to traditional routing protocols, making it a workable solution for dynamic situations.

Compliance with ethical standards

Acknowledgments

I express my sincere gratitude and indebtedness to my supervisors Engr. Prof. O. C. Nosiri and Engr. Dr. A. O. Akande for their invaluable suggestions, encouragement and thorough supervision of this work. I am also grateful especially to the Head of Department of Electrical and Electronic Engineering, Engr. Prof. N. Chukwuchekwa, who always give a listening ear to issues. Also grateful to my lecturers, Engr. Prof. Chukwudebe Gloria A., Engr. Prof. Dike Damian O., Engr. Prof. Okpara F.K, Engr. Dr. A. O. Akande, Engr. Dr. Kennedy, Engr. Prof. Agubor, C. K., Engr. Prof. Onojo, O. J., Engr. Dr. L. S. Ezema and host of other lecturers and non-academic staff of Electrical and Electrical department, I say thank you all for your immeasurable contribution towards the successful completion of this programme. Also acknowledge a mentor, Engr. Fiberesima (RSUST) for his support, contribution, and encouragement. Finally, I would like to express my profound gratitude to my husband, my children, sisters, brothers and host of other relatives for their prayers, patience, love, understanding, concern, and support both morally and financially throughout this programme. You will, and forever be in my heart. I love you all to infinity. Likewise, I say a big thank you to my friends and colleagues especially Engr. Sunday A. Lawani, Engr. Abdulazeez Muhammad Sani and Engr. Stanley Imadu for their constant support and encouragement, May God richly bless you all, Amen.

Disclosure of conflict of interest

The authors declare that they have no know competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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