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Performance Comparison of PEGASIS, HEED and LEACH Protocols in Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) is one of the most emerging and fastest growing fields in the scientific world. The most widely recognized requirement related with sensor network configuration is that sensor hubs have restricted energy spending plans. Typically, when a sensor node's battery cannot be replaced or recharged, its low battery power becomes a serious problem. The efficient use of energy source in a sensor node is a desirable criterion for scalability and prolonging the lifetime of WSN. Therefore, designing an efficient routing protocol for reducing energy consumption is one of the important issues in the network. A large number of routing protocols have been proposed in the last few decades. Some of the most popular and energy efficient routing protocols are hierarchical routing protocols like LEACH (Low Energy Adaptive Clustering Hierarchy), PEGASIS (Power Efficient GAthering in Sensor Information Systems), and HEED (Hybrid Energy Efficient Distributed clustering protocol). In this paper, these hierarchical routing protocols are studied for their pros and cons. Finally, a comparative study on these protocols is done based on several metrics such as: energy consumption, stability period, scalability, and network lifetime through simulations on different simulation environments.

Keywords: HEED, LEACH, PEGASIS, Routing Protocol, WSN.

1. Introduction

The super distant association, known as the "Sound Surveillance System (SOSUS)," was made by the United States military during the 1950s to perceive and follow Soviet submarines. This association used brought down acoustic sensors known as hydrophones that were spread across the Atlantic and Pacific oceans [1]. This distinguishing advancement is at this point elaborate today in extra serene applications like noticing undersea untamed life and volcanic activity. Up until 1980, the United States Defense Advanced Research Projects Agency (DARPA) started research in wireless sensor networks (WSNs) known as "Circulated Sensor Networks (DSN)" to officially investigate the difficulties in executing disseminated WSNs. DSNs were assumed to have a large number of spatially distributed low-cost sensing nodes that collaborated and operated autonomously, with information being sent to the appropriate node for use. Coordinated effort with colleges, for example, Carnegie Mellon University and the Massachusetts Institute of Technology Lincoln Labs permitted DSNs to be incorporated into the scholarly community. Regardless of its uncertainty at that point, WSN innovation immediately tracked down a home in scholarly world and non-military personnel logical exploration [2].

Late headways in semiconductor, systems administration, and material science advancements empower the far reaching sending of enormous scope in WSNs. Together, these innovations have empowered another age of WSNs that offer huge benefits over remote organizations created 5 to quite a while back. Then again, the utilization of Wireless Sensor Networks has detonated in late many years and is as yet developing at a disturbing rate. This is impacting the manner in which we live, as individuals depend on remote network in an ever increasing number of parts of their regular routines [3].

WSNs are comprised of countless sensor hubs that are battery-controlled and have restricted memory as well as correspondence and calculation capacities. WSN

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applications are partitioned into two sorts: occasion discovery (ED) and spatial interaction assessment (SPE) [4]. Sensors are conveyed in ED to distinguish an occasion like a backwoods fire, tremor, and so on, while in SPE, WSN plans to screen actual peculiarities like temperature, pressure, etc for a given Region of Interest (ROI). Due to the large number of uses covered by WSN, sensor network execution measurements are rigorously application explicit.. WSNs can work in unattended unforgiving conditions where human mediation is unsafe, wasteful, and here and there unimaginable [5]. Thus, "network lifetime" has turned into a typical presentation metric for practically all WSN applications. The expression "network lifetime" alludes to the time after which an organization becomes inoperable. The hidden WSN's non-usefulness is likewise application subordinate, as a matter of fact [6].

Energy effective steering algorithm [11-13] can be ordered as follows: information driven routing [14] calculation, area based directing calculation [5]and progressive directing calculation [15]. Information driven steering calculation utilizes meta information to track down the course from source to objective before any genuine information transmission to dispose of repetitive information transmission Location based directing calculation requires real area data for each sensor hub. Various levelled steering algorithm [15] separates the organization into bunches. Cluster head (CH) is chosen in each bunch. CH [16] gathers information from its individuals, totals the information and ships off sink. This approach is energy proficient however generally complex than different methodologies.

Recent advancements in wireless technology have resulted in the creation of mobile wireless sensor networks. Aside from sensor mobility, sensors in the network are low-cost and have a limited battery life. They are more material with regards to the central attributes of these organizations [7]. These organizations have an assortment of uses, including search and salvage tasks, wellbeing and ecological observing, and canny traffic signal frameworks. As per the application necessities, portable remote sensor hubs are energy restricted gear, so saving energy is quite possibly the main issues in the plan of these organization. Alongside each of the difficulties brought about by the versatility of the sensor hubs, we can note to the directing and dynamic grouping [9]. Concentrates on show that group models, which have customizable boundaries have critical effect in limiting energy utilization and broaden the lifetime of the organization. Subsequently, the principal objective of this examination is to present and choose the shrewd way involving transformative calculations for grouping in portable remote sensor networks for expanding Lifetime of the Network and right conveyance of bundles [8].

Considering the design issues in WSNs and the sheer number of protocols available to tackle them, it is very difficult to find a routing protocol which suits a specific purpose or fulfills certain requirements with better results as compared to other protocols [9].

Moreover, there are many surveys such as [6], [7] and [8] on energy-efficient hirer- chiral routing protocols analyzing their strengths and weakness depending upon their impale- mentation, but none of them focused on their performance in energy-efficiency and prolonging network lifetime for large scale WSNs. That is, the scalability of a network is also an important criterion in deciding which routing protocol is more energy-efficient than the other [18].

This motivated us to work on this study where we select three known hierarchical routing protocols, LEACH, PEGASIS and HEED and do a simulation for 100 to 1000 nodes over a network area of (100 X 100) to (1000 X 1000) square meters and compare them on metrics such as load balancing, average energy consumption and lifetime of the network [19]-[20].

The rest of the article is arranged in this manner: Section 2 confers material and method. In Section 3, results and discussion are presented. Finally, the paper wraps up in Section 4.

2. Materials and Methods

Wireless sensor networks (WSN) play an important role in today's world. It is a useful technology for sending and receiving data from various parts of the system via mini sensor nodes spread across a large area. These nodes can perform a variety of data operations such as sensing the environment, gathering and processing data, and so on. The batteries embedded in these nodes provide the necessary energy for these processes. In many applications, sensor nodes are small and equipped with a small, low-energy battery. It is critical to reduce energy consumption and extend the network's lifetime as much as possible [9]. The contributions of this study can be expressed as

- Our work includes simulation of network for various simulation parameters such as number of nodes, network area, initial energy, location of base station, crossover distance, electronics energy per bit, aggregation energy per bit, and length of packets.
- Then we simulated the LEACH, PEGASIS and HEED as directed in their original paper and ran these protocols over the above-mentioned simulated network.
- We then, stored the statistics such as residual energy of network per round, dead nodes per round, average residual energy of a node per round, variance of residual energy per round for each protocol in different simulation environments.

- Finally, the conclusion was drawn after analyzing the statistics obtained by plotting the graphs for each protocol after every simulation.

2.1. LEACH Protocol

LEACH is a straightforward TDMA-based steering convention utilized in WSNs and is one of the most established and first various levelled conventions. Heinzelman (W. R. Heinzelman et al. 2000) proposed it in the year 2000. This group-based convention arose as an energy-proficient correspondence convention for remote miniature sensor networks that utilizations randomized revolution of nearby bunch base stations known as group heads to appropriate energy load consistently among sensor hubs in the organization.
The essential elements of LEACH are:

- For the setup and operation of clusters, localized control and coordination.
- The cluster heads and related clusters are rotated randomly.
- To decrease global communication, use local compression.

Filter (S. Lindsey, et al. 2002) is a various levelled directing convention that is ordinarily utilized in WSNs. The idea proposed in LEACH has enlivened the advancement of a few comparable various levelled steering conventions. Sensor hubs in LEACH put together themselves as nearby groups, with one hub going about as the Cluster Head (CH) and different hubs as straightforward individuals from that bunch. Drain utilizes randomized group head pivot to appropriate energy utilization uniformly among hubs. The bunch heads get information from their group individuals and total it to lessen the quantity of messages shipped off the Base Station (BS). In each round, the sensor hubs freely choose themselves as group heads with a foreordained likelihood. To decrease above in group head foundation, every hub pursues a political race choice that is autonomous of different hubs. The organization runtime is separated into adjusts. In each round, every hub chooses an irregular worth somewhere in the range of '0' and '1'. Assuming the arbitrary worth is not exactly the ongoing round's limit, the hub turns into the group head:

$$T(n) = \begin{cases} \frac{p}{1-p(r \bmod \frac{1}{P}} \; if \; n \in G) \\ 0 \; otherwise \end{cases} \quad (1)$$

where n addresses the given hub, p addresses the predefined level of hubs that can be bunch heads, r addresses the ongoing round, and G addresses the arrangement of hubs that didn't become group heads in the past 1/p adjusts. Drain's execution time is separated into adjusts.

2.2. PEGASIS Protocol

The convention PEGASIS was supportive of presented by Lindsey and Raghavendra [70] in which a chain of sensor hubs is framed and every hub discusses just with its nearby neighbours. Only one selected node delivers data to the BS; otherwise, data is sent from node to node. The leader node in charge of transmission switches every round. Either the BS determines the chain's creation, or the nodes themselves use a greedy method to do it. Each node collects data from its neighbor during data collection and transfers it to the next neighboring node after fusing it with the data it has already collected. The sensor nodes die out at random areas to strengthen the system. By switching the data transmission leader in each communication cycle, this is accomplished.

2.3. HEED Protocol

The essential presumption in HEED is that every sensor hub is fit for controlling its transmission power level however they are area un-mindful. It was proposed by Younis and Fahmy [16] in 2004, this method was created as a disseminated and energy proficient group development. Notice utilizes a blend of two unique boundaries for CH determination for example remaining energy of every hub and hub degree. A hub can be chosen as a CH relying upon its lingering energy along with some likelihood. The group arrangement happens when different hubs in the organization pick their separate CHs keeping up with least expense of correspondence. The fundamental goal of HEED is to draw out network lifetime as well as supporting versatile information conglomeration.

The two clustering parameters which are used in the algorithm are Residual Energy of the node as a primary parameter and Intra Cluster Communication Cost as a secondary parameter. Higher the residual energy of the node, higher the probability of that node to become a cluster head (CH).

3. Results and Discussion

Today, the greater part of the exploration is done to create super low fueled WSN which is just conceivable provided that the general organization lifetime increments, energy utilization [16] diminishes and the organization run with high security and unwavering quality. To accomplish this, numerous calculations have been executed. They are called energy-productive calculations. These calculations in their fundamental structure have previously been carried out on different organization conventions including LEACH, PEGASIS, HEED and so on. Be that as it may, these calculations need further examination for expansion in network lifetime, energy productivity and so forth. So, the proposed algorithm is one of the energy productive conventions intended to build the organization lifetime.

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3.1. Experiment Results

The simulation of LEACH, PEGASIS and HEED was done in MATLAB. Some simulation plots has been shown in Figures 1, 2 and 3. Here, we are going to describe some of the important aspects of the simulation like assumptions, simulation parameters, simulation network environments and energy dissipation model. Table 1 represent simulation parameters.

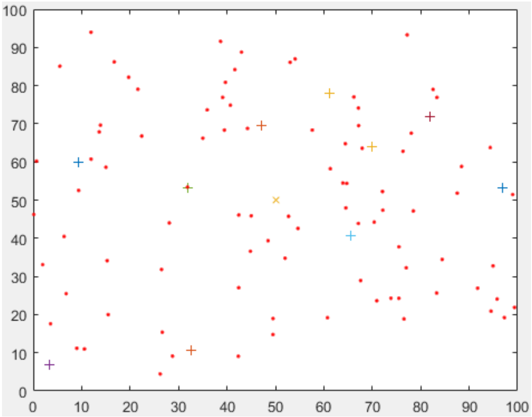

Figure 1. LEACH plot for 100 nodes at round 1334, dead nodes 20, cluster heads 6.

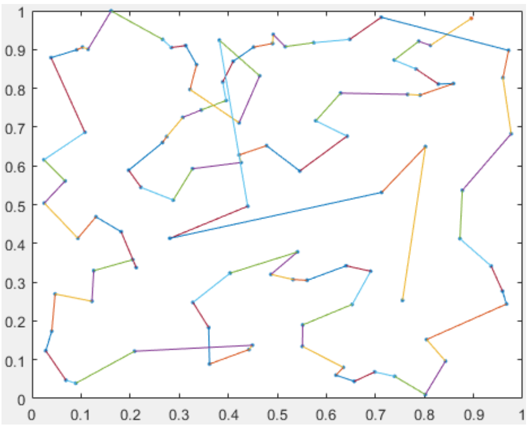

Figure 2. Chain formation in PEGASIS for 20 nodes.

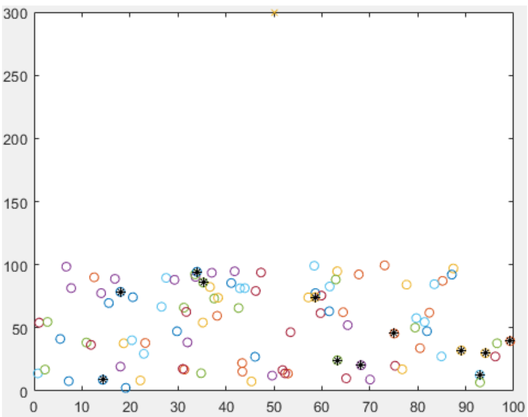

Figure 3. Chain formation in HEED for 20 nodes.

Table 1. The simulation parameters.

Simulation Parameters	Values
E_{elec} (Electronics energy loss per bit)	50 nJ
E_{fs} (Free space energy loss per bit per m^2)	10 pJ
E_{mp} (Multi-path fading energy loss per bit per m^4)	0.0013 pJ
E_{aggr} (Data Aggregation energy loss per bit)	5 nJ
Packet length (bits)	2000
P (Desired fraction of cluster heads in LEACH)	0.05
P_{min} (Minimum probability to be a cluster head inHEED)	$5*10^{-4}$
C_{prob} (Initial probability to be a cluster head in HEED)	0.05

3.1.1. Radio Energy Dissipation Model

Remote correspondence is the primary piece of energy dispersal in WSN. The energy dissemination model utilized in our re-enactment is displayed in Figure 4 [21] and is depicted beneath in Eq. 2. Depending on the distance between the transmitter and the receiver, the effective radio energy dissipation model employed both the free space (d^2 power loss) and the multipath fading (d^4 power loss) channel models. The free space model is employed if the distance is below a certain threshold, d_0; otherwise, the multipath model is used. The energy required to send a message of length k across a distance d is shown. Additionally, we expect that the radio divert is symmetric in nature for example energy expected to send a parcel from hub A to hub B will be equivalent to energy expected to send a bundle of same length from hub B to hub A.

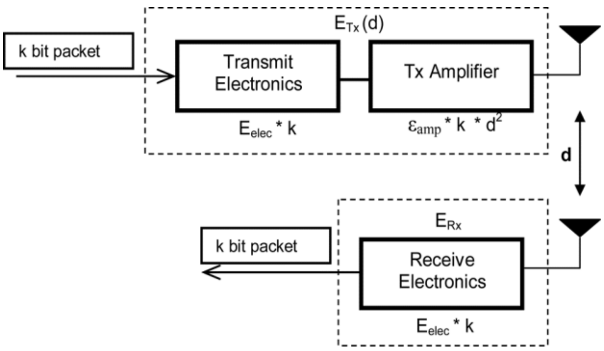

Figure 4. Radio Energy Dissipation Model in WSN [21].

The energy cost of transmission (E_{Tx}) is given as [16]

$$E_{Tx} = \begin{cases} k * E_{elec} + E_{fs} * d^2 & if\ d \le d_0 \\ k * E_{elec} + E_{mp} * d^2 & if\ d \ge d_0 \end{cases} . \tag{2}$$

Here, ‘k’ is packet length in bits, ’Elect’ is the electronics energy loss per bit, ’d’ is the distance up to which the data has to be transferred, ’Efs’ is the free space energy loss per bit per m2 , ’Emp’ is the multi-path fading energy loss per bit per m4 , and d0 is the crossover distance which is defined as [16]

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$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}}\,. \quad \textbf{(3)}$$

Therefore, depending upon the transmission distance, both the free space (E_{fs}) and multi-path fading (E_{mp}) models are used in our energy dissipation model. The energy cost for reception (E_{Rx}) is given as [16]

$$E_{Rx} = k * E_{elec}. \quad \textbf{(4)}$$

Here, 'Elect' is the electronics energy loss per bit. The energy cost for data aggregation (Eager) is given as [16]

$$E_{aggr} = k * E_{da}. \quad \textbf{(5)}$$

Here, 'Eda' is the data aggregation energy loss per bit.

3.2. Result Analysis

The simulation results obtained from the 4 network environments shows the overall relative behavior of LEACH, PEGASIS and HEED and is compared on metrics such as load balancing, network lifetime, energy consumption, and scalability. The Table 2 shows a summarized result of nodes death and the number of rounds of each protocol in each environment for comparing their behavior.

Table 2. Dead Nodes vs. Number of Round.

Environment No.	Protocols	No. of rounds		
		First Node Dies	Half Node Dies	Last Node Dies
Env.:1	LEACH	1165	1611	2209
	PEGASIS	1877	2090	2362
	HEED	207	947	2384
Env.:2	LEACH	255	669	1729
	PEGASIS	1236	2663	3600
	HEED	63	498	1867
Env.:3	LEACH	22	114	432
	PEGASIS	507	1919	3412
	HEED	6	192	673
Env.:4	LEACH	1	17	80
	PEGASIS	1	324	882
	HEED	1	59	236

3.3. Graph Plots of LEACH, PEGASIS and HEED

The graph plots obtained from the simulation describes the performance of each protocol in the simulated environment and can be interpreted on the following metrics:

Figure 5, 6, 7 and 8 shows the graph of each protocol in the 4 environments. Each figure has 4 sub plots describing the total energy, dead nodes, average energy and variance of nodes energy in the network vs. number of rounds of protocol operations.

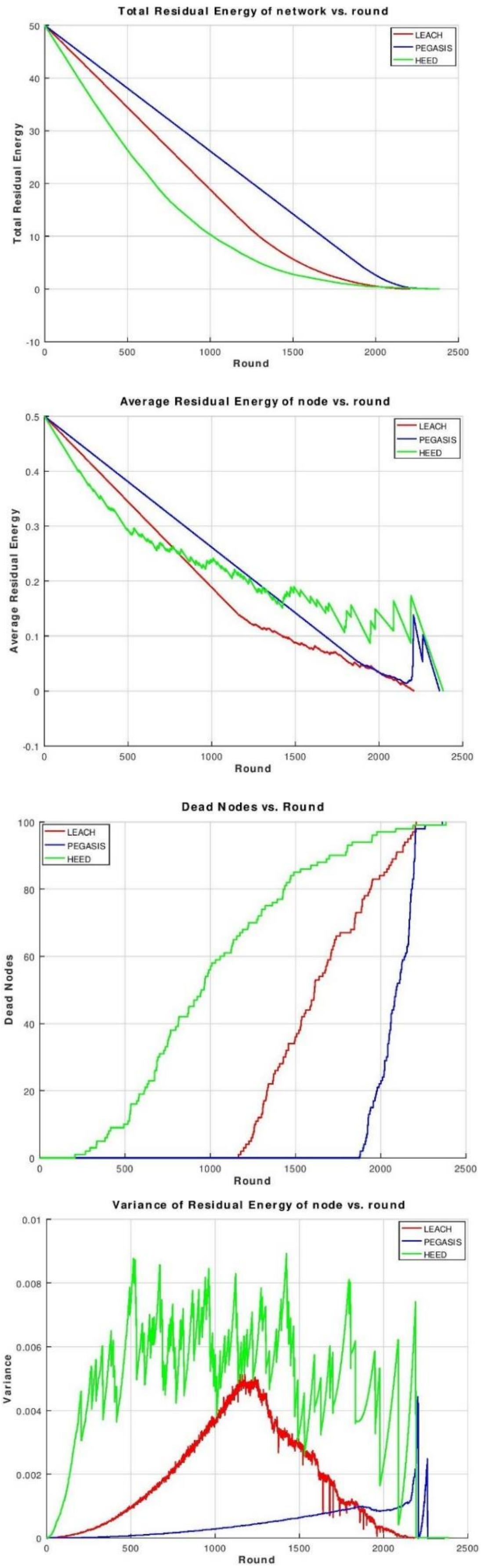

Figure 5. Graphs for Environment: 1

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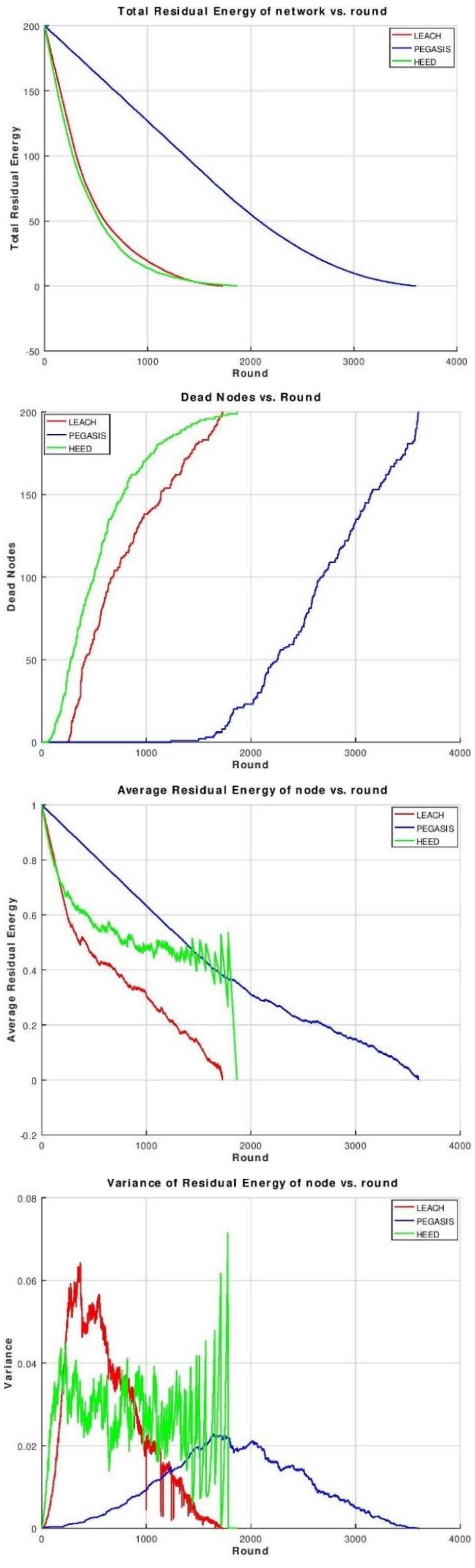

Figure 6. Graphs for Environment: 2

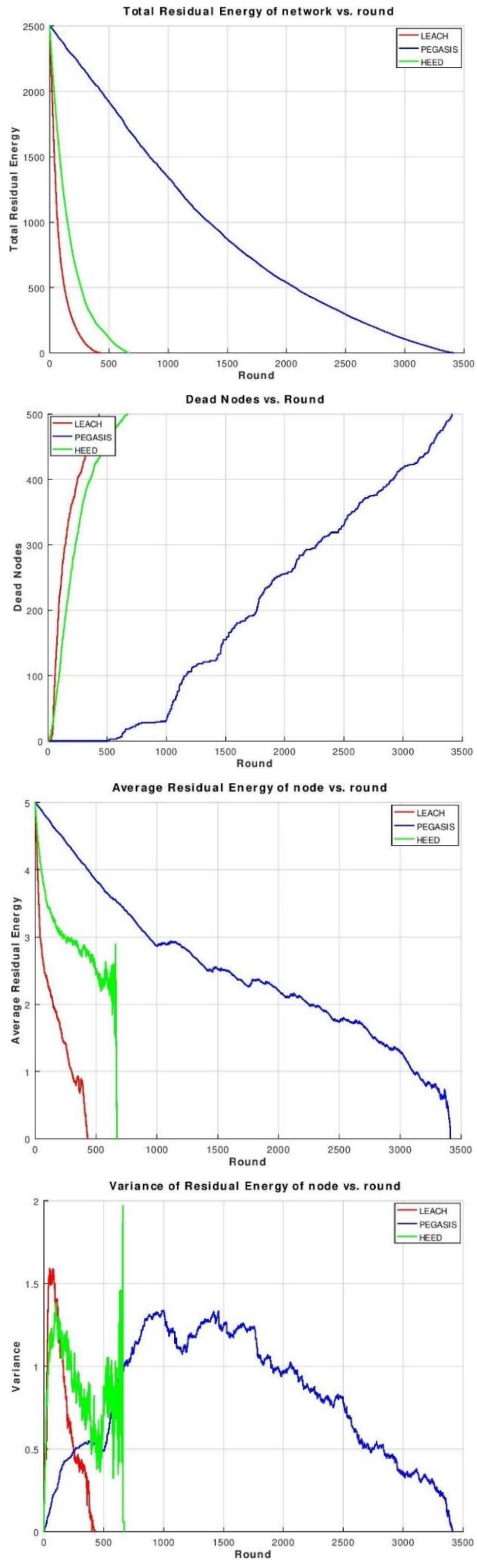

Figure 7. Graphs for Environment: 3

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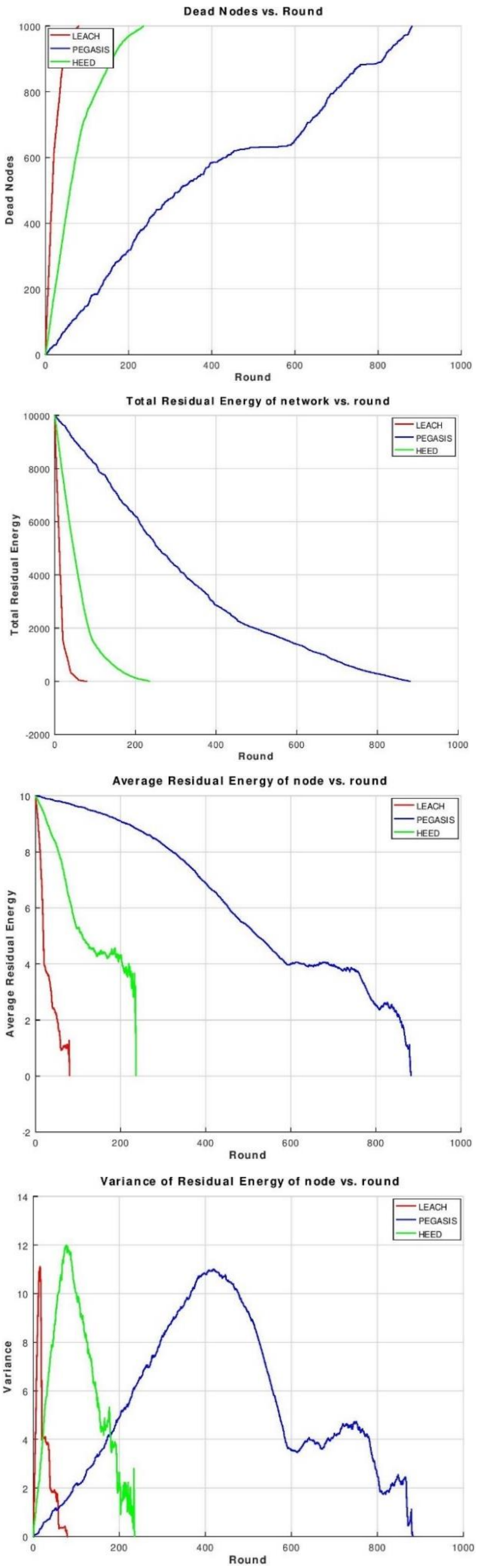

Figure 8. Graphs for Environment: 4

The graph plots obtained from the simulation describes the performance of each protocol in the simulated environment and can be interpreted on the following metrics:

Energy Consumption: The higher the total residual energy of the network for any protocol at any given round, the lower the energy consumption and higher the energy efficiency of the protocol. From the sub plots of Total Residual Energy vs. Round, we can observe that the PEGASIS residual energy curve is above the other two curves in every environment, even when the size of network was increased to 1000 nodes and the network area to 1000 X 1000 m^2, so it is highly energy efficient as compared to other two protocols. LEACH on the other hand is better than HEED for smaller network like Environment 1 and 2 but, as the network size increases, HEED becomes better than LEACH as we can observe in graph plots of Environment 3 and 4.

Load Balancing: Load balancing in WSN [9] is the act of balancing the network traffic load on the entire network such that most of the nodes survive longer and consume similar amount of energy in transferring of data from one point to the other. From the sub plots of Average Residual Energy vs. Round and the Variance of the Nodes Residual Energy vs. Round, we can observe that the average residual energy of the nodes at any given round is higher in PEGASIS and the variation in each nodes' residual energy is lower, than in LEACH and HEED in every environment i.e. PEGASIS balances the network load better than other two protocols in every environment.

Stability Period: It is defined as the number of rounds from the starting round after which the first node dies [11]. For many applications, the stability period should be higher to cover the entire network for most of the rounds to get better quality of service from the network. From the data shown in table 1 and the sub plots of Dead Nodes vs. Round of each environment, we can observer that the stability period of PEGASIS is far better than the other two protocols.

Network Lifetime: It is defined as the total number of rounds for which the protocol runs until the last node dies [16]. From the sub plots Dead Nodes vs. Round in every graph, we can observe that PEGASIS has the highest network lifetime, followed by HEED and the lowest network lifetime is for LEACH in every environment.

4. Conclusion

This paper presents a comparative study among LEACH, PEGASIS, and HEED protocols. From the simulation results, it is noticeable that PEGASIS is a highly energy-efficient protocol as compared to LEACH and HEED when scalability is also one of the factors or design issues of WSN. This is because PEGASIS has two main objectives. First, reduce the power required by each node to transmit data per round by using collaborative techniques and spread the power draining uniformly over all nodes. Second, permit just neighborhood coordination between hubs that are near one another so the transmission capacity consumed in correspondence is diminished. Hence, PEGASIS performs better on all the metrics in consideration i.e., load balancing, stability period, network lifetime, and scalability. Furthermore, WSN routing protocol is still a vast field of research and a more scalable and energy-efficient protocol is needed for data gathering in WSNs which includes future research work.

Author's Contributions

Kareem Hameed Ali: Conducted the experiment and result analysis, and then drafted and prepared the article.
A. F. M. Shahen Shah: Assisted and supervised the study, as well as helped in manuscript preparation.

Ethics

After this manuscript's publication, there are no ethical concerns.

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