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Analysis of LEAPET: A New Energy-Aware Routing Protocol for Internet of Things-Based Heterogeneous Wireless Sensor Network

Kazeem B. Adedeji*

Department of Electrical and Electronics Engineering, Federal University of Technology, Akure, Ondo State, Nigeria

Abstract

Routing protocol is required for wireless sensor network (WSN) to transmit data to a base station. Because of the resource constraint internet of thing (IoT) sensors, it is vital to have an energy efficient routing protocol for the IoT-based Heterogeneous Wireless Sensor Networks (IoT-HWSN). This study developed a new energy-efficient routing protocol for HWSN. The routing protocol combines the functionalities LEACH, PEGASIS, and Adaptive Time Division Multiple Access (TDMA) to improve energy efficiency and data transmission. In this study, 100 heterogeneous sensor nodes with an initial energy of 0.5 J were modelled and simulated in a 100 m by 100 m square area. The performance of the developed routing protocol was compared to other existing routing protocol like LEACH, A-LEACH, PEGASIS, MC-PEGASIS, EERP and A&F. The results obtained show that the LEAPET routing protocol has the superior performance while MC-PEGASIS has the second best performance. In comparison to this, LEAPET achieves an improvement in a network lifetime of more than 14.3% over MC-PEGASIS. In terms of the packet delivery ratio, the LEAPET achieved up to 98.8% and 95.6% of packet delivery ratio with 10 and 100 nodes respectively. Furthermore, the proposed routing protocol (LEAPET) yields a good result with relatively minimum delay when compared with existing routing protocols.

Keywords: Base station; energy consumption; LEACH; PEGASIS; routing protocol; sensor node.

*Corresponding author

Email address: **kbadedeji@futa.edu.ng** (K. B. Adedeji)

1. Introduction

The process of connecting millions of devices to the Internet so that they can be remotely monitored or controlled is known as the IoT. The most popular approach to achieving this high degree of connectivity is wireless technology. The swift advances in wireless technology and small, low-power, low-cost Micro-electromechanical (MEM) sensor technology [1, 2] have made it possible for wireless sensors to be utilised in large quantities to form wireless sensor networks for wide range of applications, such as intrusion detection, surveillance, monitoring, and image formation of target field. Because these sensor networks have a variety of sensor types with varying computational or communication capabilities, they can be deployed heterogeneously to improve coverage and communication performance, lower deployment costs, and achieve improved data delivery rates and throughput [3-6]. HWSNs are dedicated wireless networks with sensor nodes with different energy, processing power, communication range, and data handling capabilities. This makes them a good candidate for IoT applications. Sensor nodes (SNs) are grouped or clustered in HWSNs (Figure 1). There is a cluster head (CH) for every cluster. To transmit to a base station (BS), the CH compiles the detected data from its SNs. These sensors or the CH determine the optimal route to send the data during transmission to the BS in order to save energy usage. Routing protocol algorithms are used to accomplish this.

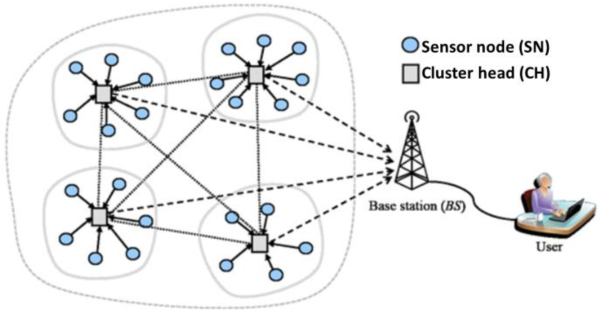

Figure 1: Architecture of a heterogeneous wireless sensor network [7]

In general, routing protocols are necessary for WSNs to send data packets to their sinks, or destinations. Different WSNs currently route their own packets through their own routing paths and sensors since their routing paths are mutually independent [8]. When sensor receives a packet from another WSN, it discards it without forwarding it to the appropriate sink. Since many more sensors can relay packets in this heterogeneous WSN, the distance between two neighbouring sensors will be reduced which increases the sensor density of this monitoring environment. In fact, if sensors are able to forward receiving packets for other WSNs, the routing efficiency will essentially improve. The packet-transmission energy used decreases with decreasing distance. Batteries are used to power SNs. Unfortunately, sensor nodes placed in harsh or complicated environments have limited battery capacity, making battery replacement and charging more difficult [9, 10]. Energy efficiency is perhaps the most important challenge when developing WSN routing methods [11, 12]. Network energy usage and longevity are directly impacted by heterogeneous wireless sensor networks with different beginning energies [13]. Thus, one of the main issues with HWSNs is energy usage. Due to the restricted resources of battery-powered sensor nodes, several research studies in routing protocol domain [14–28] prioritised energy efficiency, network lifetime, scalability, and reliability because of the importance of SNs in numerous applications. In this study, a new energy-aware routing protocol for HWSNs was developed. The performance of this routing protocol is evaluated against those of other routing protocols currently in use. Unlike previous studies [16-18], an adaptive TDMA technique was used in this study to allocate time slots for data transmission to reduce the data collision from the chain leaders. Thus, the proposed routing protocol produces the best stability period, as well as superior network lifetime, energy consumption, maintain higher data transmission (throughput) from the chain leaders to the BS while minimising data loss.

2. Review of Related Studies

Depending on the network layout, the routing protocol may either be flat or hierarchical protocol. In the flat routing protocol, every node has the same function; that is, there is no hierarchy and every node is equal. The nodes collaborate to carry out their assigned tasks, which include gathering data from the environment in which they are installed. The flat routing protocol is a type of multi-hop architecture [29]. One common example of this protocol is the Sensor Protocols for Information via Negotiation (SPIN). Before transferring data, a node in this protocol notifies its neighbours about it [30]. In hierarchical routing, the SN is divided into clusters. A CH is selected from each cluster. Data is first sent to the CH in the specific cluster where the sensor node is located, rather than being sent straight to the BS by each sensor node. Sensor nodes transmit data to the cluster heads (low level communication) in this protocol, while the cluster heads send data to the sink (high level communication). Multi-hop communication is used to implement hierarchical routing. Through data aggregation, the hierarchical protocol lowers the load of messages received by the BS, hence reducing network energy usage. The Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is a hierarchical single-hop protocol that uses the CHs to relay data to the BS and clusters sensor nodes according to the strength of the signal received. One of the most often used clustering protocols in WSN is LEACH. An improvement over the LEACH protocol leads to the development of LEACH-C. This is a LEACH variant that uses the sink to create clusters. Nodes send location and energy level data to the BS during the cluster creation process. Based on the energy required to transmit data from the cluster nodes to their cluster heads, the BS divides the network into a predetermined number of clusters and their cluster heads. Another example of a hierarchical routing protocol that arranges sensor nodes in a chain to route data effectively is the Power-Efficient Gathering in Sensor Information Systems (PEGASIS) protocol. Each node in PEGASIS alternates between being the leader for transmission to the BS and sending and receiving data from nearby nodes. Consequently, the network's sensor nodes will experience an equal distribution of energy load [31]. PEGASIS is advancement over the LEACH protocol, which builds node chains rather than clusters. The primary feature of the PEGASIS chain is that each node only communicates with its immediate neighbours and transmits data; only one sensor node, known as the chain leader, is chosen and in charge of communicating with the BS. Furthermore, Multi-chain PEGASIS (MC-PEGASIS) was developed as an improvement over the PEGASIS protocol. Instead of creating a single chain, this routing protocol splits the network into several chains. This routing protocol is paired with additional techniques like sink mobility or relative distance computations to increase energy efficiency and extend the network's lifetime compared to the conventional PEGASIS protocol [32].

The Hybrid Energy-Efficient Distributed clustering protocol **(**HEED) is a hierarchical routing protocol introduced as an extension to the LEACH routing protocol. It is designed for WSNs to group nodes into clusters to save energy and enhance network scalability. The cluster generation process is carried out in multiple cycles in HEED. Each cycle takes long time to get data from corresponding nodes in the cluster. During the first cycle, the initialisation of the CH selection is bound by a probability factor. In this case, each SN becomes a CH by using a probability factor. The probability of a node becoming a CH ($N_{CH\text{-}prb}$) is expressed by (1) and (2) [33]:

$$N_{CH-prb} \begin{cases} < 1 \\ = 1 \end{cases} \tag{1}$$

where

$$N_{CH-prb} = C_{prb}\left(\frac{P_{rem}}{P_{\max}}\right) \tag{2}$$

In (2), P_{rem} is the remaining energy in the sensor node and P_{max} is the maximum power which is equivalent to a charged battery source. The $N_{CH\text{-}prb}$ must be higher than the minimum threshold value. If $N_{CH\text{-}prb}$ <1, then the CH is a temporary cluster head. However, if $N_{CH\text{-}prb}$ =1, then the NCH will become the final CH. The currently elected CH will be added to the sets of CHs. Afterwards, each node increases its probability value to become the CH in the next round.

A lot of research studies have been conducted on the different kinds of energy-efficient routing protocols [16-28]. The studies in [16–18] suggested cluster-based routing protocol for heterogeneous wireless sensor networks in order to balance sensor energy usage. In this study, a cluster's sensors choose a leader to coordinate packet delivery and collection. A packet may make many more hops before reaching the sink, though, and such an election uses a lot of energy. These investigations on HWSNs demonstrate that sensors with varying capacities are caused by conveying varying amounts of energy.

In order to save relaying costs, an ideal path for packet delivery was chosen in [19] by gathering the statuses of its neighbouring sensors. However, the most recent data must be kept up to date, and sensor statuses from the whole monitoring environment must be gathered on a regular basis. The result presented shows that the energy consumption is relatively high. To increase routing energy efficiency, Cheng et al. [20] investigate a two-stage cooperative routing strategy. A two-stage connection cost was developed in this study, and the link cost was optimised by setting the ideal helper. To reduce the end-to-end cooperative routing cost, a distributed two-stage cooperative routing protocol was also incorporated. Although, the research study conducted by Dung and An [21] introduced stability-aware cooperative routing protocol in multi-rate mobile ad-hoc wireless networks to provide high data transmission via stable and reliable routes, energy efficiency and lifetime of a heterogeneous WSN were not taken into consideration. This is one of the important limitation of these studies.

In [24], two heterogeneous wireless technologies (such WiFi and cellular 3G/4G) were combined. The primary and secondary distribution base stations can communicate with each other quickly and reliably thanks to the technology. Through this integration, data packets of various types can be transmitted over the two radio interfaces, which act as data pipes. This allows for the application and efficiency of HWNs to meet the reliability and timeliness requirements of future smart grids. According to their research, HWNs may be good choice for smart grid data transfer. There is a need for more research in this area because the findings from these studies are insufficient to effectively overcome the energy dissipation of sensors.

3. Research Method

3.1. Overview of the LEAPET Model

LEAPET is a cross layer (hybrid) routing protocol that integrates the functionalities of LEACH and PEGASIS used in the network layer of the protocol stack and an adaptive global TDMA of the MAC layer. LEAPET combines the strengths of both LEACH and PEGASIS to balance energy consumption and reduce delay of data transmission to the sink. The global adaptive TDMA scheduling is employed to allocate and manage time slots for the leaders of the PEGASIS chains to transmit aggregated data to the BS. Instead of the assignment of static time slots to the nodes, adaptive timing is used to adjust time slot assignment based on the current conditions of the network, such as the activities of nodes, energy levels or the load traffic. TDMA ensures that there is a collision free communication between chain leaders as they simultaneously transmit aggregated data to the base station. This hybrid routing protocol enhances and ensures that an energy-efficient routing and communication is achieved among the sensor nodes in the HWSN, and in return prolongs the network life.

3.2. LEAPET Model Algorithm

Figure 2 shows the block diagram of LEAPET routing protocol. As shown in Figure 2, the first stage is the initialization stage where the parameters of the nodes are defined and the nodes are randomly deployed and initialized. Thereafter, clusters are formed using LEACH.

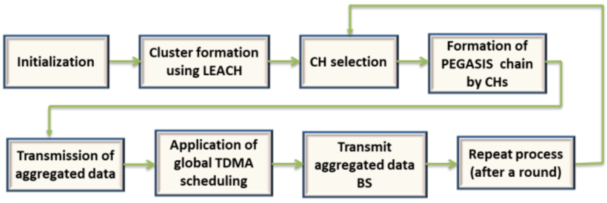

Figure 2: The block diagram of the LEAPET model

Under this stage, each cluster chooses a CH according to the LEACH routing protocol and the selected CH broadcast or informs the nodes of its headship. Electing a CH in the LEACH routing protocol is determined by the threshold value $T(n)$ according to (3) [17].

$$T(n) = \begin{cases} \dfrac{p}{1 - p\left(r \times \mathrm{mod}\left(\frac{1}{p}\right)\right)} & n \in G \\ 0 & otherwise \end{cases} \tag{3}$$

where p is the probability of each nodes becoming a CH during round 0, r is the current number of rounds and G is the set of nodes that will not be elected as CH.

Within the clusters, using TDMA, time slots for data transmission are allocated to the sensor nodes by the CH to avoid collision. The CH election considers factors like: node energy level, node degree or number of nearby nodes, node closeness to cluster center. The formation of PEGASIS chain is the stage where all the cluster heads from various clusters come together to form a chain according to the PEGASIS routing protocol. After the chain(s) has/have been formed, the chain leader(s) is/are randomly selected. Thereafter, the data is transmitted along the chain from one CH to the other until it reaches the chain leader which transmits the aggregated data from the PEGASIS chain to the base station (sink).

The energy dissipated by the communication devices of the sensor nodes was modelled both for the transmission and reception using (4) and (5). Assume that the size of each data packet is k bits, a node i send data of k bits to another node j separated by a distance of d_{ij} which is the Euclidean distance between them, the energy consumed by the sending node during transmission is expressed by (4).

$$E_{ij(TX)} = \begin{cases} k\left(E_{elec} + E_{fs} d_{ij}^{2}\right), & d_{ij} > d_m \\ k\left(E_{elec} + E_{mp} d_{ij}^{4}\right), & d_{ij} > d_m \end{cases} \tag{4}$$

In (5), E_{elec} is the electronics energy in the transceiver, E_{fs} is the free-space energy dissipation while E_{mp} is the multi-path energy dissipation. During reception, the energy consumed by each receiving node is expressed as

$$E_{ij(RX)} = kE_{elec} \tag{5}$$

The expression in (4) and (5) is the energy consumption model for a node which is assumed to be free space. Considering the power management of P_m, and the initial energy of the node E, the lifetime of the node which express the time before the node's energy reaches zero is expressed as

$$T_{lt} = \frac{E}{P_m} \tag{6}$$

Data is transmitted in rounds. Since PEGASIS chains formed can be more than one or two in a very large HWSN, therefore, the adaptive global TDMA scheduling stage assigns dynamic and adaptive time slots to the chain leaders to manage when each of them can transmit data to the BS to avoid collision according to Algorithm 1.

Algorithm 1: Adaptive global TDMA

Input: SNs, BS, and maximum frames T

Initialisation: Input network parameters and initialise

1: Assign base station as global time reference
2: Broadcast initial synchronization beacon from BS
3: Initialise S with baseline slots

4: **for** t = 1 to T **do**
5: BS broadcasts time synchronization beacon
6: **if** new nodes join the network
7: $t_{unique} \leftarrow n_j$ (unique time slots assigned to joining nodes)
8: **end if**
9: **if** (traffic or topology changes detected)
10: Adaptively recompute and update S
11: **end if**
12: Nodes transmit data in their assigned slots
13: end for
14: return S

The chain leader(s) will have the global knowledge of the network to know when data should be transmitted at the allocated time slot only to avoid collision which causes loss of energy. After the data has been transmitted to the BS, the energy level of the network is checked after a round is completed and if there is a need for re-clustering, the cycle will start again from the LEACH stage, that is, new cluster will be formed and the process is repeated.

3.3 Experimental Set-p and Simulation Environment

Modelling and simulation are done in MATLAB environment. The model consists of 100 heterogeneous SNs randomly distributed in 100 m by 100 m square area with an initial energy of 0.5 J. The configuration and parameters of the WSN used for this simulation are shown in Table 1. The BS is placed at the coordinate (50, 50). Also, 4000 rounds of simulation was run with a packet of 4000 bits.

Table 1: Simulation parameters

Parameters	Value
Number of nodes (N)	100
Area size	100 m × 100 m
Base station position	[50, 50]
Initial energy	0.25 J/node, 0.5 J/node, 1 J/node
Transmission energy (E_{tx})	50^{-9} J/bit
Receiver energy (E_{rx})	50^{-9} J/bit
Data packet size	4000
Round of simulation	4000
Free-space energy dissipation (E_{fs}))	10^{-12} J/m^2
Multi-path energy dissipation (E_{mp})	0.0013^{-12} J/m^4

3.4 Performance Evaluation

The performance of the developed routing protocol was analysed and compared with existing routing protocols based on the following metrics:

(i) Average remaining energy: This is the remainder of the energy used to extend the lifetime of the node. The system is more dependable if each node consumes small amount of energy for data transport, and the remaining energy is fairly distributed evenly across the network. The average remaining energy E_R is determined using (7).

$$E_R = E_{in} - E_c^t \tag{7}$$

where E_{in} is the initial energy of the node, and E_c^t is the energy consumed by each node during time t.

(ii) Packet Delivery Ratio (*PDR*): This is the ratio of the number of packets that are successfully transmitted to the BS. This is estimated using (8).

$$PDR = \frac{TP_R}{TP_S} \times 100\% \tag{8}$$

where TP_R is the number of packet received and TP_s is the number of packet sent.

(iii) Throughput (*TP*): This is the amount of data transferred to the BS via the nodes. This is expressed as

$$TP = \frac{TP_S \times S_P}{t} \times 100\% \tag{9}$$

In (9), S_p is the size of the packet and t is the time taken to transfer these packets.

(iv) End-to-End Delay (*EED*): This is the estimate of the time taken during data transmission from the sensor nodes to the sink node. This was estimated using (10).

$$EED = T_{DT} + T_{DP} \tag{10}$$

where T_{DT} is the time required for data transmission and T_{DP} that required for processing.

(v) Stability Period (*SP*): This is the time span from the beginning network operation until the first dead sensor occurs. This is estimated using (11).

$$SP = T_{FND} - T_{st} \tag{11}$$

where T_{FND} is the time it takes the first node to deplete all its energy and T_{st} is the time of the beginning of network operation.

(vi) Network lifetime: This time span from the beginning of network operation untill the last live node dies [34]. It was estimated using (12).

$$T_{lft} = T_{LDN} - T_{st} \tag{12}$$

where T_{lft} is the network lifetime and T_{LDN} is the time at which all the sensor nodes died.

4. Results and Discussion

4.1 Node Deployment and Initialization

Figure 3 shows the random deployment and initialisation of the sensor nodes in a specified area, such as remote farm, industrial area, etc. 100 sensor nodes were randomly deployed in a field of 100 m by 100 m area with an initial energy of 0.5 J/Node. Figure 4 shows the stability period and the network lifetime for the sensor nodes. The stability period is the one starting from the beginning of the network until the death of the first node. As shown in Figure 4, it can be observed that LEAPET presents the best stability period with more than 2000 rounds. This is due to the energy gain caused by the sink mobility. MC-PEGASIS produced the second best stability period while the least is observed with LEACH routing protocol.

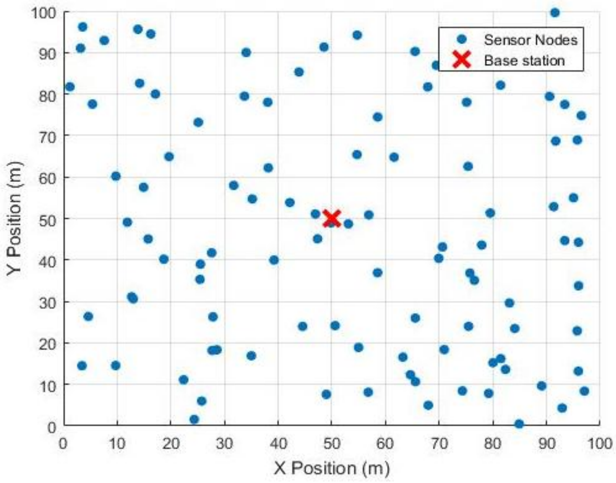

Figure 3: Heterogeneous network deployment with 100 nodes

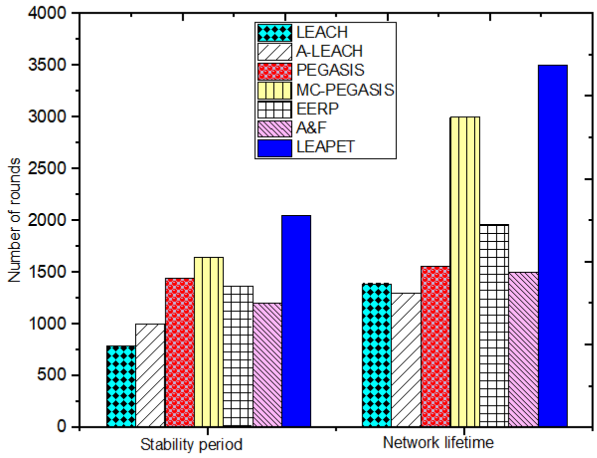

Figure 4: Analysis of the network lifetime for the protocols

Furthermore, LEAPET produce superior network lifetime than the other routing protocols investigated. This is due to the high energy levels possess by some of the sensors. The results presented revealed that the proposed routing protocol (LEAPET) achieves an improvement in a network lifetime of more than 14.3% in comparison with the MC-PEGASIS which is the second best routing protocol for this case. It is evident from the graph that the LEAPET routing protocol attains a good life for all SNs than other compared approaches.

Figure 5 shows the analysis of the throughput produced by all the protocols investigated against the node size. When 10 nodes were considered, the LEAPET indicates that throughput of about 95% is achieved and about 90.2% at 100 nodes. As the node size increases, the throughput recorded by all the routing protocols decreases.

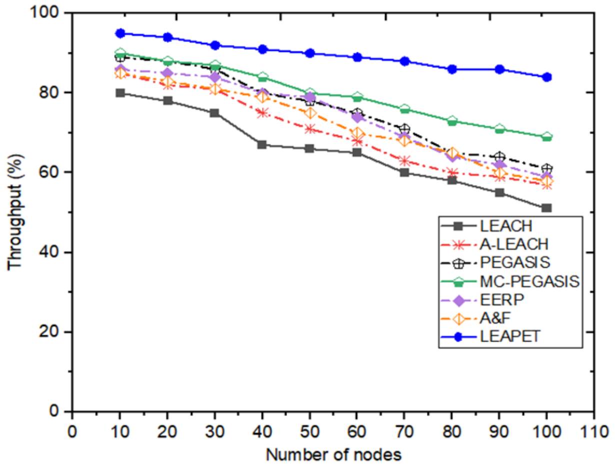

Figure 5: Analysis of throughput vs. number of node

At 100 nodes, the proposed LEAPET routing protocol achieved a throughput of 84% which is the highest among the considered protocols even when the number of nodes increases. The MC-PEGASIS obtains a slightly similar range of throughput for all the nodes. Considering these two protocols, there is 11.6% decrease in the throughput as the node increases to 100 for the LEAPET routing protocol while that of the MC-PEGASIS has about 23.3% decrease in the throughput. Thus, the LEAPET protocol confirms that the data transmission can be achieved with less energy and high throughput. The ratio of packet delivery for the different nodes are represented in Figure 6. Similar to the results presented in Figure 5, the LEAPET achieved up to 98.8% and 95.6% of packet delivery ratio with 10 and 100 nodes, respectively while the second best performing protocol (MC-PEGASIS) records a packet delivery ratio of 93% and 84% with 10 and 100 nodes, respectively. The highest packet delivery ratio is achieved by the proposed LEAPET routing protocol.

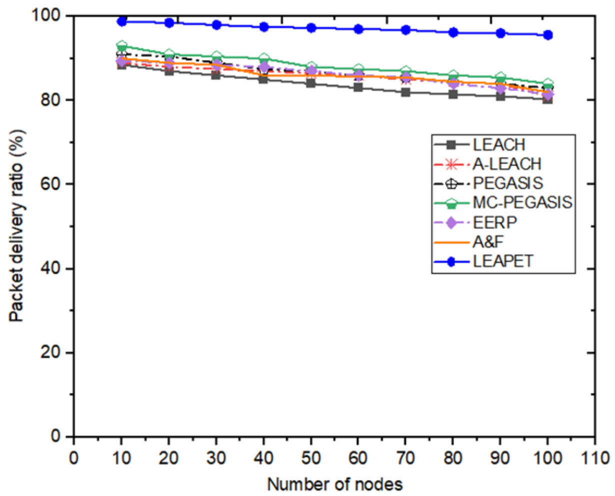

Figure 6: Analysis of packet delivery ratio vs. number of nodes

Figure 7 shows the end-to-end delay produced by the routing protocols against the number of nodes. As shown in Figure 7, it can be observed that the end-to-end delay increases with increasing node size due to the larger transmission distance. The LEAPET yields a good result with relatively minimum delay when compared with previous similar routing protocols. The results from Figure 7 indicate that the delay ranges from 3 s to 6 s for the LEAPET routing protocol, which is the least value for all particular nodes when compared with other protocols. The MC-PEGASIS and PEGASIS show nearly the range of observation for some nodes. The highest end to-end delay was observed for LEACH routing protocol.

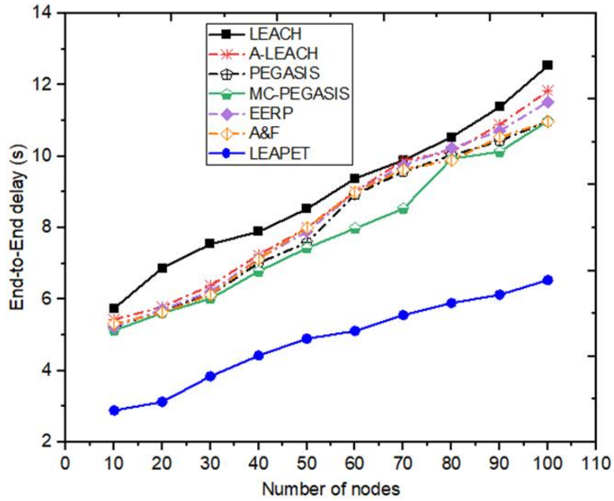

Figure 7: Analysis of the end-to-end delay vs. number of node

Figure 8 presents the results of the analysis of the average remaining energy against the initial energy of the sensor nodes.

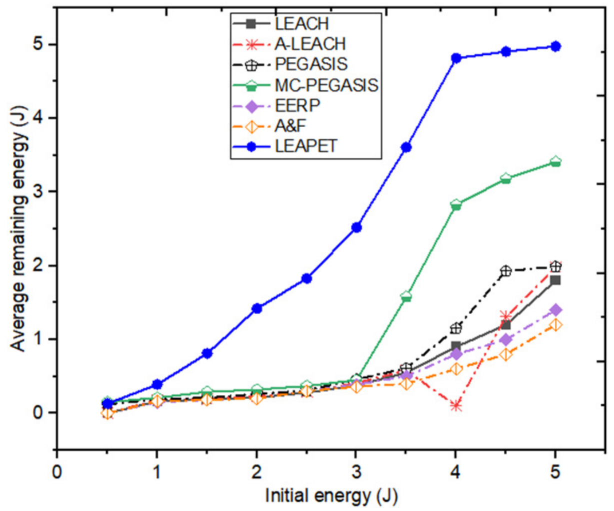

Figure 8: Analysis of average remaining energy vs. the initial energy

The results presented in Figure 8 indicate that the average remaining energy of nodes in the LEAPET routing protocol is higher than the other protocols. This may be due to the fact that the number of transmitted packets by the nodes in the LEAPET routing protocol is lower than other routing protocols. This superior performance is supported by the fact that load balancing and routing schedule managing in the LEAPET routing protocol is more efficient than others.

Figure 9 presents the results of the analysis of the number of alive nodes against the initial energy of the sensor nodes. For all the protocols, it is observed that the number of alive noes increases as the initial energy of these nodes increases. As shown in Figure 9, it can be observed that LEAPET routing protocol has the highest number of alive nodes than the other protocols. This is because of the low energy consumed by the nodes for transmitting the packets. As the number of transmission packets in the network is low, consequently, the performance of the simulated packets will be very sensible. Figure 9 also revealed that A&F routing protocol produce the least results.

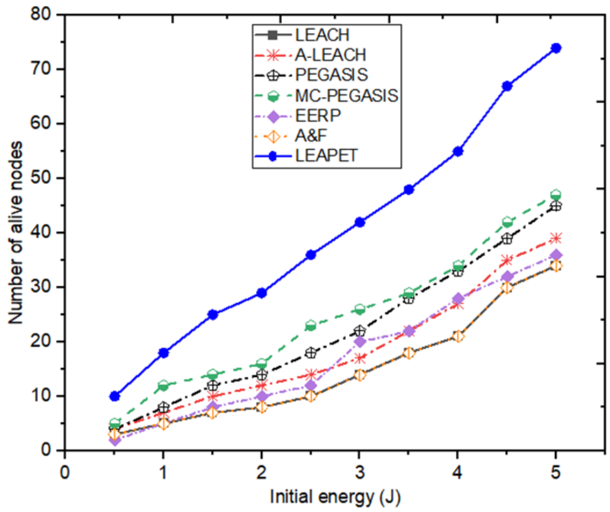

Figure 9: Analysis of the number of alive nodes vs. the initial energy

4.2 Comparison with other Hybrid Routing Protocols

A comparison of the current study with similar studies from the literature is shown in Table 2. This comparison is based on a 100 m by 100 m square area of SNs with an initial energy of 0.5 J/node for 100 nodes. Considering these studies, it can be observed that the LEAPET routing protocol has superior performance over other studies in terms of the residual energy, network lifetime of the SNs, throughput, packet delivery ratio and the end-to-end delay. While the routing protocol proposed by [38] employed generalized intuitionistic fuzzy soft set (GIFSS) approach for optimal selection of CH, the hybrid shark smell optimization (SSO), and a genetic algorithm (GA) for the effective routing, the throughput and packet delivery ratio achieved with this routing protocol after 100 nodes is lower than those achieved by the LEAPET routing protocol. Similarly, Fuzzy C-means (FCM) algorithm and Particle Swarm Optimisation (PSO) was used by the authors in [39]. The simulation results considering the same scenario of 100 nodes, yields throughput, network lifetime and packet delivery ratio less than that produced by the LEAPET routing protocol.

Table 2: Comparison with related hybrid routing protocols in 100 m by 100 m square area with initial energy of 0.5 J/node

Study	Protocol used	NL	TP (%)	PDR (%)	EED (s)
[35]	LEACH-C	1836	64	72	11.1
[36]	A-LEACH	1300	62	65	11.3
[37]	MC-PEGASIS	3000	75	84	10.8
[38]	GIFSs-SSOGA	3350	90	92.7	5.9
[39]	FCM-PSO	3247	89	91.3	7.2
This study	LEAPET	3438	90.2	95.6	5.6

5. Conclusions and Future Study

Sensor nodes have a limited amount of energy because they are battery-powered. For critical applications, it is necessary to extend the lifetime of these nodes. In order to increase the network lifetime of HWSN, this study developed a new routing protocol (LEAPET). This protocol's performance was assessed and contrasted with that of the current routing protocols. The simulation results demonstrate that, in comparison to the other routing protocols examined, LEAPET produces the best stability period with over 2000 rounds, as well as superior network lifetime, energy consumption, and throughput with comparatively low delay. When compared to current routing protocols, the proposed routing protocol significantly lowers the energy usage of WSNs. The results also demonstrate that the proposed routing protocol can maintain higher data transmission (throughput) from the chain leaders to the BS while minimising data loss. The results indicate that LEAPET can be an energy-efficient routing protocol, particularly for WSNs with moderate to high initial energy requirements. When compared to current routing protocols, the LEAPET significantly lowers the energy usage of WSNs. The results also demonstrate that the proposed routing protocol (LEAPET) can maintain higher data transmission (throughput) from the chain leaders to the BS while minimising data loss. The results indicate that LEAPET can be an energy-efficient routing protocol, particularly for WSNs with moderate to high initial energy requirements. Smart cities and environmental monitoring are just two of the real-world uses for LEAPET.

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