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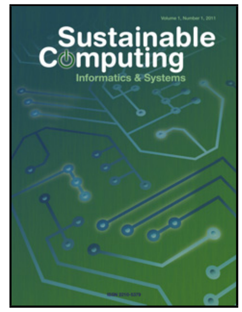

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QoS-Based Energy-Efficient Protocols for Wireless Sensor Network

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Highlights

- Clustering routing protocols for WSNs have evolved. Indeed, the protocols combine several sensor nodes, and the resultant clusters translate into hierarchical management systems, having integrated the features of different cluster members to the base stations and cluster heads.
- This study seeks to extend the literature and ensure efficient actions by proposing QoS-based energy-efficient protocols for WSNs, which provide QoS via energy consumption and end-to-end delay.
- The motivation of the study is to develop a protocol architecture that could extend network lifetimes, balance and reduce the energy consumption of networks, reduce redundancy, and increase information validity and integrity.
- The MATLAB software is used to perform the simulations. Through multiple time simulations, some of the performance metrics that are analyzed include the percentage of dead nodes, the average energy consumption for each node, the throughput, delay, network lifetime, fraction of alive nodes, and the optimum quantity of CHs in different rounds.
- Compared to the previous network protocols, it is also evident that the proposed model maintains stability relative to the determination of cluster head optimal values in the respective rounds. Similarly, the protocol outperforms frameworks such as ATEER, EDDEEC, and DEEC relative to the parameters of network throughput and delay, energy efficiency, and network lifetime, proving superior.

Abstract

Clustering routing protocols for WSNs have evolved. Indeed, the protocols combine several sensor nodes, and the resultant clusters translate into hierarchical management systems, having integrated the features of different cluster members to the base stations and cluster heads. This study seeks to extend the literature and ensure efficient actions by proposing QoS-based energy-efficient protocols for WSNs, which provide QoS via energy consumption and end-to-end delay. The motivation of the study is to develop a protocol architecture that could extend network lifetimes, balance and reduce the energy consumption of networks, reduce redundancy, and increase information validity and integrity. The MATLAB software is used to perform the simulations. Through multiple time simulations, some of the performance metrics that are analyzed include the percentage of dead nodes, the average energy consumption for each node, the throughput, delay, network lifetime, fraction of alive nodes, and the optimum quantity of CHs in different rounds. Compared to the previous network protocols, it is also evident that the proposed model maintains stability relative to the determination of cluster head optimal values in the respective rounds. Similarly, the protocol outperforms frameworks such as ATEER, EDDEEC, and DEEC relative to the parameters of network throughput and delay, energy efficiency, and network lifetime, proving superior.

List of Abbreviations/Acronyms

ATEER – average threshold energy-efficient routing

BS – Base Station

CH – Cluster Head

CREEP – Cluster-head restricted energy-efficient protocol

DEEC – Developed Distributive Energy-Efficient Clustering

EDCS – Efficient and dynamic clustering scheme

EDDEEC – Enhanced Developed Distributive Energy-Efficient Clustering

EEHC – Energy-efficient heterogeneous clustered

QoS – Quality of Service

TEAR – Traffic and energy-aware routing

WSN – Wireless Sensor Network

Keywords: wireless sensor network (WSN), quality of service (QoS), throughput, energy dissipation, network lifetime, network delay, energy consumption

1 Introduction

Most of the current wireless sensor network (WSN) protocols have been deployed with the aim of achieving the network's low power consumption [1]. However, an in-depth examination of these networks' quality of service (QoS) is yet to be realized, especially with rapidly changing technologies [2]. One of the parameters that could be used as a promising measure of QoS in WSNs entails coverage [3]. Also, this parameter could be used to determine the quality of data information [4]. Some of the advanced technologies that WSNs combine include sensor technology and wireless communication [4, 5], a path that accounts for the effective realization of interactions between the physical world and human society [6].

Of significance to note is that the sensor node, which constitutes the WSN's basic component, is powered mostly by dry batteries [7]. Should the battery be exhausted, it remains notable that the sensor nodes are deemed dead and that they are unlikely to engage in more data operations [8]. In situations where such nodes exist in harsh environments, replacing the dry batteries proves impractical [9]. The eventuality is that a subject that attracts scholarly attention (and one that reflects a research hotspot) entails some of the ways in which the sensor nodes' energy consumption could be reduced effectively, especially in scenarios demanding long-term operations [10].

In response to the above dilemma, clustering routing protocols for WSNs have evolved. Indeed, the protocols combine several sensor nodes, and the resultant clusters translate into hierarchical management systems, having integrated the features of different cluster members to the base stations and cluster heads [11]. From the majority of previous studies, this combination and evolution of WSN protocols translate into an effective reduction of the network's energy consumption [11-13]. Also, a secondary effect of this ability to reduce energy consumption has been documented to involve an extension of a network's lifetime, as well as the realization of more data iteration rounds [14, 15]. This study seeks to extend the literature and ensure efficient actions by proposing QoS-based energy-efficient protocols for WSNs, which provide QoS via energy consumption and end-to-end delay. Indeed, it is expected that the proposed routing protocol will reduce the communication delay and enhance network reliability, eventually translating into reduced energy consumption; hence, efficiency. Of importance to note is that the implementation of the proposed protocols is achieved in MATLAB.

In most cases concerning the aspect of cluster routing, LEACH has been used as a benchmark. Indeed, LEACH aids in the encapsulation of an energy balancing data-forwarding approach, which aims at achieving energy balance. Thus, LEACH has received widespread usage due to the need to steer improvements in the network lifespan, eventually saving the energy of the sensor node. When LEACH is employed, the initial phase constitutes the setup stage in which there is the formation of clusters, as well as the election of cluster heads relative to T(n) as the threshold function. With nodes assuming a random number, the latter is eventually compared with the threshold function. In this case, when a given node generates a number that is found to be less than the given threshold value, it forms a cluster head. The threshold function in LEACH-based approaches becomes in equation 1:

$$T(n) = \begin{cases} \dfrac{p}{\left(1 - PX\left[rmod\left(\frac{1}{p}\right)\right]\right)} \\ 0, \end{cases} ------------ [1]$$

However, it is important to note that whereas LEACH exhibits some degree of superiority because it ensures that in sensor nodes, energy is conserved, it comes with some limitations. For example, in various clusters, there is an unequal node distribution, which causes faster energy drain. The situation is compounded by the presence of lesser nodes in each cluster. Another limitation of LEACH is that when a network is expanded, there tends to be an energy-distance trade-off, which occurs between the base stations and cluster heads. Similarly, in LEACH, given the concept of the random number, chances of nodes becoming cluster heads are not reserved, implying that the energy efficiency is affected. Also, in LEACH, data transmission is less secure, with an additional failure to consider node heterogeneity relative to link reliability, computation capability, and energy. Lastly, apart from energy-related variables, LEACH fails to consider additional QoS variables such as throughput, packet delivery ratio, and delay.

In this study, the fitness function entails the node's average and residual energy, the number of times a given node tends to remain in operation as a cluster head, the number of neighboring nodes, the number of nodes per cluster, and the node distance from a given base station (BS), especially during cluster head (CH) selection. Thus, the study seeks to contribute to the current state-of-the-art in several ways. For example, the study proposes a new hybrid cluster algorithm for both homogeneous and heterogeneous networks – aimed at improving wireless sensor networks' QoS parameters. Also, regardless of variations in the number of nodes, the proposed system seeks to redesign the TDMA schedule, ensuring that in the respective nodes, the same energy dissipation is guaranteed. Thus, the proposed approach is projected to steer improvements in the nature of the network's lifetime. Lastly, the study is deemed important because it seeks to ensure that for wireless sensor networks, the energy efficiency is enhanced relative to cluster head selection and node distribution on the fitness function.

1.1 Study Objectives

This study's objectives are stated as follows:

a) To design an efficient wireless body area network protocol using:
   - Energy Dissipation
   - Distance criterion, stability period of network and network lifetime
   - Throughput
   - The efficiency of wireless sensor networks
b) To design an efficient wireless sensor network protocol using:
   - Energy Dissipation
   - Field Dimension and Positioning of Nodes
c) To design a transmission control protocol for wireless sensor network using:
   - Energy Dissipation
   - Loading parameter
   - Reliable transmission mechanism

1.2 Rationale/Importance of the Study

Indeed, some of the beneficial outcomes that this study might lend to this research area include the provision of insights into how the proposed protocols might extend network lifetimes, balance and reduce the energy consumption of networks; as well as reduce redundancy, and increase information validity and integrity. Also, the study is deemed relevant and contributory to the current state-of-art in WSN scholarly investigations because it is projected to allow for the development and implementation of wireless body area networks that allow for the realization of optimal performance after considering and optimizing the parameters of energy dissipation, throughput, WSN efficiency, distance criteria, network stability period, and network lifetime.

1.3 Related Work

In WSNs, most topology control protocols and routing protocols have had their primary goal lie in the aspect of energy efficiency. Compared to the case of homogeneous WSNs, however, heterogeneous WSNs have proved challenging relative to the development of energy-efficient clustering algorithms, especially because of the presence of composite real environments [2]. This challenge associated with heterogeneous environments has been explained by the trend in which the dispensation of networks occurs with nearby interference, turbulent links, and dissimilar sensors. Thus, the last decade has witnessed an increase in scholarly attention relative to the development of energy-aware WSN networks. For instance, the Energy-Efficient Heterogeneous Clustered (EEHC) protocol has been developed. This development has targeted tri-level networks [3, 5]. Indeed, the system has been documented to be capable of electing cluster heads in a way that considers the residual energy of the sensor nodes via probability threshold functions. Compared to LEACH, EEHC has been affirmed to be more successful, especially due to its associated superior performance. The success or superiority over LEACH has been associated with a promising aspect of improved network lifetime. In another study [7], an energy paradigm has been established, with TEAR (traffic and energy-aware routing) proposed. The aim has been to ensure that the stability interval is refined. Also, some studies [8, 10] have focused on the development of the cluster-head restricted energy-efficient protocol (CREEP), while others have focused on the efficient and dynamic clustering scheme (EDCS) protocols. The focus of these investigations has been in contexts involving heterogeneous clustering networks. In the findings, it has been observed that the focus of CREEP lies in the reduction of the number of cluster heads in each round, aimed at steering improvements in the lifetime of the given networks. Thus, the protocol has been asserted to achieve two-level heterogeneity. Also, the latter formulations have been observed to aid in the amelioration of network lifespan.

Additional scholarly focus has been on the cases of the Enhanced Developed Distributive Energy-Efficient Clustering (EDDEEC) and the Developed Distributive Energy-Efficient Clustering (DEEC) [11, 13]. For the case of DEEC, findings have demonstrated that there is the formulation of the node initial energy-based probability function, as well as the average network energy function. With high energy ratios associated with the nodes, in this case, they become cluster heads. On the other hand, upon evaluating the case of DEEC, given the respective rounds, the network energy is not considered. Additional studies have focused on the case of ATEER (average threshold energy-efficient routing) technique [17]. When compared to the performance of other protocols proposed previously, findings regarding the case of ATEER implementation demonstrate that the protocol is suitable for and worth applying to scenarios entailing reactive- and proactive-based networks. Thus, ATEER is seen to exhibit superior performance when compared to cases where there is the implementation of EDDEEC and DEEC protocols, especially because in heterogeneous environments, ATEER preserves more energy and also steers improvements in the lifespan of the networks.

However, it is imperative to note that still, ATEER exhibits some limitations. For example, the protocol fails to account for the distance between base stations and cluster heads, implying that when this distance increases, there is the consumption of more energy [1]. Also, for the case of ATEER protocol implementation, there is an unequal distribution of sensors in the given clusters, which could cause a faster rate of energy drain in smaller clusters, compared to situations involving bigger clusters [4]. It can also be seen that when ATEER is adopted and implemented, it does not limit the number of times that the given nodes could translate into cluster heads [6]. Similarly, ATEER does not modify; neither does it consider the data transmission's TDMA schedule [5]. Additional observations denote that given some channel parameters such as interference, link quality, and noise, ATEER fails to consider their effect, especially during the transmission of data [9]. Lastly, ATEER only considers or focuses on the variable of energy efficiency, implying that it fails to give insight into the behavior of other QoS parameters, pointing to its limited applicability and also a lack of clarity regarding how it performs or behaves as a protocol when other QoS variables are examined.

Additional investigations have been on multi-core processing systems and how thermal-aware scheduling approaches aid in optimizing system performance [29]. With settings such as data centers in the entirety and their associated servers and embedded systems, computing platform design has been the main area of investigation in relation to the software design for such platforms. Apart from unrestricted temperature implications concerning the software system designs, the investigations have been motivated by the need to discern how parameters such as effective thermal management and potential hardware failure could affect the processors' thermal packaging cost, as well as the impact of the behavior of the aforementioned parameters on long-term savings. In the findings, it has been documented that when dynamic thermal management approaches are adapted and implemented, the effective utilization counters the potential problem of overheating, especially when software and hardware controlling mechanisms are also used in embedded systems. Additional findings demonstrate that upon utilizing server systems, optimal results tend to be realized in relation to efficient task scheduling and advanced dynamic thermal management because, on the overall cooling costs, a positive impact is exerted; hence, ensuring that the system components' lifetime is prolonged. [29]. Indeed, such scholarly results are relevant to the current study in such a way that they increase understanding about some of the ways in which temperature management could be achieved via task scheduling and mapping, an inference proving highly beneficial to the WSN system design context. It is also worth noting that the literature is relevant and contributory to the current study because it points out the importance of combining attributes such as performance constraint and temperature to achieve system optimization, including in the case of WSNs, eventually arriving at ideal models and optimization techniques via the new research directions.

Scholarly investigations have also been conducted concerning a multi-objective evolutionary algorithm (MOEA)-based technique of task scheduling has also been proposed, aimed at realizing Pareto optimal solutions. Factors that have been considered during the investigation of the performance of this model include temperature (T), energy €, and performance (P) [30]. For the algorithm, specific performance interactions that have been investigated include genetic operators, the determination of the solution space's initial population, and problem-specific solution encoding. For these parameters, they have worked collectively towards efficient solution realization in a timely manner. From the findings, it has been affirmed that when multiple schedules are embraced, they provide various values for makespan, the peak temperature, and the energy consumed. The eventuality is that the implementation of such frameworks offers an efficient approach through which trade-offs among certain objectives can be determined or identified in the target machine pairs and applications [30]. Similarly, it has been documented that when the proposed MOEA model is implemented, which aids in task scheduling to achieve the desired system optimization, the perceived three-way optimization is realized timely. As such, the model poses advantages in such a way that upon its adaption and implementation, it allows for significant temperature and energy reductions collectively and not in isolation [30]. Concerning the current study, which focuses on WSN system optimization via the implementation of a proposed model, such scholarly investigations and their associated findings are critical and contributory because they increase understanding of how collective operations of variables such as temperature and energy, especially if they are collective, affect system optimal performance; hence, costs.

Further scholarly investigations have targeted the case or context of task scheduling on a performance- and energy-aware basis, especially in distributed and parallel systems [31]. In such investigations, it has been avowed that for high performance, which is mostly enabled by highspeed networking that applies to government, scientific, and commercial settings or contexts, it continues to burgeon with increasing storage and computational resources [31]. Therefore, the focus has been on how system optimization in relation to network designs could be achieved in large-scale systems that include computational grids, especially because such grids are found to consume a lot of energy, arising from massive sizes with which they are associated. Important to note is that for such systems, their cooling and energy costs interact with and compare to procurement costs with which they are associated [31]. Therefore, surveys have been conducted around this subject of network system optimization by discussing some of the scheduling and allocation algorithms to discern their effectiveness in allowing for the development of optimal network systems; hence, the establishment of software through which energy dissipation and power could be reduced on the target platforms' workflows. Specific platforms that have been targeted in such investigations include distributed systems, multicore processors, and single processors. Indeed, the studies are important because they focus on how different application scheduling models and power management approaches aid in increasing the energy efficiency and power in network platforms, lending themselves to the current study, whose focus is on WSN environments. Specific findings from these studies suggest that upon applying to parallel, multicore, and single architectures in relation to workflow energy-aware scheduling, algorithms that respond to and address algorithmic, software, and architectural issues tend to reduce energy costs, making the systems efficient while realizing performance optimization.

In WSN environments, the subject of energy management has also been investigated [31]. Here, it has been asserted that WSNs exhibit certain unavoidable issues with which network system designers continue to grappled, one of them being the subject of energy management and the associated challenges. In a network, therefore, guaranteeing durability and efficiency, as affirmed in [32], calls for the need to stretch beyond hardware solutions and strive to gain alternative software solutions through which there could be better control of events between the source and the destination, especially in an optimized way that allows for significant energy saving and, in turn, extend the lifetime of the WSN networks. Hence, protocol strategies and computer-based tools have been introduced and explored [32], with findings suggested that in situations where routing protocols pave the way for fluid information flow and intra-system interactions, resources and power are likely to be optimized in surroundings entailing dense networks [32]. An additional area that has been investigated includes wireless MEMS networks in mobile and wireless networks [33]. In such investigations, it has been documented that some of the areas in which wireless MEMS network gain application include systems for smart cities, health applications, agricultural monitoring of food safety, space applications, environmental monitoring, infrastructure monitoring, and manufacturing [33]. Specific findings have demonstrated that upon utilizing routing protocols that seek to optimize WSN networks by combining energy and power attributes concurrently, there is likely to be a significant increase in the overall network platform. Lastly, the subject of Zigbee wireless networking has been investigated [34]. Particularly, it has been affirmed that based on IEEE 802.14.4 standard that governs wireless personal networks, Zigbee paves the way for the establishment of very low power and low cost networks. As such, Zigbee has been established to support the objective of WSN network lifetime extension by ensuring that the networks on which it is applied and implemented run for several years, rather than last for mere months [34]. The eventuality is that through Zigbee implementation, the resultant networks that are created from actuators and sensors could allow for the wireless controlling of numerous electrical products in the form of security, industrial, and medical sensors, as well as remote controls [34]. In relation to the current study, such scholarly insights are important and highly contributory because they aid in understanding how the design of WSN networks that abide by an IEEE standard such as Zigbee aids in extending network lifetime through energy optimization; hence, reduced costs of overall WSN system operation [34]. However, an area that can be seen to be lacking and one that calls for in-depth scholarly analysis is that which entails an examination of a newly proposed protocol and how it compares with previously proposed models concerning factors such as energy dissipation, throughput, WSN efficiency, distance criteria, network stability period, and network lifetime.

2 Methodology

Various network domains are used to simulate the proposed mechanism. Also, MATLAB software is used to perform the simulations. Through multiple time simulations, some of the performance metrics that are analyzed include the percentage of dead nodes, the average energy consumption for each node, the throughput, delay, network lifetime, fraction of alive nodes, and the optimum quantity of CHs in different rounds. The motivation of the study is to improve on previous protocols such as EDDEEC and ATEER, which exhibits drawbacks such as the failure to consider the distance between the base station and the cluster head, unequal sensor distribution, a sole focus on energy efficiency as the determining parameter, failure to account for the effect of channel parameters (such as interference, link quality, and noise – during data transmission), and the failure to restrict the number of times at which nodes could become cluster heads.

The proposed protocols entail two models. These models include the energy dissipation model and the network model. Some of the parameters that the network model targets include: data dissemination to the base station, data aggregation, election of cluster head, and micro-sensor deployment. On the other hand, the energy model seeks to account for the parameters of the aggregation of sensed data from individual nodes to the cluster head nodes, reception, and energy dissipation relative to or because of transmission. It is also notable that the protocols' assumptions are as follows:

- ✓ In the entire network, there is an elliptical Gaussian distribution model-based deployment of nodes
- ✓ Constraints of computational capability, energy, and memory do not impair the base stations and that the base stations are also assumed to be positioned at centralized zones
- ✓ There is symmetric communication physical link in the selected nodes, with Y to X and X to Y packet transmissions' energy consumption and data rate being the same
- ✓ Relative to the initial energy, network nodes are heterogeneous and also non-rechargeable
- ✓ In terms of battery energy, nodes are heterogeneous, but their communication and processing capabilities are similar
- ✓ A unique ID characterizes each node and that upon deployment, with the base station included, they are all non-mobile

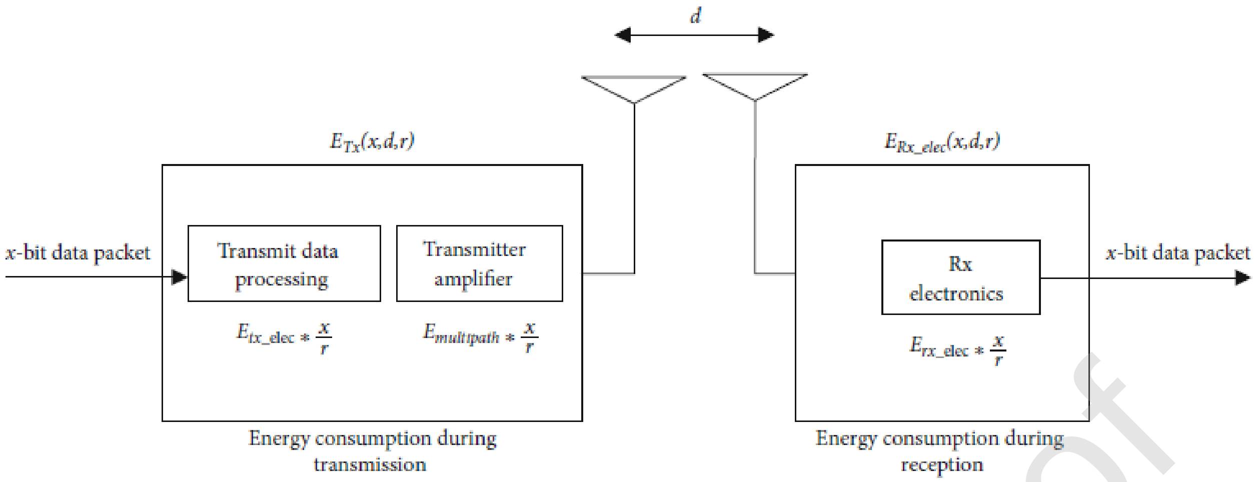

Figure 1: An illustration of the proposed energy consumption framework

From the literature, one of the factors that affect the routing, security, and energy of sensor nodes involves node positioning [13-15]. On the other hand, the deployment method determines the lifespan of the network [14]. The eventuality is that batteries are likely to be drained faster when nodes are positioned closer to base stations compared to those that are positioned farther from the base stations. In this study, this problem is countered by ensuring that the proposed energy consumption model considers a two-dimensional Gaussian distribution function, a consideration poised to counter the perceived WSNs' energy hole problem and, in turn, achieve the required network lifespan – and also energy balancing.

With the assumptions presented above and also the network's energy consumption model established, another path that is worth describing in this methodology involves the protocol structure that will be simulated through MATLAB software. From the literature, a framework such as the ATEER protocol exhibits superior performance compared to the case of the EDDEEC and DEEC protocols, especially when considering performance parameters such as energy efficiency and network lifetime [16, 17]. Also, this superiority is pronounced in situations where the protocols are implemented in heterogeneous environments [18]. However, the model falters in such a way that it does not account for the impact that could be posed by distance on the threshold function; yet an increase in the base station-cluster head distance is associated with higher energy costs [19]. Also, the aforementioned protocol fails to account for the frequency at which nodes become cluster heads, failing further to consider the factor of data redundancy [18-20].

Another aspect that is worth considering is the radio energy model of the protocol. From Figure 1 above, the proposed protocol's radio energy model constitutes the multipath fading and the free space models [2]. Indeed, the decision about the latter models depends on the variables constituting the distance from the receiver to the transmitter. Another issue that is worth considering and illustrating entails the case of the optimum number of CHs. To express the cluster heads, given some sensing area and N as the number of nodes, then the division of the nodes gives Nc clusters. The eventuality is that we have the outcome N/Nc representing the average nodes in each cluster.

2.1 A Focus on the Proposed Protocol Architecture

As documented earlier, findings from most of the previous studies demonstrate that ATEER exhibits superior performance when compared to the cases of EDDEEC and DEEC protocols. This superiority has been documented relative to the evaluation of the parameters of energy efficiency and network lifetime [3]. In particular, these results are documented for scenarios involving heterogeneous environments [4]. However, it is important to note that despite this superiority, ATEER comes with some limitations. The eventuality is that the need to establish a new protocol that seeks to respond to the drawbacks, which were mentioned earlier, could not be overstated. For example, ATEER does not consider the variable of distance and how it affects the threshold function; yet scholarly reports suggest that when cluster heads exist far away from the base stations, the need for system efficiency implies that they are not worth selecting [7-10]. In particular, when the distance between the base station and the cluster head is great, the energy cost increases [2]. It is also important to indicate that when ATEER is incorporated, it fails to account for the number of times that the given number of times that nodes end up becoming cluster heads [11]. Similarly, ATEER fails to account for the attribute of data redundancy, implying that when there is a steady-state phase, given the cluster, the sensed-data transmission is continuous [14, 16]. With the aforementioned factors ignored by ATEER, the resultant problem is that the network lifespan tends to be depleted [3-6].

In this study, the simulation is conducted in such a way that a genuine node for the cluster head is selected and the threshold function amended to alter the selection criteria for the cluster head. Additionally, the method ensures that only the sensed information that is updated is sent. Also, the selection criteria for the cluster heads are redesigned to ensure that the proposed approach considers factors such as the number of sending nodes for the respective clusters, the quantity of the neighbor nodes, the distance between the cluster head nodes and the base stations, and the average energy of the network node, parameters that fail to be accounted or considered when protocols such as EDDEEC, DEEC, and ATEER are employed.

The eventuality is that for the proposed approach, there exists member nodes and cluster heads and that redesigned schedules are transmitted by the latter to the former. The proposed method is also designed in such a way that for the protocol architecture, sensor nodes exhibit an awareness of the exact moment to switch off energy and transform into sleep modes, a step or redesign poised to steer WSN efficiency in relation to the energy consumption parameter. Also, the proposed approach or protocol architecture holds that no single node could send data that exceeds any of the other intra-network nodes, a trend projected to allow for the proposed QoS-based energy efficient protocol to yield a significant saving of the node energy, having countered the attribute of potential inefficient dissipation.

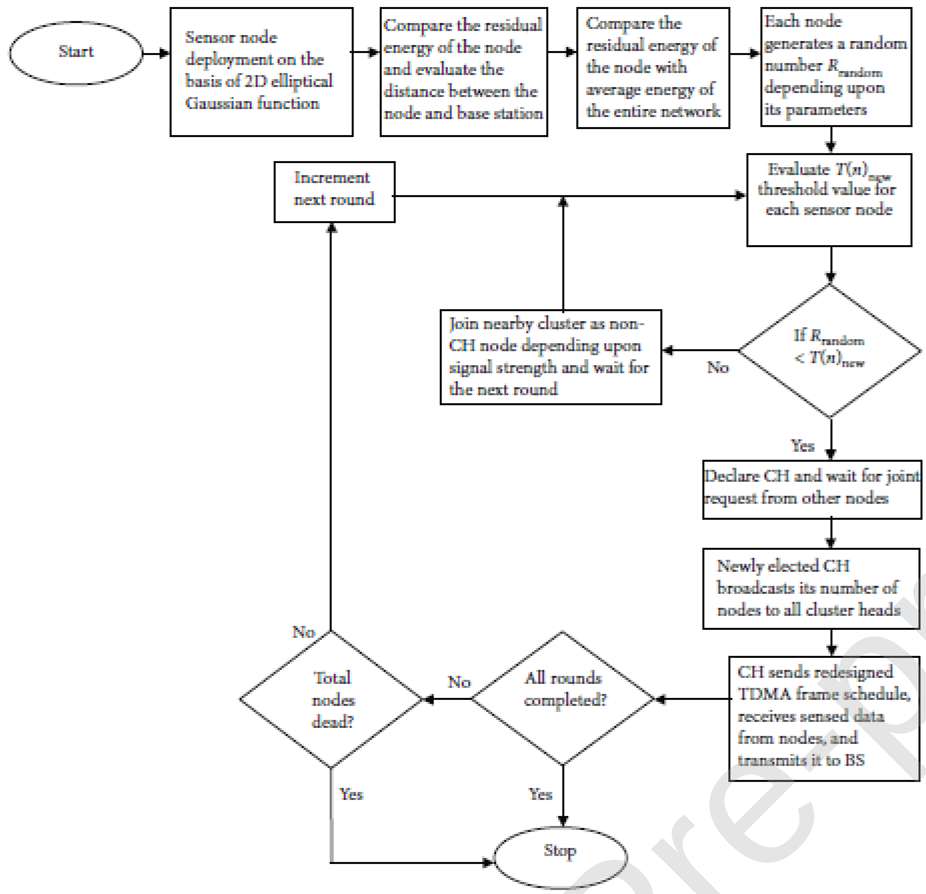

Figure 2: An illustration of the proposed protocol architecture's implementation steps

From the flowchart in Figure 2 above, the proposed protocol operates in such a way that it is only after falling in the neighborhood radius that the given nodes are perceived as neighbors of others. Also, when a node exhibits a higher number of neighboring nodes, it is more likely to translate into a cluster head. Another parameter that is worth establishing involves the average distance occurring or existing between the cluster head nodes in relation to their expected member nodes. Also, in the protocol architecture, the proposed system considers the average distance between the base stations and cluster heads.

At this point, the focus goes to the proposed fitness function for the protocol architecture. Indeed, certain critical parameters characterize the fitness function. Given the varying trade-off values, there is the merging of the critical parameters to reduce to a threshold function. Also, the proposed fitness function for the protocol architecture exists or operates in such a way that in each round, there is a trade-off between the distance that separates base stations and cluster heads and the nodal residual energy. It is also worth noting that the value of the threshold of the cluster head could undergo some expansion, especially due to the consideration of the neighboring nodes, as well as the frequency with or at which nodes remain as cluster heads.
Thus, we have the fitness function expressed in the form in equation 2:

$$E_{res} + \left(1 - \frac{1}{E_{\text{avg}}}\right) + \frac{1}{d_{BS}} + \left(Ng_n/CH_t X(1 - log_{10} d_{sr})\right) - - - - - - - - - [2]$$

Indeed, this fitness function is has been adopted and is justified by its capacity to ensure that certain aspects are maintained. The aspects include the repetition of the node as a CH, the number of neighboring nodes, the distance of communication between the base station and the cluster head, and the priority between node residual energy.

Imperatively, the fitness function has been designed to inform the criteria of the proposed protocol relative to cluster head selection. At this point, it is also imperative to consider the case of homogeneous scenarios and how the threshold function could be designed in a way that might deem the proposed system effective. Imperative to indicate is that when homogeneous environments are considered, the eventuality is that the same initial energy is possessed by each node. Given such homogeneous environments, the eventual threshold function becomes in equation 3:

$$T(n)Homo = \begin{cases} T(n)X fitness\ function \\ 0, \end{cases} ---------[3]$$

With the fitness function considered and the equation substituted, we have equation 4:

$$T(n)Homo = \begin{cases} T(n)X\left[E_{res} + \left(1 - \frac{1}{E_{\text{avg}}}\right) + \frac{1}{d_{BS}} + \left(Ng_n/CH_t X(1 - log_{10} d_{sr})\right)\right] \\ 0, \end{cases} ----[4]$$

Another experimental scenario that is worth considering in relation to the proposed protocol involves a heterogeneous environment and the nature of the threshold function. From the literature [3], when practical and real-world situations are considered, heterogeneous scenarios characterize WSN networks. In these scenarios, there is a difference or variation in the initial energies possessed by different nodes. Thus, a new formula is established to ensure that a higher probability of becoming a cluster head is linked to nodes with higher remaining energies. Also, the new formula holds that when the distance between the cluster heads and sensor nodes increases, there is a decrease in the chances of selecting cluster heads in a current round. Hence, the threshold function in heterogeneous environments is in equation 5:

$$Pi - hetro \ = \begin{cases} \dfrac{p}{1 + m_a \cdot (a + m_s \cdot s)} \ \text{x fitness function E for } n \text{ normal,} \\ \dfrac{P(1+a)}{1 + m \cdot (a + ms \cdot s)} \ \text{x fitness function E for } n \text{ advanced} \\ \dfrac{P(1+s)}{1 + m_a \cdot (a + ms \cdot s)} \ \text{x fitness function E for } n \text{ super.} \end{cases} \quad --[5]$$

The table below highlights the experimental conditions or the values of different simulation parameters that were considered.

Name of the simulation parameter	Value of the MATLAB simulation parameter
The control packet size	200.00 bits
The initial node energy	4.00J
The number of simulation rounds for selected cluster heads	8000.00
Number of simulation nodes	100.00
The size of the data packet	3000.00 bits

Table 1: A summary of the study's MATLAB simulation parameters

3 Results and Discussion

In the MATLAB software simulation exercise, and based on Table 1 about simulation parameters, this study relied on 100 nodes. The area that was used to gain insights was 100 by 100 square meters, with Gaussian distribution aiding in the deployment of the selected nodes. It is also notable that the simulation of the proposed protocol architecture or framework involved different network domains. With a hybrid nature of this technique, the sets of nodes that were considered involved heterogeneous and homogeneous forms. From an outcome validation perspective, a process that sought to discern the degree to which the proposed method would perform better, if any, the protocol was compared with the performance of previous heterogeneous mechanisms such as ATEER, EDDEEC, and DEEC, as well as homogeneous LEACH models.

3.1 The Case of the Perceived Optimum Cluster Head Number

From the literature, energy consumption in WSN environments depends on the cluster head number for each round [21]. Particularly, previous scholarly results demonstrate that when the value of the cluster head is high, the energy consumption tends to be high because the nodes end up carrying out additional data aggregation processes [22, 23]. On the other hand, when the number of cluster head nodes is less, the data delay could be longer, having supposed that individual nodes exhibit information to be relayed to the base stations [24, 25]. These assertions imply that there is a need for a stable number of cluster head nodes and that they also ought to be optimal, upon which better energy efficiency might be realized [26,27]. In this study, findings demonstrated that for the proposed protocol architecture, if the cluster head number is about 5, the level reflects an optimal situation at which better energy efficiency could be realized. Indeed, these results were attributed to the redesigning of the method of selecting cluster heads.

3.2 Focusing Network Lifetime and Load Balancing Ability

Given the base stations, nodes send their perceived information for the respective rounds. This process causes energy dissipation [19]. With energy dissipation, there is likely to be degradation in WSN performance – as rounds pass by. In the eventuality or at some point, the first node could die [28]. Therefore, the MATLAB software simulation process sought to discern the proposed protocol architecture's ability to improve the lifetime of WSNs, with a specific focus on trends in the number of dead nodes – upon implementing the model. For the case of ATEER, EDDEEC, and DEEC, their network lifetime stands at 7123.00, 5899.00, and 2899.00, respectively [25]. For the proposed protocol, simulation results demonstrated that the architecture, if implemented, ensures that the WSN lifetime stands at 7921.00. Hence, it was observed that the proposed system steers improvements in WSN lifetime, with the positive outcome attributed to the redesigning of the cluster head threshold function.

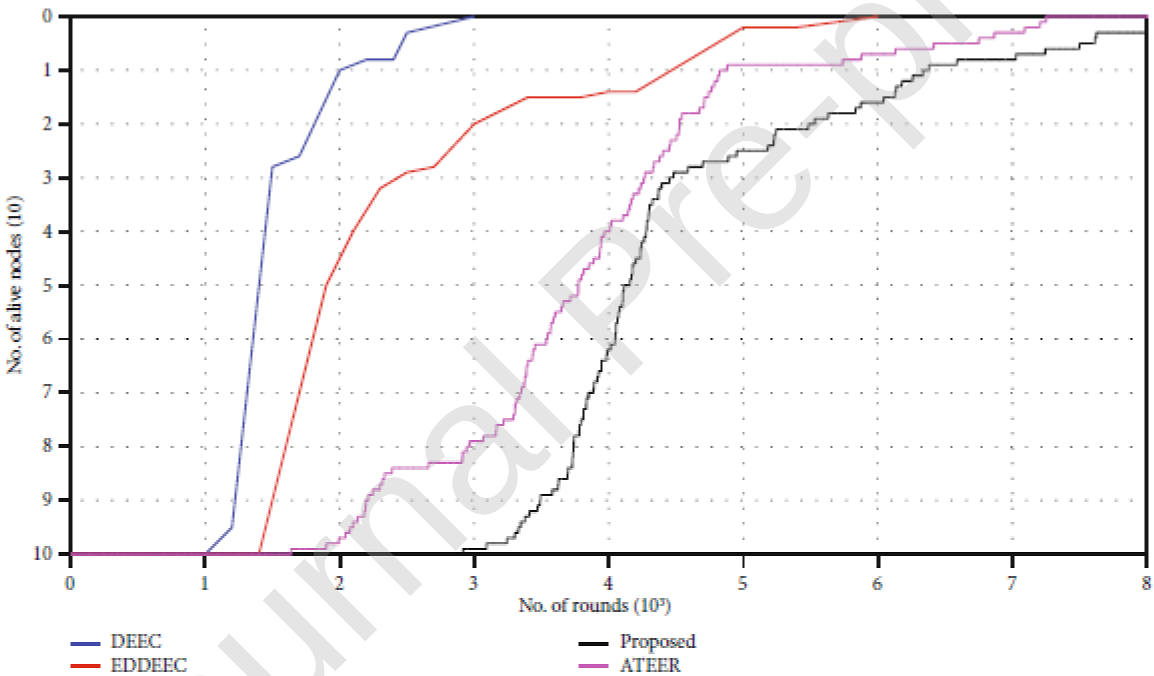

Figure 3: A comparison of WSN lifetime performance for the proposed and different protocols (in terms of the number of dead nodes during rounds)

3.3 Results for the Case of the Number of Alive Nodes

Apart from the evaluation of the proposed model's performance regarding the WSN lifetime, which was discerned through the number of dead nodes, MATLAB software simulation proceeded to examine the protocol's performance relative to the number of nodes that would be alive after different rounds. The results were also evaluated by comparing the values obtained with those that had been reported previously for different (other) protocols. Imperative to note is that the alive nodes were those that, given a data transmission process, they exhibited adequate energy for participation. With a focus on the first node dead, the proposed protocol yielded superior results, implying that it offers better WSN network stability for an extended period.

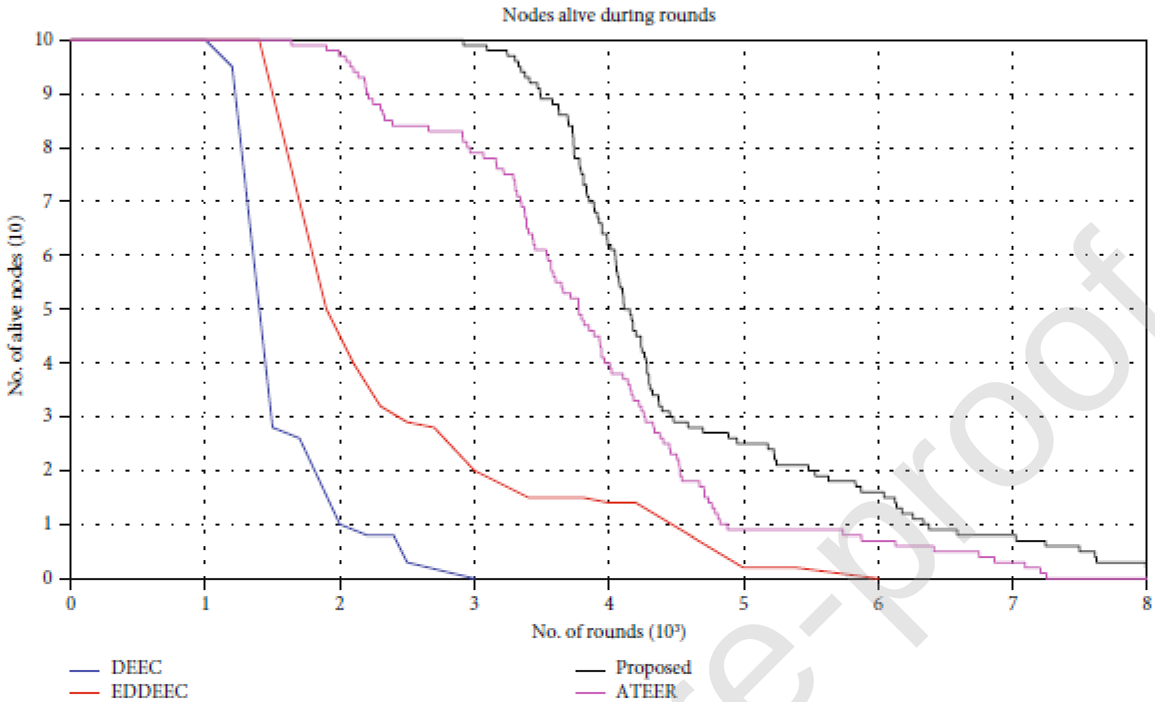

Figure 4: A comparative outcome relative to alive nodes for different rounds

3.4 Results for Network Delay and Throughput

In WSN mechanisms, given a specific time and the base station, throughput reflects all packets received successfully [9, 10]. In this case, based on the earlier MATLAB simulation results, the proposed protocol exhibited a redesigned threshold that accounted for network lifetime extension, an outcome that also translated into or led to enhanced throughput. Hence, at the base station, the framework suggested that if implemented, it could enhance the sum of the packets received successfully.

Regarding the attribute of WSN network delay, previous studies document that the parameter entails the period of a lapse between a sensor node's initially generated data unit and the last data unit that, within a certain communication round, the base station receives. Compared to the case of ATEER, the proposed protocol had a lesser delay, having simulated delay variations for different rounds of WSN communication. Indeed, this superior performance was attributed to the model's arrangement in which its selection threshold for cluster heads was based on the separation between the base station and cluster heads; whereby, it elected nodes closer to base stations as the cluster heads. Thus, it is this protocol architecture that accounted for the proposed model's superior performance in which it exhibited lesser delay variation that the case of ATEER protocol with which it was compared.

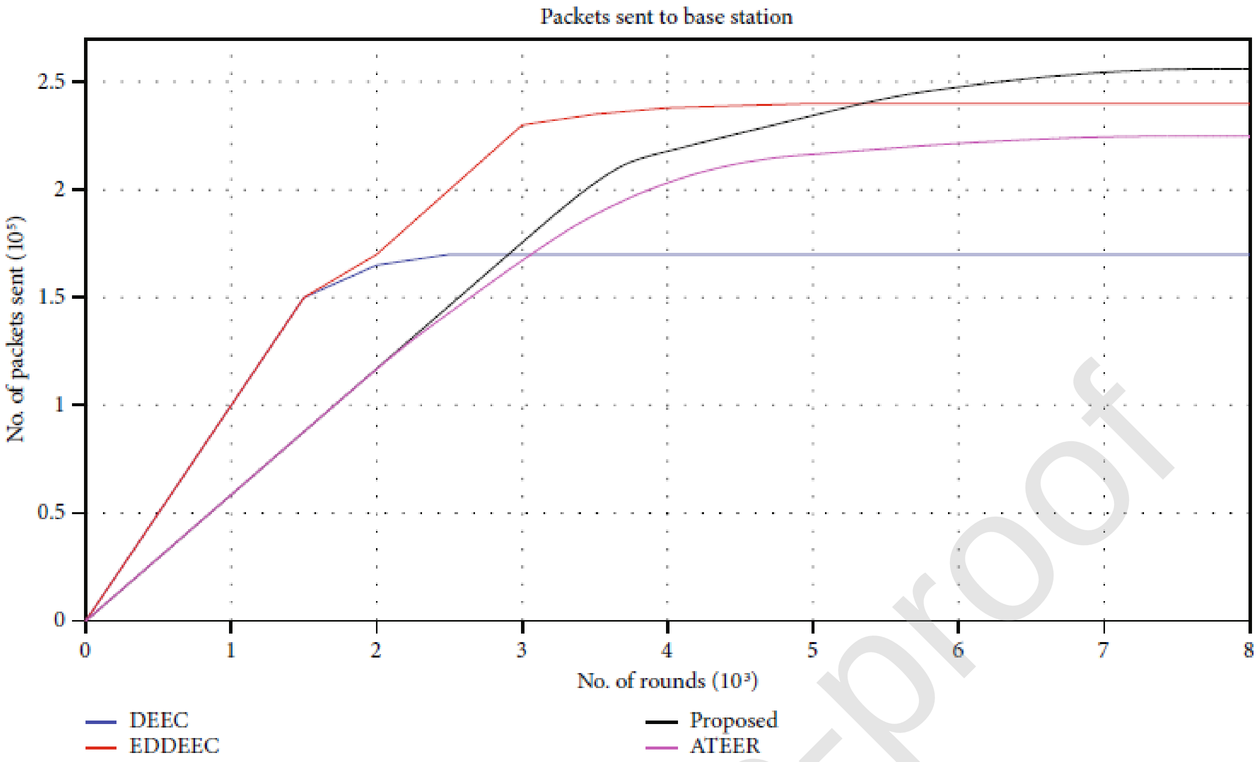

Figure 5: The proposed protocol's performance for network throughput versus ATEER

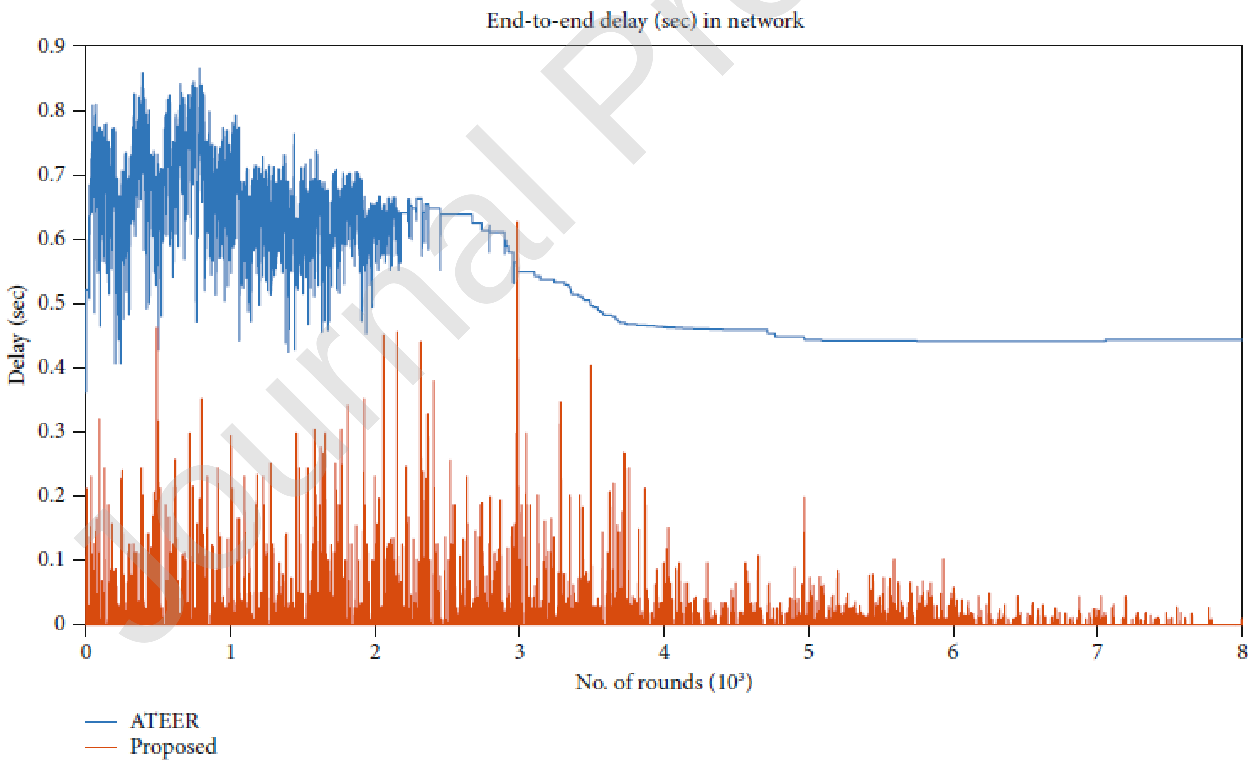

Figure 6: A comparative outcome in relation to WSN network delay (delay variation)

3.5 Focusing on Energy Cost and Consumption Parameter

From the literature, energy consumption from the perspective of WSN networks reflects the sum of the energy cost that a network might require for information aggregation, reception, and transmission. In this study, MATLAB software simulation results demonstrated that the proposed protocol architecture comes with minimum energy consumption, a state of performance efficiency that was found to outperform the ATEER protocol. Indeed, this enhanced WSN performance concerning the parameter of energy consumption was attributed to a situation in which during steady-state phases, the protocol configuration would allow for the nodes to enter sleep mode operation. Through this sleep mode, the eventuality is that the respective cluster heads would be safeguarded from shallow listening, with the respective member nodes also safeguarded from a common frame's multiple transmissions.

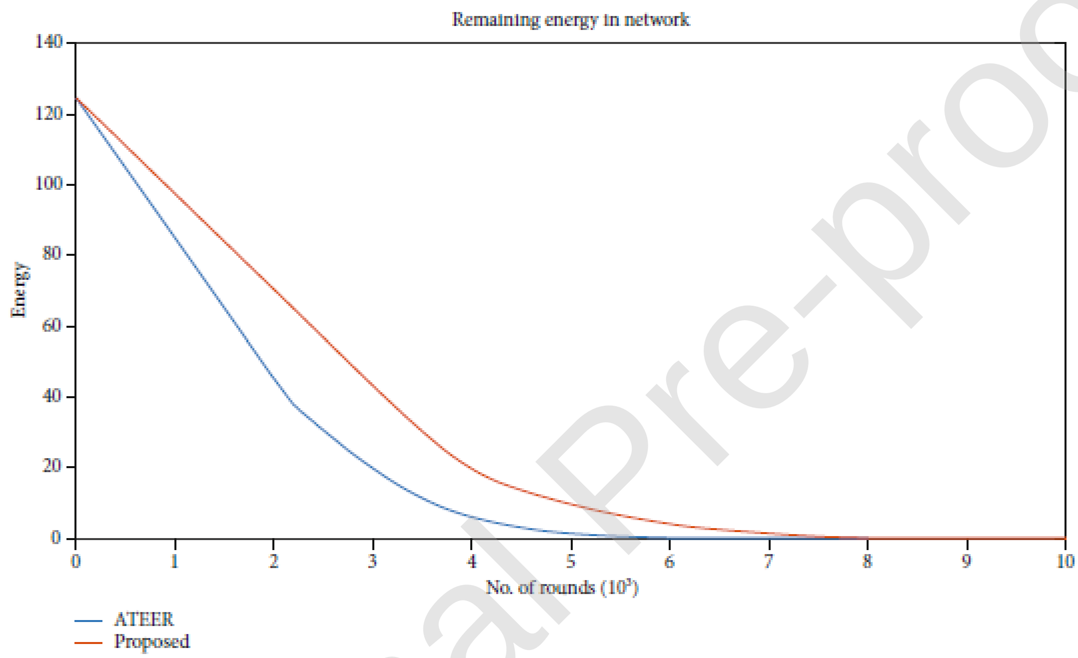

Figure 7: A comparative illustration of the energy consumption performance

Indeed, the proposed protocol architecture is that which comes in the form of a QoS-based energy-efficient framework, which has been implemented in the contexts of homogeneous and heterogeneous WSNs. Notably, the proposed framework is hybrid, and it is seen to come with three main benefits. These benefits, which reflect its capacity to enhance WSN performance, hence, efficiency, include the ability to maintain service integrity quality, the ability to improve network lifetime, and improved energy efficiency (via reduced consumption, hence, cost reduction). Of imperative to note is that the proposed protocol's superior performance is attributed to its designed fitness function that exhibits numerous merits, making the model to outperform other protocols with which it has been compared. Some of the merits arising from the fitness function of the proposed protocol include the determination of the distance between the base station and the cluster head nodes, the average network energy, the energy of the residual node, the neighboring node count, the number of times that a given node in the WSN network remains or serves as the cluster head, and the number of nodes contained in each cluster. The eventuality is that the proposed protocol's fitness function, upon integration with the probability threshold function, affects the procedure of selecting cluster heads. Through protocol redesign, the proposed model ensures that in different clusters (and in each round), nodes traverse the same number of packets. Compared to the previous network protocols, it is also evident that the proposed model maintains stability relative to the determination of cluster head optimal values in the respective rounds. Similarly, the protocol outperforms frameworks such as ATEER, EDDEEC, and DEEC relative to the parameters of network throughput and delay, energy efficiency, and network lifetime, proving superior.

4 Conclusion

In conclusion, this paper has established that based on the MATLAB simulation results, the proposed WSN QoS-based energy-efficient protocol, based on the parameters of throughput and network lifetime, outperforms ATEER, DEEC, and EDDEEC by 10.00%, 26.00%, and 63.00% respectively. Hence, the study infers that the protocol is well suited and better placed to be used to design WSNs in real-world and real-time situations. In relation to future research, it is recommended that scholarly investigations extend this paper by examining the degree to which the proposed protocol architecture might assure system privacy and security. Also, it is recommended that future research focuses on how the WSN protocol could be employed in varying environmental conditions, upon which its feasibility and adaptive ability might be discerned.

AUTHORSHIP STATEMENT

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication.

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I and the co-authors of this manuscript confirm that all the above mentioned information is correct to the best of our knowledge.

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