Optimizing Energy Efficiency and Prolonging Lifetime in WSNs, using the Genetic Algorithm and Predictive Coding Approach

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Optimisation de l’efficacité énergétique et prolongation de la durée de vie des WSN à l’aide de l’algorithme génétique et de l’approche de codage prédictif

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RÉSUMÉ

Les réseaux de capteurs sans fil (WSN) ont révolutionné les applications de surveillance et de suivi dans divers domaines. Ces réseaux sont constitués de petits nœuds de capteurs chargés de collecter et de transmettre les données à une station de base centrale à des fins d’analyse et de prise de décision. Cependant, le défi omniprésent dans les WSN réside dans les ressources énergétiques limitées de ces nœuds, ce qui a un impact significatif sur leur durée de vie opérationnelle.

Cette étude aborde la question critique de l’efficacité énergétique dans les WSN en proposant un protocole de routage innovant économe en énergie. L’objectif principal est de prolonger la durée de vie opérationnelle du réseau tout en maintenant la qualité et la couverture des données. Pour y parvenir, la recherche intègre des algorithmes génétiques (GA) pour optimiser les décisions de routage et utilise le codage prédictif (PC) pour améliorer l’efficacité de la transmission des données.

S’appuyant sur des algorithmes génétiques, le protocole de routage optimise les chemins de communication en sélectionnant intelligemment les itinéraires qui minimisent la consommation d’énergie. Le codage prédictif renforce cette approche en compressant les données avant la transmission, réduisant ainsi efficacement la surcharge énergétique associée au transfert de données.

La motivation de cette recherche vient du fait que les protocoles de routage économes en énergie existants ont souvent du mal à répondre de manière globale aux diverses applications et aux diverses contraintes énergétiques des WSN. En réponse, cette étude vise à fournir un protocole de routage plus robuste et adaptable, capable de mieux gérer la consommation d’énergie et de prolonger la longévité du réseau.

L’efficacité du protocole proposé est rigoureusement validée par des simulations approfondies menées dans Matlab. Les mesures d’évaluation englobent des facteurs tels que les nœuds morts, le débit, la consommation d’énergie et le délai du réseau. Les résultats démontrent un avantage marqué par rapport au protocole de routage standard Leach-CR. Le nouveau protocole permet de réaliser d’importantes économies d’énergie et d’allonger la durée de vie opérationnelle des réseaux de capteurs sans fil.

Par rapport aux protocoles existants, l’approche intégrée des algorithmes génétiques et du codage prédictif offre des avantages inégalés, démontrant son potentiel pour révolutionner la gestion de l’énergie dans les WSN. Les implications sont considérables, car cette recherche est prometteuse pour améliorer l’efficacité et la durabilité des réseaux à travers des applications pratiques.

En conclusion, cette recherche contribue à l'avancement des WSN en offrant une solution complète au défi de l'efficacité énergétique. En intégrant de manière transparente les algorithmes génétiques et le codage prédictif, le protocole proposé démontre son potentiel pour révolutionner la gestion de l'énergie et prolonger la durée de vie opérationnelle des réseaux de capteurs sans fil, bénéficiant ainsi à terme d'un large éventail d'applications pratiques.

Mots-clés: Réseaux de capteurs sans fil, efficacité énergétique, protocole de routage, algorithmes génétiques, codage prédictif, durée de vie opérationnelle, simulation, Matlab, IoT

Optimizing Energy Efficiency and Prolonging Lifetime in WSNs, using the Genetic Algorithm and Predictive Coding Approach

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ABSTRACT

Wireless Sensor Networks (WSNs) have revolutionized monitoring and tracking applications across various domains. These networks consist of small sensor nodes responsible for collecting and transmitting data to a central base station for analysis and decision-making. However, the pervasive challenge in WSNs is the limited energy resources of these nodes, which significantly impacts their operational lifetime.

This study addresses the critical issue of energy efficiency in WSNs by proposing an innovative energy-efficient routing protocol. The primary objective is to prolong the network's operational lifetime while maintaining data quality and coverage. To achieve this, the research integrates Genetic Algorithms (GAs) to optimize routing decisions and employs Predictive Coding (PC) to enhance data transmission efficiency.

Building on the foundation of Genetic Algorithms, the routing protocol optimizes communication paths by intelligently selecting routes that minimize energy consumption. Predictive Coding augments this approach by compressing data before transmission, effectively reducing the energy overhead associated with data transfer.

The motivation for this research stems from the fact that existing energy-efficient routing protocols often struggle to comprehensively address the diverse applications and varying energy constraints of WSNs. In response, this study seeks to provide a more robust and adaptable routing protocol that can better manage energy consumption and extend network longevity.

The proposed protocol's effectiveness is rigorously validated through extensive simulations conducted in Matlab. Evaluation metrics encompass factors such as dead nodes, throughput, energy consumption, and network delay. The results demonstrate a marked advantage over the standard Leach-CR routing protocol. The new protocol achieves significant energy savings and leads to an extended operational lifespan of wireless sensor networks.

In comparison to existing protocols, the integrated approach of Genetic Algorithms and Predictive Coding offers unparalleled benefits, showcasing its potential for revolutionizing energy management in WSNs. The implications are far-reaching, as this research holds promise for enhancing network efficiency and sustainability across practical applications.

In conclusion, this research contributes to the advancement of WSNs by offering a comprehensive the solution to the energy efficiency challenge. By seamlessly integrating Genetic Algorithms and Predictive Coding, the proposed protocol demonstrates its potential to revolutionize energy management and extend the operational lifespan of wireless sensor networks, ultimately benefiting a wide array of practical applications.

Keywords: Wireless Sensor Networks, Energy Efficiency, Routing Protocol, Genetic Algorithms, Predictive Coding, Operational Lifetime, Simulation, Matlab, IoT

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
AODV	Ad Hoc On-Demand Distance Vector
BS	Base Station
CR	Current Route
CV	Current Values
EADV	Energy-Aware Distributed Vector
Er	Error
ETS	École de Technologie Supérieure
FF	Fitness Function
GA	Genetic Algorithm
GECR	Genetic algorithm based Energy-efficient Clustering and Routing
IoT	Internet of Things
LEACH-CR	Low-Energy Adaptive Clustering Hierarchy with Crossover Routing
LGCA	Localized Game theory Clustering Algorithm
NR	New Route
PC	Predictive Coding
POR	Population Of the Routes returned
PR	Previous Route
PV	Past Values

SN	Sensor Node
WSN	Wireless Sensor Network

INTRODUCTION

In an era characterized by rapid technological advancements and increasing interconnectedness, wireless sensor networks (WSNs) have emerged as a pivotal technology with applications spanning from environmental monitoring to healthcare systems. As these networks continue to evolve, ensuring their energy efficiency and sustainability becomes paramount. This thesis delves into the realm of WSNs, specifically focusing on the design and evaluation of an energy-efficient routing protocol aimed at enhancing network longevity and data transmission reliability.

Over view of WSN

Historically, the concept of WSNs emerged between the late 1970s and 1990s, initially being tailored for military applications with inherent limitations in computational power and battery life. The 2000s marked a foundational era for WSNs with a surge in commercial interest, the introduction of technologies like MICA motes, and a focus on power conservation, routing, and data aggregation. Applications during this period spanned environmental monitoring, agriculture, and health. The subsequent decade, the 2010s, saw WSNs integrating with cloud computing and becoming central to the burgeoning Internet of Things (IoT) landscape. This era also witnessed advancements in communication technologies such as Zigbee and LoRa and expanded applications into domains like smart cities and industrial automation. In the current era of the 2020s and beyond, the spotlight is on integrating AI and machine learning, emphasizing security, evolving towards energy harvesting, and aligning with state-of-the-art communication platforms like 5G.

A Wireless Sensor Network (WSN) consists of spatially distributed autonomous sensors that monitor physical or environmental conditions such as temperature, sound, pressure, etc., and cooperatively pass their data through the network to a main location for analysis. The WSN is built of "nodes," where each node is equipped with one or more sensors. These nodes can be small and inexpensive, allowing a network to consist of thousands or even millions of nodes.

Components

In Wireless Sensor Networks (WSNs), the topology defines how sensor nodes are arranged and how they communicate with each other and with a central point of data collection. Key components in this topology include the sensor nodes, cluster heads, the sink, and the base station. Each plays a distinct role:

1. Sensor Nodes: These are the basic units of a WSN, responsible for collecting data from their environment. This data could be anything from temperature readings to images or sounds, depending on the network's purpose. Sensor nodes typically have limited processing power and energy resources.
2. Cluster Heads: In many WSN topologies, especially those that use clustering (such as LEACH), sensor nodes are grouped into clusters. Each cluster has a designated leader known as the cluster head. The primary role of a cluster head is to collect data from the nodes in its cluster, perform some data aggregation or processing to reduce redundancy, and then transmit the aggregated data to a higher level in the network hierarchy, typically the sink or base station. Cluster heads are crucial for reducing the amount of data transmission required in the network, thereby saving energy.
3. The Sink (or Gateway): The sink, sometimes referred to as the gateway, acts as a liaison between the sensor nodes (or cluster heads) and the base station. In some network architectures, the sink is responsible for gathering data from individual sensor nodes or cluster heads and then transmitting this information to the base station. The sink can perform additional roles like data filtering, aggregation, and preliminary analysis.
4. Base Station: The base station is usually a more powerful computing system with fewer energy constraints compared to sensor nodes. It is the ultimate recipient of the data collected by the network. The base station can perform complex data processing, analysis, and storage. It can also serve as the interface between the sensor network and the end-user or other networks (like the internet).

In summary, sensor nodes gather data in a typical WSN topology and send it to their cluster head. The cluster heads aggregate this data and forward it to the sink. The sink then transmits the collected data to the base station for further processing and use. This hierarchical structure efficiently reduces energy consumption in the network, as it minimizes the long-range transmissions that individual sensor nodes must make.

Features

1. Low Power Consumption: Since these networks are often deployed in hard-to-reach areas (e.g., underwater, in forests), energy efficiency is a critical factor.
2. Scalability: WSNs are often designed to be highly scalable, meaning you can add hundreds or thousands of nodes with little effort.
3. Self-Organization: Nodes in WSNs usually organize themselves into a network after being deployed.
4. Fault Tolerance: WSNs are generally designed to be robust and continue functioning even when some nodes fail.
5. Adaptability: Modern WSNs can adapt to the data by, for example, reducing the sampling rate when not much is happening and increasing it when a certain event occurs.

Applications

1. Environmental Monitoring: Tracking wildlife, detecting forest fires, and monitoring air and water quality.
2. Military Applications: Surveillance, intrusion detection, and battlefield monitoring.
3. Healthcare: Patient monitoring and drug administration.
4. Industrial Monitoring: Condition monitoring of machines and processes.
5. Smart Cities: Traffic monitoring, waste management, and smart lighting.
6. Agriculture: Soil moisture monitoring, animal tracking, and farm equipment monitoring.

Challenges

1. Energy Conservation: Finding ways to reduce energy use to prolong the life of the battery-powered nodes.
2. Security: Ensuring data integrity and privacy is a big concern, especially for military or healthcare applications.
3. Data Overload: Managing the vast amounts of data generated.
4. Interoperability: Ensuring different types of WSNs can work together.

WSNs are a rapidly evolving technology and are becoming an integral part of the emerging Internet of Things (IoT) systems. With advancements in miniaturization and energy efficiency, the capabilities and applications of WSNs are expected to grow.

Problem Statement

The deployment of wireless sensor networks has brought forth challenges related to energy consumption and network lifetime. As sensor nodes are often battery-powered and may be deployed in remote or hostile environments, optimizing energy consumption is crucial to extend the network's operational lifespan. Traditional routing protocols may not effectively address these challenges, necessitating the development of innovative solutions tailored to the specific requirements of WSNs.

Research Objectives

The primary objective of this research is to design, simulate, and evaluate an energy-efficient routing protocol that addresses the energy consumption concerns inherent in wireless sensor networks. This protocol seeks to extend the network's operational lifetime while maintaining data transmission reliability and overall network performance.

Research Questions

To guide the investigation, this study seeks to answer the following research questions:

- How can an energy-efficient routing protocol be designed for wireless sensor networks to optimize energy consumption?
- What impact does the proposed routing protocol have on key network performance metrics, such as energy consumption, throughput, latency, and network lifetime?

Scope and Limitations

This research focuses on developing and evaluating an energy-efficient routing protocol within the context of wireless sensor networks. While the proposed protocol is designed to enhance network energy efficiency and lifetime, other factors, such as security and scalability, are outside the scope of this study. Additionally, the research's applicability primarily concerns scenarios where limited energy resources constrain network nodes.

Significance of the Study

The significance of this study lies in its potential contributions to the field of wireless sensor networks. By addressing the energy consumption challenges, the proposed routing protocol could pave the way for more sustainable and reliable WSN deployments. The findings of this research can aid network administrators, researchers, and policymakers in optimizing network design for enhanced energy efficiency.

Literature Review Overview

The literature review explores existing research on wireless sensor networks, energy-efficient routing protocols, and related optimization strategies. Notable studies have highlighted the importance of energy-aware routing algorithms, clustering techniques, and data aggregation methods to prolong network lifetime and improve data delivery rates.

Methodology Overview

The research methodology entails designing the proposed routing protocol and simulating its performance using a simulation tool. Matlab is chosen as the simulation platform due to its capabilities in evaluating network behaviour and energy consumption. The simulation parameters include network size, energy model, communication ranges, packet sizes, and various energy consumption factors.

Thesis Structure

This thesis is organized into five chapters. Chapter One provides an introduction to the research, highlighting the study's problem statement, objectives, and significance. Chapter Two offers a comprehensive literature review, examining relevant studies in the field. Chapter Three details the methodology employed, explaining the design and simulation of the proposed routing protocol. Chapter Four presents the simulation results and their analysis, comparing the proposed protocol's performance against a baseline routing protocol. Finally, Chapter Five concludes the thesis by summarizing key findings, discussing their implications, and suggesting avenues for future research.

In the subsequent chapters, this thesis aims to contribute to the discourse on energy-efficient routing protocols for wireless sensor networks. By addressing the pressing issue of energy consumption, the proposed protocol strives to enhance the sustainability and efficiency of wireless sensor network deployments.

CHAPTER 1

BACKGROUND STUDIES

This chapter provides an in-depth literature review and analysis of past studies related to the development of energy-efficient routing protocols for WSNs. We will commence by shedding light on the selected research domain and the pertinent challenges we address in this thesis. Subsequently, we will delve into relevant background studies, drawing parallels with our proposed model and highlighting their constraints.

Foremost, it's imperative to elucidate the chosen research domain and the challenges we aim to address within this thesis. The pervasive use of autonomous, multifunctional, both mobile and stationary sensor node (SN) devices has paved the way for innovative sensor-based network applications. A wireless sensor network (WSN) is a cohesive system comprising numerous SNs and at least one base station (BS). Given the diverse applications of WSNs in various facets of life, especially for monitoring and tracking, their adoption has witnessed a marked uptick. However, alongside the myriad advantages they offer, WSNs come with inherent challenges. Paramount among these challenges is the energy efficiency of the WSNs.

Energy efficiency stands out as a paramount concern in WSN applications that demands urgent resolution. Past research endeavors have seen scholars primarily gravitate towards developing energy-efficient routing protocols. Yet, in spite of the plethora of such protocols tailored for enhancing network energy efficiency, the challenge persists. In this thesis, we address the ever-present issue of energy efficiency. Our approach integrates the latest algorithmic innovations into our model, aiming to optimize WSNs via energy-efficient routing. An exhaustive description of our proposed model can be found in the methodology section. Furthermore, a critical exploration of the current energy-efficient routing protocols for WSNs, as documented in existing literature, is imperative.

1.1 Background Studies

A routing protocol is identified as the opportunistic one that deals with most efficiently managing the resources to increase the network life span and saving the energy of SNs. This routing protocol mainly deals with the data transmission of nodes by controlling the energy resources more effectively. A power load at a node is not better for WSN performance because the death of a node affects the overall performance badly. The proposed model was used to count the list of candidates to transmit the data to decrease power expenditure and improve the network's life span. The relationship of this model with the proposed scheme is based on obtaining the best routing for the data communication that helps to enhance the sensor nodes' energy in a balanced way to achieve a long network lifetime (A. Boukrache et al., 2007).

1.1.1 Game Theory Approach

This energy-efficient scheme uses the game theory approach to find the optimal path. This approach works based on the pricing and payments to obtain the best route that helps reduce energy consumption and save the power capital for the sensor nodes in the WSN. This algorithm helps to enhance the network lifetime through load distribution and reliability for routing. The relationship of this approach with the proposed routing mode is route finding for the WSN to distribute the energy load among the sensor nodes and help the overall network remain active for extra time (Babak Arisian, 2010).

A routing protocol uses the game theory model to choose the optimal path in WSNs. This model is based on the game theory method that stands on the pricing and payments to get the optimal route for data transmission. If the data packet is delivered to the destination nodes, it will pay some considered quantity to the sender node. To find the path for data broadcasting, the utility function must be positive for all the possible destination nodes, like the BS or the intermediate nodes. This model's main factors are reliability, energy, and traffic burden. The relationship of this approach with the proposed approach is based on route optimization that efficiently helps reduce energy spending, distributes the load on the sensor nodes in the network, and enhances the network through energy efficiency (Xiaoyan MA., 2017).

1.1.2 LGCA Game Theory

This article is based on the concept of previously discussed models that identified routing protocol for WSN as the CROSS and LEACH. The CROSS model requires global information about the nodes, energy usage, and the packets exchanging. This article presents a model based on the localized game theory clustering algorithm (LGCA) concept. In this routing scheme, each node in the network played a game greedily with its neighbour according to the communication distance radius. After the step, all nodes play a bid to be chosen as cluster leaders as per their cluster by achieving the payoff value. The relationship of this model with the proposed model is the route selection for the data transmission in the network to reduce energy utilization. This model is limited due to the route selection to reduce energy spending. However, it needs to consider the factor of the average energy utilization, which is also essential to achieve a long-time network life (Hajer et al.., 2018).

1.1.3 Data compression and the predictive coding theory

The designed model meets the critical issues of energy efficiency for WSNs through data compression, one of the most adopted approaches to reduce the data size. In the sense of the WSNs data communication, the process of data compression is applied on the multi-hop data communication because on the hop nodes in the network are overloaded with data packets for transmission toward the next reception or sink that consumes extra energy resources of that SN which can cause earlier death and affect negatively on the overall network.

The reviewed algorithm uses the unified algorithm framework for loss and lossless data compression, which provides the flexibility to choose based on their desire from them. The relationship of this reviewed routing protocol to our newly proposed model is that this one also performed the data compression using different techniques to reduce energy utilization. Our model performs the same task using the predictive coding theory for wireless sensor networks. (Yao Liang., 2011)

1.1.4 Genetic Algorithm-Based Routing

Routing is the most crucial task for limited energy sensor-based networks in multi-hop routing. It is significant to reduce the relay hop nodes load if necessary to prolong the network lifetime. A genetic algorithm-based approach that deals with energy issues and minimizes the distance between communication nodes in each round. It is a quicker approach to estimating the current situation of the network for route schedule. This model uses the computational efficiency of the genetic algorithm to obtain the solution to the problem. The relationship of this approach with the proposed model in the thesis is utilizing the genetic algorithm for the route selection and aggregating the data at the relay nodes to make the network more energy efficient. However, the approach differs (Suneet K et al., 2013).

1.1.4.1 Multi-hop Route Finding

A genetic algorithm-based multi-hop route finds between two communication devices in WSN. The model was an optimal multi-hop path-finding algorithm by proposing a new fitness function. This algorithm's main job is to reduce the energy utilization for data communication and enhance the network lifetime. This algorithm is more relevant to the proposed approach in this dissertation, having a similar aim to attain energy-efficient routing using the genetic algorithm. Nevertheless, the way of dealing with optimizing efficient routes is different. The limitation of this algorithm is that it just deals with the single-hop data communication mechanism in the network. (Mohammed Al-Shalabi et al., 2019).

1.1.4.2 Route Finding with Downward Distance

An algorithm that uses the genetic algorithm to find out the route for the WSN to reduce the energy utilization for the communication between nodes and enhance network lifetime.

This approach justifies its results in a different context compared to the well-known existing approaches. To evaluate this algorithm to the proposed model, it is also doing the exact job as we are trying differently. But this approach is more relevant to the proposed model in the context of energy efficiency and network lifetime through the distance and energy consideration. However, this model uses the downward distance of the communication devices, and the proposed model uses the energy load distribution on the sensor nodes in the network. The limitation of this approach is its need to distribute the sensor nodes' energy among overall nodes else. Then, choose the shortest distance node. Because, in this way, the sensor nodes may die earlier, and the gap between the first node dispatch and the last node dispatch is not better for the overall network performance (Adeel Abro et al., 2019).

1.1.4.3 3D Area Genetic Algorithm

This algorithm is used to enhance the network's lifetime of sensor nodes based on its relatively unexplored 3D area in WSN. This scheme uses the genetic algorithm to make the nodes' chain communicate the network data for WSN. This approach is also helpful in balancing energy utilization and communication at a short distance; less energy is more beneficial to enhance the network lifetime. The relationship of this approach with our model is the route selection strategy to reduce energy utilization and a similar algorithm. However, the direct approach of the node's route selection varies. The proposed model deals in a way that balances the energy load and delivers essential data more quickly and efficiently. It has limited to homogeneous SNs networks for better results in the context of energy efficiency (Anqil Somauroo et al., 2019).

1.1.4.4 Connection-oriented Genetic Algorithm

A dominant genetic algorithm to find the optimum energy-efficient route is presented that is applied to the connection-oriented crossover and mutation to manage the feasibility of the solution. The generated solution is based on different situations, such as the energy efficiency of the WSN. This routing approach is more relevant to the proposed algorithm that deals with efficient routing to reduce energy consumption using the genetic algorithm in WSN. However, the limitation of this routing protocol is that it is more efficient for the mobile data-gathering nodes by performing the optimum energy-efficient routing to save energy resources (Shanthi D L et al., 2020).

1.1.4.5 Chaotic Genetic Algorithm

A chaotic genetic algorithm balances the load to enhance the network lifetime for WSNs. It performs both the best cluster head selection as well as the best optimal path using the coding for single chromosomes for communication. Its process relies on single fitness functions for minimal energy utilization and load balancing to enhance the network lifetime. The relationship of this model with our proposed algorithm is the utilization of the same algorithm, but the primary purpose is varied. The model uses cluster head selection, and the proposed model uses the algorithm for efficient routing optimization. This approach is limited to optimal route selection; however, the proposed model deals with the routing based on the optimal and opportunistic route selection using the genetic algorithm to distribute the energy load more efficiently to enhance the network lifetime of WSN (C. Wang et al., 2020).

1.1.5 Huffman Coding Scheme

A scheme that performs lightweight data compression using a conventional Huffman coding scheme in measurement time and locations. This model deals with general knowledge instead of dealing with device knowledge. The designed model deals with the first value sensed delivered uncompressed until its previously observed value computes its difference. The procedure and the others remain the same as it is. This is for the energy-saving purpose that leads toward the network lifetime enhancement. Its relationship with the proposed model is using the data compression approach to reduce data via compression to save energy resources for wireless sensor networks. Both approaches have the basic knowledge of network lifetime enhancement (Henry et al., 2014).

1.1.6 Robust Data Compression

An algorithm that performs the data compression more efficiently is highly robust and varies on different WSN characteristics. It justifies performance by efficiently using the real-world data set for different scenarios. The robust data compression is the main contribution of this model; this is done by considering the weakness of the existing data compression algorithm. The relationship of this model with our proposed approach is the compression of the data to transmit using fewer energy resources for the limited energy-based SN in the network. Reducing the data size for transmission more efficiently reduces the energy utilization in the wireless sensor networks, which impacts the network lifetime, and prolongs (Yao Liang et al., 2014).

1.1.7 GECR Genetic Algorithm

A genetic algorithm based energy-efficient clustering and routing approach identified as GECR uses the initial population as the last round value for the current round to improve search efficiency. The scheme combines the clustering and routing into single chromosomes to get the energy expenditure and a fitness function is created to enhance energy efficiency. Also, load balancing is considered in the construction of the fitness function. This is useful in balancing the energy utilization that makes the network more energy efficient than others. Significant contributions of this model are the energy-efficient clustering and routing through a genetic algorithm that balances the energy utilization to enhance energy efficiency. The relationship with our model is that both will propose a routing model for energy efficiency through efficient route selection using the genetic algorithm. In the proposed model, the routes are decided based on the data importance that makes unbalanced data transmission. (Rianshu Wang et al., 2018).

1.1.8 Power Efficiency Gathering Algorithm

An algorithm that enhances power efficiency gathering sensor information system alleviates the hot spot problem. The optimal route selection to reduce the energy consumption that enhances the network lifetime and latency of the WSN. Also, this one uses threshold values to save the nodes from dying earlier; nodes adjust the communication ranges to balance the energy load. The relevancy of this routing protocol with the proposed model can be evaluated based on factors like efficient routing and load balancing to achieve energy efficiency and network lifetime. The relationship of this approach with the proposed model is routing data through neighbour nodes and distributing the SNs load. This approach can be limitedly utilizable for predefined scenarios due to the threshold values for better performance (Jin Wang et al.,2018).

1.1.9 Ant Colony Algorithm

An ant colony algorithm was used to choose the optimal path for the WSN to reduce energy expenditure and network lifetime enhancement. This algorithm provides the optimal route to the mobile sink for movement toward the center and saves extra energy resources. The significant contribution to the model is using the ant colony algorithm to choose the optimal route. This algorithm is more related to the proposed approach because of the optimal route selection for the energy efficient route selection to save energy and network lifetime enhancement (Biswa et al.., 2020).

1.1.10 Bayesian Predictive Approach

An algorithm that deals with data compression to minimize energy usage for data communication. It is a Bayesian predictive approach that performs lossy compression. Its deals with transferring the error term instead of the actual data. Predictive sensing mixes Bayesian inference with predictive coding. Prediction is made by the Bayesian inference instead of regression models as in traditional predictive coding. In this way, it can utilize prior information and provide inferences conditional on the data without relying on asymptotic approximation. In the context of this algorithm's relationship with the proposed routing protocol, it has used the predictive coding theory as we are trying to compress the data before transmission to enhance the network lifetime in WNS. This protocol is limited to lossy data compression rather than loss and lossless data compression (Chen Zhang et al., 2020).

1.1.11 Leach Hierarchal Protocol

Leach is a hierarchal energy-efficient routing protocol that is one of the most adopted and efficient considered models for WSNs. Multiples of the routing protocol exist that are based on the concept of the leach routing protocol with some modification. One of the recently designed routing protocols, identified as the leach-CR, is a hybrid model of the leach-C and leach-R routing protocols that is more efficient compared to them. In this model, the sensor nodes choose cluster heads for each cluster in the network. Then the cluster head close to the sink is used as an intermediate cluster head to receive the data from the cluster heads located at long distances as compared with cluster heads found in the neighbourhood, and this makes the load distribution between the nodes and prolongs the network lifetime (Nurfazrina et al. et al., 2021).

1.1.12 LEACH-CR Protocol

LEACH-CR stands for Low-Energy Adaptive Clustering Hierarchy with Crossover Routing, an advanced protocol for Wireless Sensor Networks (WSNs). It builds upon the original LEACH protocol, which conserves energy by forming clusters of nodes with one node acting as the cluster head. This cluster head collects data from other nodes and sends it to the base station. By doing so, it reduces the number of direct communications between individual nodes and the base station, which can be energy-intensive.

The CR in LEACH-CR refers to Crossover Routing, which is an enhancement that applies genetic algorithm techniques to optimize the routing paths within the WSN. This means LEACH-CR not only clusters the nodes but also intelligently determines the best path for data to travel through the network. By simulating natural selection, it evaluates and combines different routing paths, keeping the routes that result in lower energy consumption and discarding the less efficient ones.

In practical terms, LEACH-CR is valuable for extending the operational lifespan of a WSN. Since sensor nodes usually have limited battery life, optimizing how they use energy is critical. LEACH-CR's adaptive approach to routing helps even out the energy load across the network, ensuring no single node bears too much burden. Additionally, it can dynamically adjust to changes, like when nodes run out of battery or are added to the network.

1.1.13 Ad Hoc On-Demand Distance Vector (AODV) Routing

The Ad Hoc On-Demand Distance Vector (AODV) Routing protocol is tailored for mobile ad hoc networks and operates reactively, meaning it only establishes routes when required. This approach suits Wireless Sensor Networks (WSNs) by conserving energy: it minimizes unnecessary route discovery broadcasts, a significant energy drain in WSNs. By activating route discovery only upon data transmission needs, AODV helps extend the battery life of sensor nodes.

However, AODV's design is inherently geared towards networks with mobile nodes, which may limit its effectiveness in typical WSNs where nodes are usually static. The protocol doesn't naturally account for the residual energy of nodes in route selection, which can be a drawback in static networks where energy conservation and distribution are crucial. Thus, while AODV can reduce energy consumption through fewer broadcasts, its full potential in WSNs may require adaptations to suit the static nature of these networks and to consider the energy levels of nodes for optimal route selection.

1.1.14 Energy-Aware Distributed Vector (EADV) Routing

The Energy-Aware Distributed Vector (EADV) Routing protocol enhances the standard Ad Hoc On-Demand Distance Vector (AODV) protocol by integrating energy considerations into routing decisions in Wireless Sensor Networks (WSNs). Unlike AODV, which primarily seeks the shortest route, EADV also accounts for the energy levels of nodes, selecting routes that go through nodes with higher energy reserves. This approach helps in balancing the energy usage across the network, thus aiming to extend the overall lifespan of the WSN.

EADV's focus on energy levels is particularly valuable in WSNs, where nodes are typically battery-powered and located in environments where battery replacement is challenging. By avoiding routes that overuse low-energy nodes, EADV contributes to a more reliable and long-lasting network.

However, EADV's implementation can be more complex than AODV. It requires constant monitoring of nodes' energy levels, potentially increasing control traffic and, to some extent, the network's energy consumption. Additionally, the routing decision process is more intricate due to the need to balance path length with node energy levels.

In essence, EADV represents a significant stride towards energy-efficient routing in WSNs, although its effectiveness needs to be balanced against the potential increase in network overhead and complexity.

Summary

The literature review section delves deeply into studies closely related to the thesis's theme, which revolves around crafting an energy-efficient routing protocol for WSNs. The primary emphasis is on examining established routing protocols for WSNs' energy conservation as they appear in existing literature, and how they connect with the current thesis. Key concepts from background research are spotlighted in the literature review, emphasizing their relevance to the suggested energy-efficient routing model. Various studies in the review are explored, each presenting unique concepts aimed at achieving energy efficiency in WSNs. These concepts vary based on factors such as network designs, deployment of sensor nodes, and the methodologies and algorithms employed for clustering and routing.

In essence, the literature review chapter offers an in-depth examination of existing energy-saving routing protocols for WSNs. This scrutiny delves into the intricacies of these protocols, their links to the thesis's proposed protocol, and areas yet to be explored in research.

CHAPTER 2

TECHNOLOGY REVIEW

The study aims to address long-standing issues related to energy efficiency in Wireless Sensor Networks (WSNs). Despite the wealth of existing literature that primarily focuses on energy-efficient routing protocols, a definitive solution has not been found. To bridge this research gap, the study formulates a new research question focused on developing a more effective energy-efficient model for WSNs. One of the study's key innovations is the use of Artificial Intelligence to optimize routing paths and perform data compression, which is expected to balance energy consumption among sensor nodes and extend the network's overall lifespan.

The study also tackles the design of an energy-efficient routing protocol for WSNs. This design aims to resolve major issues affecting WSNs, including unequal energy consumption and the inefficiencies related to long-distance data transmission. Algorithms are implemented to optimize energy use by ensuring that it is more evenly distributed among sensor nodes, thus extending their operational lifespan. Additionally, the study takes on the issue of excess energy consumption due to redundant data transmission, offering more efficient techniques to keep sensor nodes alive for a longer duration and improve overall network performance.

In summary, the study integrates findings from the literature review, utilizes artificial intelligence techniques, and proposes new, efficient protocol designs to tackle both unbalanced and extra energy consumption. The overarching goal is to create a more energy-efficient and sustainable Wireless Sensor Network.

2.1 Addressing Gaps in WSN Energy-Efficiency: A Literature Review

In the literature review, various studies have attempted to address energy problems in Wireless Sensor Networks (WSNs) primarily through the development of energy-efficient routing protocols. Despite these efforts, a comprehensive solution to the energy challenges remains elusive. Recognizing the merit in pursuing energy-efficient routing, this study adopts this approach as well. Previous models have looked into several factors to enhance network lifetime and minimize sensor nodes' energy consumption, including clustering mechanisms, cluster head selection methods, and routing. This study aims to refine existing models by focusing on efficient route optimization and reducing unnecessary data transmission, with the ultimate goal of lowering energy consumption and extending the network's lifespan.

2.1.1 Formulating a Research Question to Address Persistent Energy Efficiency Issues in WSNs

The literature review examines several approaches to improving energy efficiency in Wireless Sensor Networks (WSNs) through routing protocols. Despite these efforts, the issue persists, especially as WSN applications continue to expand into various sectors. To address this, it is essential to identify research gaps and formulate a specific research question aimed at finding the most effective energy-efficient model for WSNs. Consequently, the research question for this study has been designed to target these unresolved issues and seek more energy-efficient outcomes for WSNs.

2.2 Utilizing AI for Efficient Routing and Data Compression in WSNs

Artificial Intelligence (AI) enables computer systems to emulate human-like intelligence, particularly in handling large data sets and making decisions based on pattern recognition. AI also offers robust algorithms that can address challenges in various fields such as medicine, engineering, and computer science. In the context of Wireless Sensor Networks (WSNs), routing and data compression are critical issues. AI algorithms can optimize routing paths from source nodes to destinations, while AI-based data compression techniques can minimize redundant data, thereby conserving energy resources.

In this study, AI algorithms will be employed to achieve efficient route optimization and data compression, enhancing the overall network performance. These methods contribute to a balanced distribution of energy consumption across sensor nodes in the network, reducing the overall energy usage. By implementing these AI-driven techniques, the study aims to achieve a more energy-efficient routing protocol and to extend the operational lifespan of the network's nodes.

2.3 Design Challenges and Goals for Energy-Efficient WSN Routing

Designing an energy-efficient routing protocol for Wireless Sensor Networks (WSNs) is critical for ensuring that sensor nodes can communicate effectively while conserving their limited energy resources. Factors such as unequal energy consumption among nodes, premature failure of some nodes, and inefficient long-distance data transmissions contribute to energy waste and suboptimal network performance. Maximizing the operational lifespan of sensor nodes is crucial for the network's overall effectiveness. To improve both the network lifespan and its performance, it's essential to address these challenges by designing a more energy-efficient routing protocol. This study aims to tackle the issues identified in existing literature on energy-efficient routing protocols for WSNs, applying efficient techniques to provide a more effective solution.

2.4 Addressing Energy Efficiency Gaps in WSN Routing Protocols

The energy issue is a significant concern in Wireless Sensor Network (WSN) applications. This study addresses this by developing a more efficient routing protocol, a commonly discussed solution in existing literature but one that has not yet been optimized. Our approach specifically targets issues of unbalanced energy consumption and excess energy use in data transmissions within the network. We recognize that factors such as the distance between devices and the volume of data transmitted contribute to higher energy use. By tackling these problems with innovative techniques, this study aims to offer a more efficient and effective solution for energy conservation in WSNs.

2.5 Optimizing Energy Distribution in Wireless Sensor Networks: A Comprehensive Approach

In the existing literature, various models aim to optimize energy-efficient routing for Wireless Sensor Networks (WSNs). However, given the diverse applications of WSNs, energy imbalance remains a persistent issue. This study addresses this problem by developing an optimized route selection mechanism. The goal is to distribute energy usage evenly across sensor nodes, thereby extending network lifetime. To achieve this, we employ advanced algorithms that not only facilitate efficient data transmission but also equalize energy consumption among the nodes, offering a more comprehensive solution for energy-efficient routing in WSNs.

2.6 Addressing Energy Consumption in Data Transmission for Wireless Sensor Networks

This study focuses on the issue of excessive energy consumption during data transmission in Wireless Sensor Networks (WSNs), which can lead to premature failure of sensor nodes and degrade overall network performance. Current approaches often struggle with this problem, especially when sensor nodes act as intermediate hops and handle large amounts of data. By tackling the issue of excessive energy usage in data transmission, this study aims to extend the lifespan of sensor nodes and enhance the network's overall efficiency.

2.7 Summary

This chapter aims to address critical energy efficiency issues in Wireless Sensor Networks (WSNs). While existing literature offers various solutions, mainly through routing protocols, these have not fully solved the energy consumption problem. The inefficiency often stems from imbalanced energy use across sensor nodes and excessive energy spent during large-volume data transmission. This study seeks to fill this research gap by developing an energy-efficient routing protocol that minimizes energy consumption and prolongs the network's lifespan. The thesis uses advanced algorithms to optimize route selection and manage data transmission to reduce energy waste effectively. The research aims to achieve a balanced energy distribution among nodes and efficient data transmission, enhancing WSN performance and sustainability.

CHAPTER 3

METHODOLOGY

Wireless Sensor Networks (WSNs) have found ubiquitous applications ranging from environmental monitoring to healthcare, playing a crucial role in data collection and transmission. However, their deployment is often constrained by limited battery life, posing a severe challenge to the network's longevity and efficiency. While various studies have focused on enhancing energy efficiency in WSNs, they have not adequately addressed the complexities arising from the diversity of WSN applications. Moreover, the existing approaches often fall short in tackling issues such as unbalanced energy expenditure among sensor nodes, leading to premature network failure. Against this backdrop, this thesis aims to revolutionize energy efficiency in WSNs by introducing an innovative routing protocol that incorporates Artificial Intelligence (AI) algorithms and data compression techniques.

3.1 Issues

The main focus of the content revolves around the challenges faced by Wireless Sensor Networks (WSNs), particularly concerning their energy efficiency. These sensor nodes are becoming increasingly popular for tracking and monitoring applications. However, they have inherent limitations such as small size and constrained abilities in sensing, processing, storing, and transmitting data. These limitations extend to their energy resources as well, making it difficult for them to operate for extended periods.

The issue of energy efficiency has been extensively highlighted in existing literature, but no definitive solution has been found so far. Part of the problem is that WSNs have a wide range of applications, and what works in one context might not be effective in another. This makes it difficult to develop a one-size-fits-all solution for the energy efficiency problem. In essence, even though there have been various studies aiming to improve the energy efficiency of WSNs, none have been able to fully solve the issue, leaving a gap in the research and an ongoing problem that needs to be resolved.

While the primary concern is energy efficiency, there are also secondary challenges like the cost of implementing and maintaining these networks. The increasing adoption of sensor-based systems like WSNs makes it even more critical to address these challenges in a timely manner.

3.2 Objectives

The study in question is focused on tackling significant challenges in the field of Wireless Sensor Networks (WSNs), specifically in terms of their energy efficiency. WSNs are networks of spatially distributed sensors that collect and transmit data. They're used in a variety of applications like environmental monitoring, healthcare, and industrial automation. However, these sensor nodes are typically small and battery-powered, which makes their operational lifespan critically dependent on efficient energy use.

Prior research has tried to mitigate the energy issue by developing specialized routing protocols aimed at energy conservation. These protocols use various algorithms to determine the most energy-efficient paths for data transmission within the network. However, according to the study, these efforts have not sufficiently solved the problem. The reason for this gap might be the "one-size-fits-all" approach that fails to consider the diversity of WSN applications, leading to suboptimal energy efficiency in certain scenarios.

The new study aims to make two major contributions to this field. First, it focuses on the problem of unbalanced energy expenditure. In many WSNs, certain nodes may end up shouldering a disproportionate amount of the data transmission load, draining their batteries more quickly and causing the network to lose coverage and functionality. The study aims to devise a routing protocol that balances this load more equitably among all sensor nodes, ensuring that no single node becomes a bottleneck, thus extending the overall network lifespan.

The second issue is that of 'extra' energy expenditure, likely due to inefficient data handling procedures like redundant data transmission, or sending large amounts of raw, unprocessed data. The study plans to integrate data compression techniques into the routing protocol. By transmitting compressed data, the network would use less energy for each unit of information sent, further boosting energy efficiency.

So, the primary objective of this study is not just to create another energy-efficient routing protocol, but to build one that addresses these specific, nuanced issues. By focusing on efficient route selection to balance energy load and incorporating data compression techniques, the study aims to develop a more targeted, effective solution that will substantially increase the energy efficiency and longevity of Wireless Sensor Networks.

3.3 Methodology

The methodology for the study is centered around creating an energy-efficient routing protocol for Wireless Sensor Networks (WSNs) that addresses two major problems: unbalanced energy expenditure and excessive energy use for data transmission. These issues contribute to premature sensor node (SN) failure, which compromises network performance.

The study employs Artificial Intelligence algorithms to tackle these challenges, specifically using a genetic algorithm and predictive coding theory.

1. Genetic Algorithm: The genetic algorithm is used for route selection to distribute the data transmission load evenly among the sensor nodes. Genetic algorithms are optimization algorithms inspired by the process of natural selection. They use a population of possible routes, evaluate their fitness based on some criteria (in this case, energy efficiency), and evolve the population over several generations to find the most efficient route. This allows the network to balance the energy load among different nodes, extending the lifespan of individual nodes and thus the entire network.
2. Predictive Coding Theory: To address the issue of excessive energy use for transmitting data, the study employs predictive coding theory to compress data before it's sent. Predictive coding estimates the most probable upcoming data values based on previously encountered data. Because you're only transmitting the errors between the predicted and actual data,

you can significantly reduce the size of the data being sent. This compression reduces the energy required to transmit data to the base station.

By incorporating both of these algorithms—genetic algorithms for route optimization and predictive coding theory for data compression—the study aims to develop a routing protocol that is both balanced in energy expenditure and efficient in data transmission.

The algorithms' efficiency and behavior within this new scheme will be described in detail in the study, likely involving mathematical models to provide a theoretical underpinning for their operation. This comprehensive approach aims to address the weaknesses in previous methodologies and offer a more robust, energy-efficient solution for WSNs.

3.4 Adopted energy model

This section elaborates on the challenges and mechanisms associated with Wireless Sensor Networks (WSNs). Specifically, it delves into the roles and limitations of sensor nodes, small devices that sense, store, and transfer data within these networks. These nodes are vital for monitoring and tracking applications, but they operate on limited energy. Given this energy constraint, much of the research and technological development in WSNs focuses on energy efficiency. Over time, various routing mechanisms have been proposed to manage the flow of data in a way that minimizes energy use, aiming to extend the operational life of both individual nodes and the entire network. Routing protocols, which are sets of rules for data transfer within the network, often employ mathematical equations to predict energy consumption for different activities like communication and data reception. This predictive approach helps in designing more energy-efficient routing mechanisms, thereby optimizing the overall performance of WSNs. It should not be mentioned that the following equation is used in the routing protocol.

$$Etx = Eelec * K + Eamp * K * D^2 \tag{3.1}$$

The previously mentioned equation 3.1 serves as the formula for assessing how much energy is consumed during data transmission in the new routing protocol for Wireless Sensor Networks. In this equation,*Etx* denotes the entire energy spent for a single data transfer from one device to its receiving counterpart.*Eelect* indicates the electrical power needed for the transfer, while the variable *K* is a stand-in for the data packet's size. *Eamp* amplifies the signal for transmission, and *D* signifies the distance between the communicating devices. Additionally, another equation, 3.2, calculates the energy consumption when a sensor node receives data.

$$Erx = Eelec * K \tag{3.2}$$

In the given formula 3.2, *Erx* serves as an indicator for the cumulative energy required to accept a data packet from another sensor node within the network. *Eelec* signifies the energy specifically expended for receiving the data packet, and *K* stands for the dimensions of that packet in the network. This formulation is utilized to gauge energy consumption in various energy-saving routing schemes for Wireless Sensor Networks.

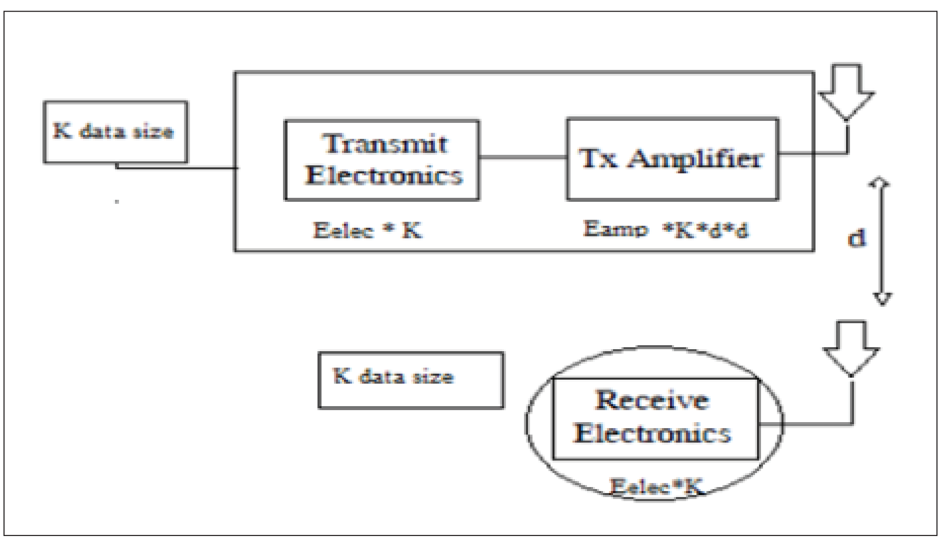

Figure 3.1 Adopted Energy Model
Taken from Wang et al. (2018, p. 433)

3.5 The proposed routing Model

In the proposed routing protocol for the Wireless Sensor Network (WSN), the network design assumes a single base station (BS) situated within the network's area. The energy consumption of the sensor nodes (SNs) varies depending on how far they are from the base station. Specifically, nodes that are farther away will consume more energy for transmitting data, while those closer to the base station will use less energy.

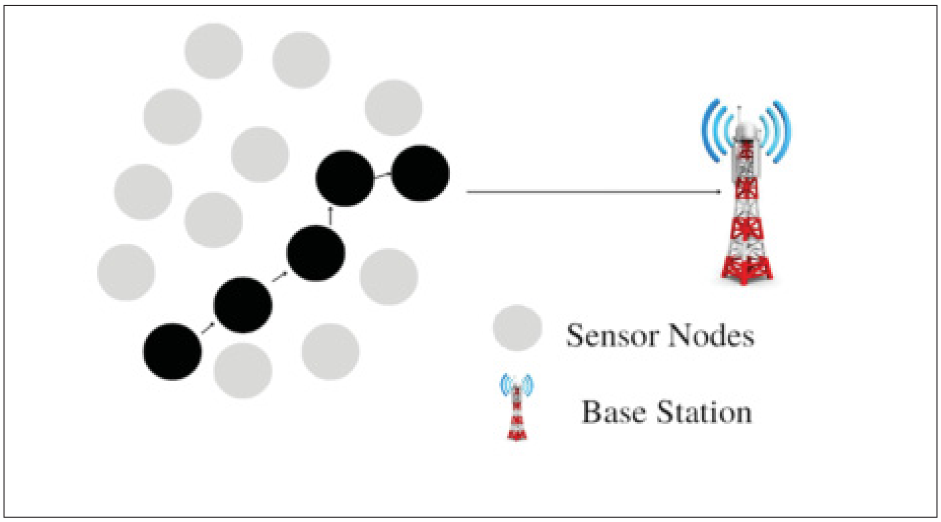

Figure 3.2 Adopted Network Model
Taken from Manisha et al. (2021, p. 12)

Instead of directly sending data to the base station, sensor nodes within the network forward their data to an intermediate sensor node. This intermediate node then takes on the responsibility of transmitting the collected data to the base station. One of the critical aspects of this protocol is to smartly select this intermediate node. The ideal intermediate sensor node should be one that facilitates efficient energy load distribution among all the sensor nodes in the network, ensuring that no single node drains its energy too quickly, thus contributing to the overall energy efficiency of the system.

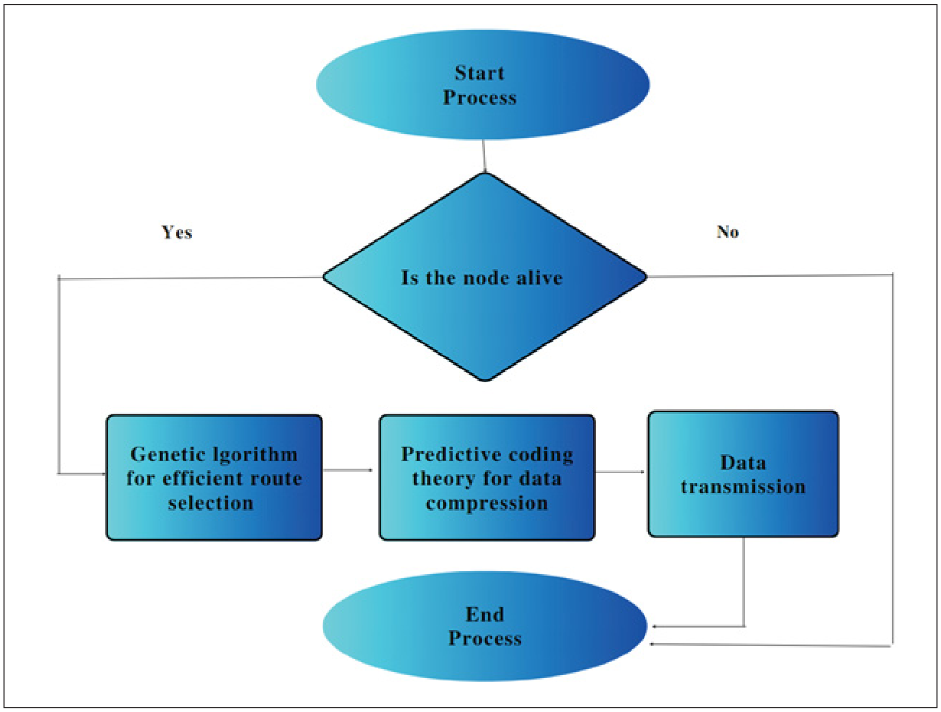

Figure 3.3 Flowchart of the proposed routing protocol for WSN

3.6 Genetic algorithm for energy efficient route selection

In the context of the proposed model for Wireless Sensor Networks (WSNs), energy-efficient route optimization is a key focus. The algorithm aims to select routes that take into account both energy balance and low energy expenditure, to boost the overall energy efficiency of the network. The model uses a Genetic Algorithm (GA) to optimize routes, which is an algorithm inspired by the mechanisms of natural selection and evolution in biology.

The Genetic Algorithm is well-suited for complex optimization problems and is rooted in Darwin's theory of evolution. It is used in a variety of fields, from computational science to commerce, to solve complex issues. The algorithm encodes solutions into "chromosomes" and then iteratively refines these solutions through processes akin to natural selection, mutation, and crossover.

Here’s how it works in the study:

1. Sensor nodes are randomly placed in the WSN, serving as the initial "population" in the Genetic Algorithm.
2. A "fitness function" evaluates each sensor node based on its remaining energy, distance to other nodes, and the data load it handles. This fitness function is used to select nodes that will serve as part of the optimal data transmission path.
3. Crossover operations are then performed, combining attributes from pairs of nodes to potentially create more "fit" offspring nodes.
4. Mutation operations can also occur, introducing small random changes to nodes, based on a probability function.
5. Nodes are then selected for the next generation based on their fitness scores, and crossover operations are performed on the most fit candidates.

The algorithm iterates through these steps, continually refining its selection of nodes for data transmission, until the nodes have exhausted their energy resources. The idea is to continually optimize the path for data transmission based on these criteria, thus extending the lifetime and efficiency of the WSN.

3.6.1 Algorithm

This Genetic Algorithm is designed to select efficient Sensor Nodes (SNs) for routing in a network. Here’s a step-by-step explanation of the algorithm:

- **Input:** The algorithm starts by taking the size of the network as input. This is likely the total number of nodes or the geographical size of the network.
- **Output:** The desired outcome is to determine the most efficient Sensor Nodes (SNs) to be used as the next hop in the routing process.
- **Assumptions:**Before running the algorithm, certain assumptions about the network are made, although these are not detailed in the provided steps.
- **Numbers of Sensor Nodes:**The algorithm requires knowledge of the total number of sensor nodes present in the network.

- **Efficient SNs as the Next Hop (ENH):** An array (ENH) is initialized, which will eventually hold the list of efficient sensor nodes for the next hop.
- **Pc (Probability-based Nodes Crossover):** A predefined probability that determines how often a crossover operation will occur during the algorithm's execution.
- **Pm (Probability-based Nodes Mutation):** A predefined probability that determines how often a mutation will occur.
- **Routes:** The algorithm considers the current route (Cr), the previous route (Pr), and a new route (Nr) as part of its process.
- **Fitness Function (FF):** The algorithm evaluates routes using a Fitness Function, which is based on factors such as distance between nodes, their residual energy, and the number of data packets.
- **Population of Routes (POR):** This is the set of all possible routes that the algorithm will consider.
- **Fitness Function on Routes (FF_RP):** The Fitness Function is applied to the routes in the population to evaluate their suitability.
- **While Loop:** The main loop of the algorithm begins, where the population of routes is processed.
- **Crossover:** A crossover function is applied to the routes, combining the current route and the previous route based on the crossover probability (Pc). This simulates genetic recombination.
- **Mutation:** A mutation function is applied to the routes, which introduces small changes to the current route with a mutation probability (Pm). This introduces variability into the population.
- **Selection:** The algorithm selects the fittest sensor nodes for routing from the population, based on the evaluation from the Fitness Function.
- **End:** The loop ends once all routes in the population have been processed.
- **Return:**Finally, the algorithm returns the array of routes, which presumably includes the routes with the most efficient next-hop sensor nodes according to the Fitness Function.

This Genetic Algorithm is a bio-inspired optimization process that iteratively improves the selection of sensor nodes for routing in a network by simulating evolutionary processes such as selection, crossover, and mutation.

1. Input: Size of the network
2. Output: Efficient SNs as the next hop
3. Assumptions
4. Numbers of sensor nodes in the network
5. Efficient SNs as the next hop: *ENH*=[]
6. Pc: (Probability-based nodes crossover)
7. Pm:(Probability based nodes mutation)
8. Current route: Cr, Previous route: Pr, New route: Nr
9. FF (Fitness Function) is Calculated using the distance, residual energy, and data packets.
10. POR: Population of the routes returned
11. FF_RP=The Fitness function applied on the routes of the (POR)
12. While(POR)
13. Crossover(Cr, Pr,Pc)
14. Mutation(Cr,Pr, C,Pm)
15. Selection of the fittest SNs for routing
16. End
17. End
18. Return the route array

3.7 Predictive coding theory for data compression

In the proposed model for Wireless Sensor Networks (WSNs), Predictive Coding Theory is employed for data compression. Originally a concept from neuroscience that describes how the brain makes predictions based on past experiences, Predictive Coding Theory is adapted here to improve the efficiency of data transmission in WSNs. The idea is to reduce redundancy in the data before it is transmitted, which in turn saves energy.

The steps involved in applying Predictive Coding Theory to data compression in WSNs are as follows:

1. Data Storage for Prediction: Data at the sensor nodes are stored in an array to enable future predictions. If there is redundancy in the values, the previous data value is used to predict the next one.
2. Residual Calculation: The prediction error, or residual, is calculated by comparing the actual and predicted values. This comparison could be linear or non-linear in nature.
3. Quantization: In this step, the prediction error is represented with the minimum number of bits possible, thus further reducing the data size.
4. Encoding: The quantized residual values are encoded using lossless compression techniques such as arithmetic or Huffman coding.
5. Transmission: These compressed residual values are then transmitted to the sink or base station within the network.
6. Reconstruction: At the receiving end, the base station reconstructs the original data from the compressed values.

By using Predictive Coding Theory for data compression, the model aims to reduce the amount of data that needs to be transmitted. This is particularly useful given the energy constraints of the sensor nodes in WSNs. Less data to transmit means lower energy consumption, which aligns well with the overall goal of creating an energy-efficient routing protocol for WSNs.

3.7.1 Algorithm

The Predictive Coding algorithm described here uses past data to predict current values and encode the data for transmission. Here's a breakdown of the steps:

- **Variables:**The algorithm defines four variables:
  - **Past Values (Pv):**These are previously recorded data points.
  - **Current Values (Cv):**These are the most recent data points that need to be predicted.
  - **Data Packets (Xi):**These are the individual units of data, where 'i' represents the index in a series (1, 2, 3, ..., n).

- **Error (Er):** This is the difference between the predicted values and the actual current values.

- **Start Process:** The algorithm initiates the predictive coding process.
- **Read the Data Packets:** The algorithm reads the incoming data packets, Xi, where 'i' increments from 1 to 'n', representing each data packet in sequence.
- **Prediction:** For each new data packet, the algorithm predicts the current data sample (Cv) based on the past data sample (Pv). This step involves using a model or method for prediction, which is not specified but could involve statistical methods or machine learning models.
- **Calculate the Error (Er):**After predicting the current value, the algorithm calculates the error (Er) by comparing the predicted value to the actual current value. This error is a measure of how accurate the prediction is.
- **Encoding Process:**Once the error is calculated, the algorithm encodes the data. This could involve encoding the error value instead of the actual data value, which is often smaller and therefore can be transmitted more efficiently.
- **Data Transmission:** Once the error is calculated, the algorithm encodes the data. This could involve encoding the error value instead of the actual data value, which is often smaller and therefore can be transmitted more efficiently.
- **Data Transmission:**The encoded data (which might be the error values) is then transmitted to the intended destination.
- **Iterative Process:**The algorithm goes back to step 2 and repeats the process for each new set of incoming sensor data. This iterative process ensures that the algorithm is continuously updating its predictions and encoding new data as it arrives.
- **End the Process:** The process ends when there is no more incoming sensor data to be processed.

Predictive coding is efficient because it often only needs to transmit the error between predicted and actual values, which tends to be smaller than the raw data itself, especially in cases where the predictions are relatively accurate. This method is particularly useful in sensor networks where conserving bandwidth and reducing the amount of data transmitted can save power and resources.

1. Variables (Past Values=Pv , Current Values= Cv, Data Packets=Xi , Error=Er)
2. Start Process
3. Read the data packets Xi=(i=1,2,3,,,,n)
4. Predict for each time the current data sample Cv using the past data sample Pv
5. Calculate the error Er
6. Encoding process
7. Data Transmission
8. The process starts from step 2 until the end of the incoming sensors data
9. End the process

3.8 Summary

The Methodology chapter is a pivotal section in the research, laying out the techniques and processes employed to achieve the study's objectives. It starts by offering a concise overview of the research phase through diagrams and figures for easier comprehension. Issues identified in the literature review are discussed, followed by the specific objectives and research questions guiding the study.

The methodology then delves into the nuts and bolts of the proposed approach, detailing the energy consumption calculation model, routing mechanism, and network topology design. The chapter highlights the study's primary contributions, which focus on mitigating problems like unbalanced and excessive energy consumption in Wireless Sensor Networks (WSNs). Two key techniques—the Genetic Algorithm and Predictive Coding Theory—are elaborated upon, explaining how they solve specific issues in WSNs.

The Genetic Algorithm is employed for route optimization, and Predictive Coding Theory is used for data compression. Both techniques are explained in a step-by-step manner, alongside mathematical models illustrating their application in the proposed routing protocol. The chapter concludes with a flow chart that encapsulates the study's proposed model, followed by a chapter summary. Overall, this chapter serves as a comprehensive guide for understanding the methodology employed in the research.

CHAPTER 4

SIMULATION AND RESULTS

This chapter is related to the simulation performance and the evaluation of the results for the proposed model in this study. Initially, this chapter explains the basics of the simulation environments, such as the tool used for the simulation in this thesis and the parameters used to perform the simulations. The simulation tool is a platform that observes the behaviour of the proposed model based on several conditions and analyzes the performance based on several evaluation parameters. The existing model analyzes and evaluates the results to justify its effectiveness and efficiency. To assess the performance of the proposed routing protocol for the WSN energy efficiency, the total energy consumption, the latency, the throughput, and the number of dead nodes are considered. These evaluation parameters are simulated with the baseline and the proposed model in this chapter, with separate graphs from the simulation results. Evaluating the results provides valuable insights into the proposed model and the utilizable to optimize the behaviour of the network. Moreover, the chapter offers a complete analysis of the obtained results. It highlights the scenarios providing enhanced results in energy-efficient routing and long network lifetime. The study also examines the behaviour of the network and finds areas where improvements can be made, and provides an analysis based on the strong and weak points of the proposed model. This chapter summarizes the main factors of the simulation's performance and results evaluation in the proposed model. The efficiency and effectiveness of the proposed model are based on the multiples of the conditions and emphasize the importance of the simulation performance and evaluation of results to develop better models.

4.1 Contributions

This research represents a pivotal step forward in the quest for energy-efficient routing protocols within Wireless Sensor Networks (WSNs). Our work contributes to the field in multiple, noteworthy dimensions:

- At the core of our contributions is the development of a novel, energy-efficient routing protocol for WSNs. Utilizing cutting-edge algorithms, this protocol not only maximizes energy efficiency but also extends the lifetime of the network.
- Beyond energy conservation, our proposed model addresses a range of performance indicators such as route optimization and data transmission volume. By solving these interrelated issues, we significantly reduce overall energy consumption in WSNs.
- A distinctive feature of our work is the incorporation of the Genetic Algorithm for intelligent route optimization, as well as the application of predictive coding theory for data compression. These algorithmic choices collectively boost the network's operational efficiency.
- To substantiate our theoretical contributions, comprehensive experiments were executed using Matlab simulation tools. These tests rigorously assess performance metrics like energy consumption, latency, throughput, and node mortality.
- A thorough comparison with baseline models is presented, lending credence to the superior performance of our proposed model. This comparative study incorporates detailed analyses across multiple evaluation parameters, offering a holistic view of the model's effectiveness.
- This study promises to have a favorable impact on real-world applications relying on WSNs. By achieving energy efficiency and enhancing network performance, we pave the way for more sustainable and reliable sensor networks.

By tying together advanced algorithms, meticulous simulation, and robust comparative analysis, this study provides a comprehensive framework for enhancing the energy efficiency and overall performance of Wireless Sensor Networks. The findings and methodologies outlined here offer a valuable foundation for future research aimed at further optimizing WSNs.

4.2 Simulations

We carried out simulations for our newly designed routing protocol for wireless sensor networks using Matlab. To make a fair comparison, we kept the simulation parameters consistent with those used in the established leach-CR routing protocol. The primary goal of running these simulations was to measure how well our new model performs compared to the baseline, specifically in terms of energy efficiency and extending the network's lifespan. Matlab was particularly useful for this, given its strong capabilities in analyzing network performance, especially in relation to energy usage metrics.

Both the proposed routing model and the leach-CR protocol were tested within the Matlab environment. This enabled us to make a thorough performance assessment between the two. The key metrics used for evaluating performance included the network's operational lifespan, overall energy usage, the number of nodes that depleted their energy, data throughput, and latency. Graphical representations were used to present the results, with the x and y axes indicating relevant data points.

These simulation outcomes offer valuable insights for network administrators, shedding light on the potential effectiveness and practicality of implementing the proposed model.

4.2.1 Parameters

In this research, the crux of designing and evaluating an energy-efficient routing protocol for wireless sensor networks hinges on in-depth simulation studies. These simulations are not merely a step in the research process; they are essential for the nuanced analysis of the proposed model. By simulating the behavior and performance of the model under various parameters and conditions, we are able to garner insights that would be difficult to obtain otherwise.

The choice of simulation parameters is of paramount importance because it directly affects the efficiency and reliability of the network. For the current study, the simulation process involves several key parameters such as the size of the network where the sensor nodes are deployed, the energy consumption model, the communication ranges of the nodes, the energy values associated with data transmission and reception, and the data packet size. Additional factors like the distance between communication devices and the specific traffic patterns and routing metrics also play a crucial role.

Optimizing the results for energy efficiency is a main objective. To do this, it's critical to define and appropriately configure these simulation parameters precisely. Metrics such as total energy consumption, the demand on nodes, packet delivery ratios, and the time taken for data transmission between nodes are calculated. These metrics serve as reliable indicators of the overall network performance.

To make a meaningful comparison between the proposed model and an existing baseline, it's essential to maintain consistent simulation parameters. Using the same fundamental values for both allows for a reliable assessment of the performance improvements offered by our proposed model. The results, which will be obtained through the simulations, will subsequently be evaluated against this baseline to determine the efficacy of the proposed model.

This section sets the stage for the empirical evaluation that follows, making it easier for readers to understand the methodology and rationale behind the simulation process.

Table 4.1 The Parameters values for the simulation of the proposed model in the thesis

Parameter symbols	**Parametric Values**
Simulation tool	Matlab
Network area in meter	100x100
The total energy of the nodes	2 joules
Data packet size in bits	500
Number of nodes	20 and 50
Etx (Transfering circuity energy consumption)	50x0.000000001
Erx(receiving circuitry energy consumption)	50x0.000000001
Efs (Energy used to amplify the signal)	10x0.000000000001
Eamp (amplifying circuitry energy consumption)	0.0013x0.000000000001
Data aggregation Energy	5x0.000000001
Location of the base station	(50,50)
Network Topology	Random & Grid

4.3 Results

The simulations for the proposed model are executed using Matlab, with the parameters detailed in a preceding table for clarity. In these simulations, sensor nodes are randomly situated within a defined network area, with a base station strategically located at the center of this network. These nodes have the primary functions of data sensing, processing, and forwarding either to a subsequent hop or directly to the base station.

Evaluative criteria for the simulation outcomes revolve around several key performance indicators: total energy expenditure, the number of nodes that exhaust their energy reserves (referred to as 'dead nodes'), data throughput, and network latency. These are measured across varying rounds of operation to assess the model's performance and endurance over time.

This simulation isn't conducted in isolation but is rather juxtaposed with the leach-CR model for comparative analysis. The core aim of such a comparative evaluation is to underscore the advantages and enhancements offered by the proposed model. Priority is given to showcasing the superior performance of the proposed model in terms of the selected evaluation parameters.

Following the completion of the simulation runs, a comprehensive set of results is presented. These results are subjected to detailed analysis to shed light on the nuanced performance attributes of the proposed routing protocol. Each metric is explored in full, providing a well-rounded view of the model's efficacy and limitations.

By documenting the simulation process, evaluative criteria, and subsequent results in this manner, the thesis offers a complete and meticulous account of the research methodology and its corresponding findings. This thorough approach not only validates the proposed model but also equips the reader with the necessary context to appreciate its contributions and implications.

4.3.1 Evaluation Metrics and Energy Consumption Analysis

The foremost metric used for gauging the network's performance in this research is the total energy consumption across its lifetime, expressed in terms of rounds. This measure provides a comprehensive view of how efficiently the sensor nodes utilize their limited energy resources throughout the network's operational lifespan. Given the finite nature of these resources, an energy-efficient routing protocol is crucial. The intent is to maximize the network's functionality while minimizing its energy consumption, thereby enhancing its operational longevity.

The major activities contributing to energy usage in each round include data collection, data processing, storage, and data transmission either to adjacent nodes or directly to the base station. The energy consumption of these activities varies depending on multiple factors such as the size of the data packets and the distance between communicating nodes. Thus, an intelligently designed routing protocol can make a significant impact by minimizing these energy expenditures. This is achieved through various approaches like minimizing long-range communications and avoiding superfluous data transmissions. These measures help prolong the network's active period.

Conclusively, an ideal scenario in terms of energy consumption would be to maximize the number of operational rounds while keeping the total energy expenditures at a minimum. This balance is indicative of a highly efficient network with a prolonged operational lifetime. To validate the effectiveness of the proposed model in achieving this balance, simulation parameters from a baseline routing protocol are employed for comparative analysis. Results, including graphical representations, are subsequently presented to highlight the differences in performance between the proposed model and the baseline.

This section thus serves as a critical component of the thesis, thoroughly explaining the considerations for energy efficiency, the methodology for its measurement, and its role in evaluating the proposed model's effectiveness.

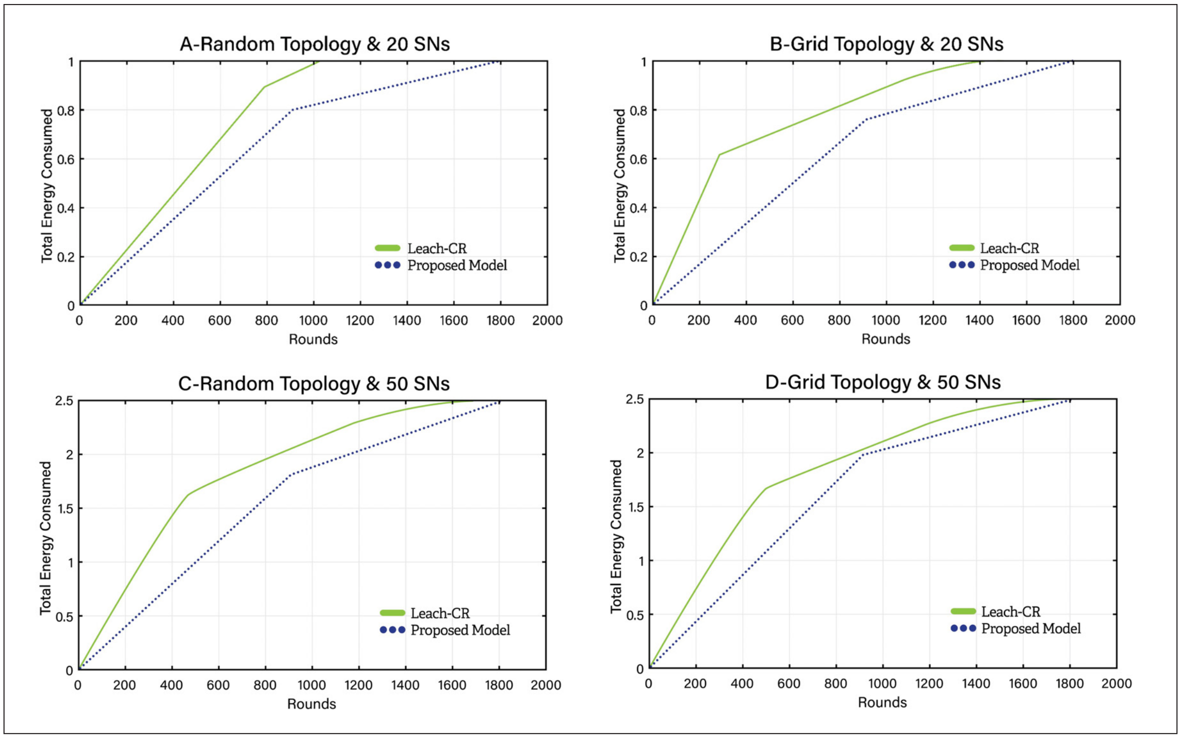

Figure 4.1 Total energy consumption in the Network Results

The displayed graph contrasts the performance of a new model against a standard one, specifically examining energy usage relative to operational rounds in a wireless sensor network. This graph is divided into various subplots to break down performance under different conditions, such as differing numbers of sensor nodes (20, 50) and the positioning of the base station (either central or distant).

In the first subplot, marked as A, the new model is pitted against the leach CR model in a randomly organized network with a centrally located base station and 20 sensor nodes. The second subplot, B, also involves 20 sensor nodes but uses a grid network layout. In both plots C and D, the number of sensor nodes is increased to 50; the former with a random topology and the latter using a grid layout. Each subplot features two lines: red for the new model and blue for the leach CR model.

The new model consistently shows enhancements in network lifespan, especially noticeable in subplot A, where it surpasses the leach CR model's 1,016 rounds with a total of 1,812 rounds. While there are less significant differences in other scenarios, the new model still performs better in terms of network lifetime. For example, with 50 sensor nodes in a random network, the proposed model achieves a lifetime of approximately 1,817 rounds, outlasting the leach CR model's 1,698 rounds.

In summary, the new model offers substantial gains over the existing baseline in multiple tested scenarios. The improvements are particularly significant in networks with fewer sensor nodes, indicating optimized energy-efficiency. The data suggests that the new model could be a more energy-efficient routing protocol for wireless sensor networks.

4.3.2 Evaluating the Impact of Dead Nodes on Wireless Sensor Network

In wireless sensor networks (WSNs), dead nodes pose a serious challenge to the network's overall performance and reliability. Dead nodes are sensors that have run out of energy resources and become non-operational. Their presence affects various network functions such as data collection, monitoring, and inter-node communication. Consequently, dead nodes can severely impair the network's ability to perform its intended tasks, especially in critical applications like environmental monitoring, disaster response, and health monitoring.

The network's performance is often evaluated based on its lifetime, which is quantified by the number of operational rounds. Dead nodes can create coverage gaps, disrupt data collection, and break routing paths, leading to packet loss, delay, and reduced throughput. These disruptions have far-reaching implications on network efficiency, particularly in applications that require real-time and reliable data.

Given these challenges, it is crucial to examine the frequency and distribution of dead nodes in relation to the network's operational rounds. This evaluation provides valuable insights into the network's performance and allows for the selection of more appropriate, application-specific routing protocols. Moreover, this metric becomes crucial in designing systems that aim for maximum efficiency and reliability.

In the proposed model, special attention is given to assessing the dead nodes against the number of rounds. The goal is to extend the network's lifetime before the onset of the first node's death. By focusing on this aspect, the model aims to improve network efficiency and robustness, providing a more reliable platform for various applications.

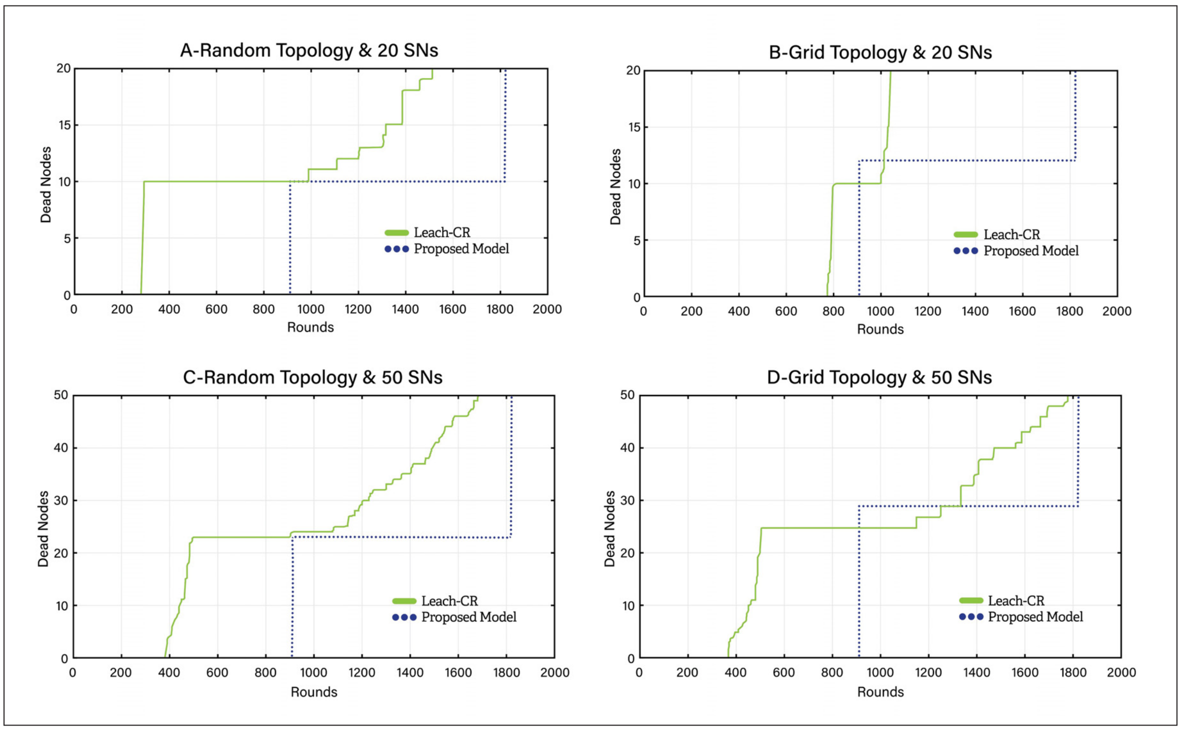

Figure 4.2 Numbers of dead nodes results

In the referenced figure, a variety of scenarios are displayed that consider different network topologies and the location of the base station, either at the center or away from the network. These scenarios are designed to evaluate how the number of dead sensor nodes varies with the number of operational rounds in the network, thereby providing valuable information on system performance.

The figure includes several subplots labeled A to D. Subplot A demonstrates the performance of a proposed model in a random network topology with the base station centrally located and 20 sensor nodes. Subplot B focuses on a grid network topology with the base station also centrally placed and the same number of sensor nodes. Subplots C and D extend these evaluations to scenarios involving 50 sensor nodes.

In subplot A, the proposed model shows a notable difference between the round at which the first node dies (280) and the last node dies (1580), indicating improved network lifetime. In contrast, the baseline model, Leach-CR, performs less efficiently. Subplot B, based on grid topology, shows a slight difference between the times the first and last nodes deplete, but the proposed model still shows an advantage in terms of network lifetime.

For scenarios with 50 sensor nodes, the baseline model's performance is notably less efficient compared to the proposed model, especially in terms of the round numbers at which the first and last nodes die. The proposed model consistently shows better performance in increasing the network's lifetime, regardless of whether the network uses a random or grid topology.

In summary, the detailed analysis of how dead nodes affect network lifetime across different scenarios and topologies offers important insights. These insights can guide users in understanding how to optimize network performance, particularly in terms of energy-efficient routing. The proposed model, with its slightly altered parameters, presents a more energy-efficient solution and is suitable for different types of network topologies and sensor node counts.

4.3.3 Optimizing Throughput and Lifetime in WSNs

In wireless sensor networks, throughput measures the total volume of data that is sent to the base station by the sensor nodes during network operations. It serves as a key indicator for assessing network performance and is often evaluated against the number of network rounds. Rounds in the network signify its lifespan, with more rounds indicating higher performance. This is because, during each round, all active sensor nodes relay their data to the base station. Consequently, more rounds equate to more data being sent.

Each new round offers an opportunity for the network to improve its routing algorithms, adjust its transmission power, enhance its data transmission capabilities, and thereby achieve better performance. In network simulations, the rounds continue until the final sensor node depletes its energy, although this endpoint is not predefined.

To gauge network efficiency, it's essential to find a balance between throughput and the number of rounds. While increasing the number of rounds can boost throughput, researchers also have to account for challenges like avoiding network congestion and minimizing overhead. In light of these evaluation criteria, this study aims to prolong network lifetime and improve throughput by optimizing energy consumption. The results of this proposed model are presented in the following section.

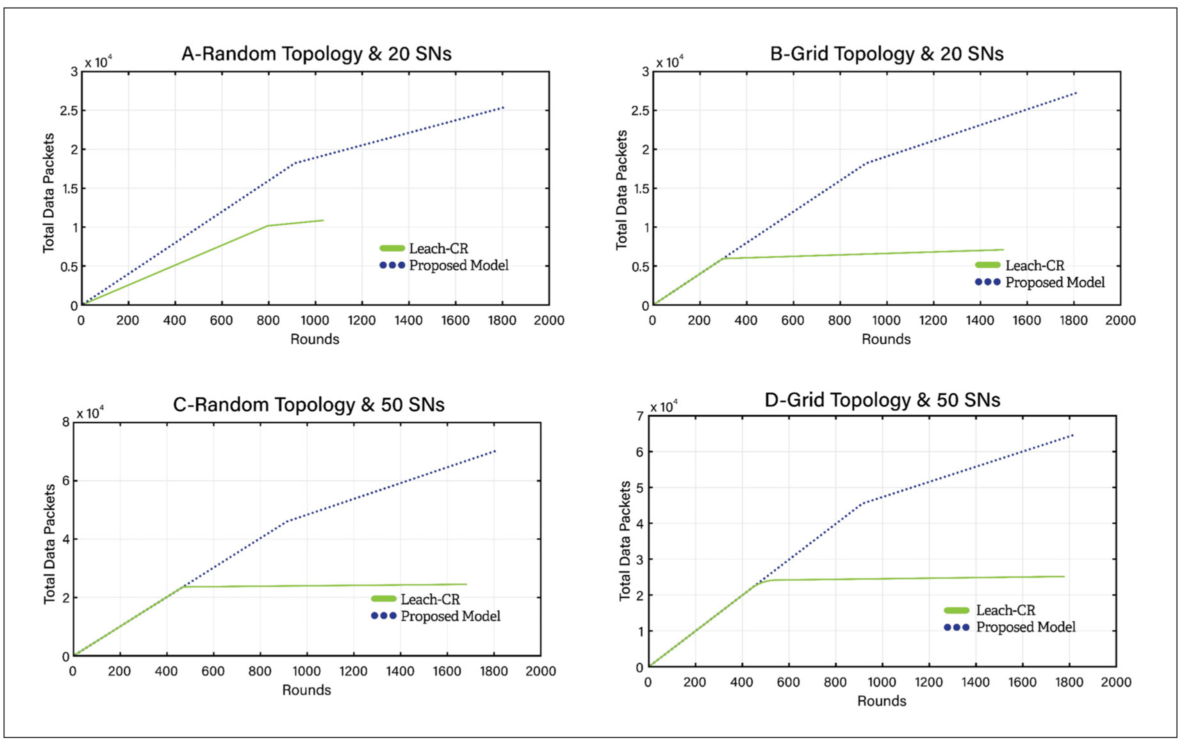

Figure 4.3 Throughput of the network results

The diagram illustrates the network throughput in relation to the number of rounds across different scenarios, including varied network topologies (random and grid) and base station placements (central and peripheral). This is aimed at a comprehensive evaluation of network performance.

The figure is segmented into several subplots, each depicting a comparison between a proposed model and a baseline routing protocol within a specific Wireless Sensor Network (WSN) scenario. Subplot A focuses on a random network topology with the base station at the center, encompassing 20 sensor nodes. Subplot B presents results for a grid-based network also with 20 sensor nodes. Subplot C displays data for a random network topology with a larger set of 50 sensor nodes, and subplot D does the same for a grid topology with 50 nodes. Blue lines represent the leach-CR model, while red lines display the proposed model's outcomes. The metric is the total number of data packets sent to the base station over a certain number of rounds.

In subplot A, with a random topology and 20 sensor nodes, the leach-CR model sent 10,893 packets over 1,030 rounds. Conversely, the proposed model transmitted 25,368 packets over 1,806 rounds, showcasing significant energy and lifespan efficiencies. In subplot B's grid topology scenario, the leach-CR model sent 7,020 packets over 1,520 rounds, while the proposed model sent 27,290 packets over 1,819 rounds. This reaffirms the proposed model's advantages. In subplot C, the leach-CR model in a random topology with 50 nodes sent 24,522 packets over 1,680 rounds, while the proposed model sent 69,800 packets over 1,810 rounds. Subplot D shows the leach-CR model in a grid topology with 50 nodes sent 25,325 packets over 1,773 rounds, whereas the proposed model sent 64,400 packets over 1,810 rounds.

The model we've developed has been put to the test in a variety of scenarios and has consistently shown marked improvements. This affirms its value as an algorithm tailored for Wireless Sensor Networks (WSNs). The flexibility of the model to adapt to different applications allows for customization, leading to the best outcomes in both energy conservation and extended network life. The research highlights the critical role of selecting the appropriate network configuration and the precise number of sensor nodes to achieve efficient and varied performance. Evidently, in every tested scenario, our model has proven to be superior in energy efficiency.

4.3.4 Evaluating Packet Transfer Success Rates in Wireless Sensor Networks

Wireless Sensor Networks (WSNs) are versatile platforms with applications spanning environmental monitoring, healthcare, military surveillance, and agricultural management. Given this range of use-cases, performance evaluation relies on several metrics, among which packet delivery success rate is of paramount importance. The higher the rate of successful packet delivery from sensors to the base station, the more reliable and effective the network becomes, especially when transmitting critical data.

In the context of this thesis, we utilize simulation methods to gauge the success rate of packet delivery relative to the number of rounds within the network. The aim is to elevate this rate to near-perfect levels, ensuring real-time network functionality and accurate data transfer. By focusing on these two parameters—success rate and the number of rounds—we gain valuable insights into the overall performance of the WSN.

Simulated assessments offer both researchers and system engineers valuable data to better understand and optimize network performance. These simulations are particularly useful for contrasting our proposed routing protocol against established baseline protocols in WSNs. Results from these simulations, displayed in subsequent figures, validate the efficacy of our proposed model in enhancing packet transfer success rates.

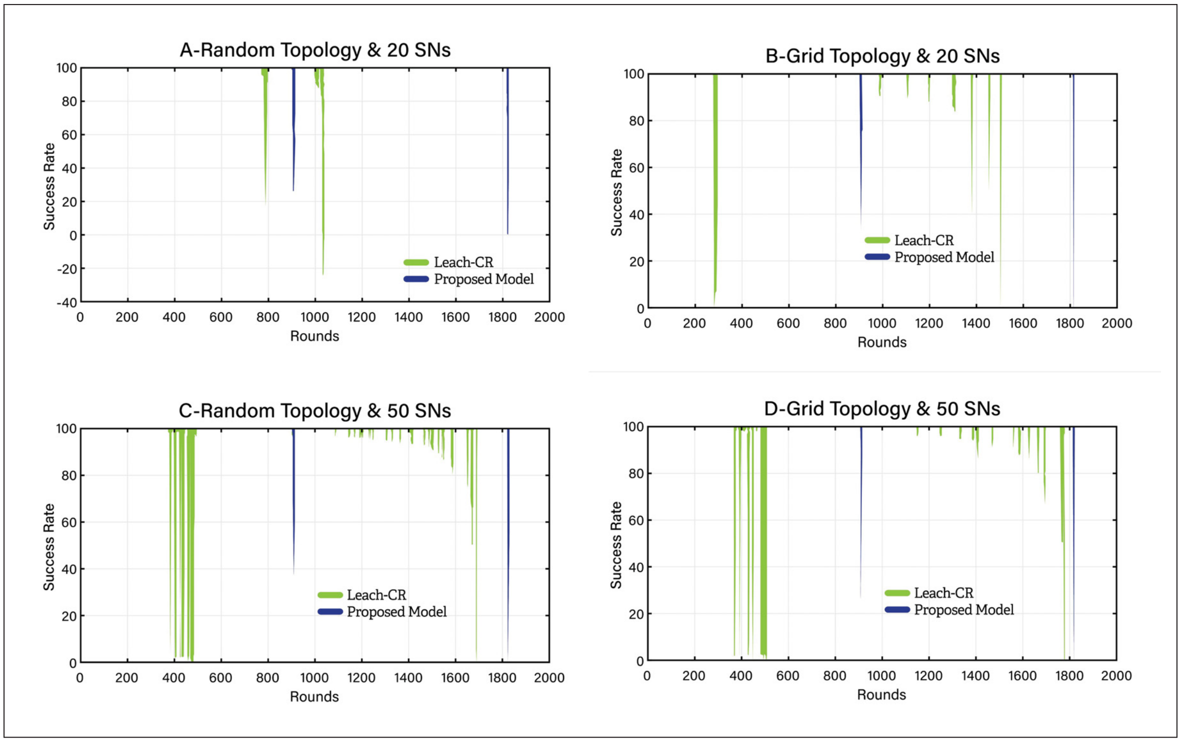

Figure 4.4 Success rate of the packet transmission to the base station

Figure 4.4 illustrates the packet transfer success rates in relation to the number of rounds within the network. The results are presented for both random and grid network topologies, taking into account variations in the location of the base station—whether central or peripheral. Subplot A reveals the outcome for a random topology network featuring 20 sensor nodes. The leach-CR model maintains a 100% success rate for the initial 778 rounds, whereas our proposed model sustains this rate for 910 rounds. Following these rounds, both models experience packet loss, reducing their perfect success rates. In this scenario, the proposed model outperforms the leach-CR model, as depicted by the red lines in the figure.

Subplot B provides the data for a grid topology network with 20 sensor nodes. Here, the leach-CR model retains a 100% packet transfer success rate for the first 281 rounds, while the proposed model doesn't experience its first packet loss until 913 rounds. This highlights the superior performance of our proposed model.

In subplot C, which focuses on a random topology with 50 sensor nodes, the leach-CR model achieves a 100% success rate up to 385 rounds. On the other hand, our proposed model maintains this rate for 909 rounds. Both models eventually experience some packet loss, but our model fares better overall.

Subplot D, featuring a grid network with 50 sensor nodes, shows similar results. The leach-CR model keeps a 100% success rate up to 368 rounds, while our proposed model sustains it for 909 rounds, further confirming the proposed model's efficacy over the baseline leach-CR model.

In summary, our proposed model excels in maintaining higher packet transfer success rates, which is crucial for the network's reliability and real-time performance. Packet loss is a serious concern as it compromises the quality of decision-making and predictive analytics in the WSNs. Moreover, examining performance across different scenarios allows for a more nuanced understanding, aiding users in selecting the most effective network configuration. This contributes to better energy efficiency and extends the network's lifespan, optimizing overall WSN performance. In other words, the provided study conducts simulation-based evaluations of packet transfer success rates in Wireless Sensor Networks (WSNs) to assess the efficacy of a proposed routing protocol relative to the established LEACH-CR model. The success rate of packet delivery is a critical measure of network reliability, especially for transmitting vital data across diverse applications.

Utilizing simulations to model various network topologies and sensor node configurations, the study aims to optimize the success rate of packet delivery. The simulations provide a comparative analysis of the routing protocols, revealing that the proposed model sustains a higher success rate over a more extended number of rounds than LEACH-CR, suggesting improved reliability.

Figure 4.4 graphically demonstrates this enhanced performance in different network setups, indicating that the proposed model maintains a 100% success rate for a longer duration across varying topologies and sensor node quantities. These findings are significant for their potential to inform the design of more efficient and reliable WSNs in practical scenarios, emphasizing the importance of network configuration and sensor node placement in achieving optimized outcomes.

In essence, the study adds to the academic discourse on WSN performance, providing evidence that the proposed model could lead to better energy efficiency and network longevity, which are pivotal for the practical deployment of WSNs in real-world applications.

4.4 Summary

The chapter on simulations and results serves as a critical component of the thesis, offering in-depth analysis and evaluation of the proposed model in comparison to established baseline models in wireless sensor network (WSN) routing protocols. Various metrics were employed to gauge the effectiveness and efficiency of our proposed model. Designed with energy conservation and longevity in mind, the proposed model displayed notable improvements over existing protocols.

The methodology for the simulations is meticulously documented in the chapter, facilitating easy replication of the results for interested readers. Findings are vividly illustrated through charts and tables, enhancing both the chapter's readability and interpretive value.

In summary, this chapter furnishes a holistic view of the proposed model's performance, emphasizing its advantages in energy efficiency and network lifespan. The clear, detailed presentation of simulation methodologies and results facilitates both comprehension and further academic exploration.

CONCLUSION AND FUTURE WORKS

5.1 Conclusion

The ever-increasing utilization of Wireless Sensor Networks (WSNs) stands as a testament to its transformative impact on various aspects of computer science. Despite the advancements, the issue of energy efficiency remains an acute challenge, given that sensor nodes are energy-constrained by their finite batteries.

This study addresses the issue by proposing a novel energy-efficient routing protocol for WSNs based on artificial intelligence techniques, particularly Genetic Algorithms for route optimization and Predictive Coding for data compression. Through an extensive review of existing literature and their limitations, this study underlines the necessity and innovation behind its approach.

The simulation results clearly demonstrate the effectiveness of the proposed protocol against the baseline model, LEACH-CR, across multiple evaluation metrics including energy consumption, number of dead nodes, throughput, and latency. By achieving superior performance in energy efficiency and network longevity, this study contributes significantly to the WSN domain and lays down a foundation for reliable, efficient data communication in WSNs.

This literature has extensively documented the challenges of energy efficiency in WSNs due to the limited battery life of sensor nodes. Previous studies have explored various routing protocols, like LEACH-CR, to address these challenges. The proposed model in this study builds upon this foundation, introducing an energy-efficient routing protocol that leverages artificial intelligence techniques, specifically Genetic Algorithms for route optimization and Predictive Coding for data compression.

The simulation results presented in this study not only corroborate the findings of previous literature—affirming the importance of energy efficiency in WSNs—but also extend them by showcasing the enhanced capabilities of AI-driven approaches. The proposed protocol's outperformance of LEACH-CR in energy consumption, network longevity, and other key metrics indicates that the integration of AI techniques can effectively address the limitations of current models.

Moreover, the results contribute to the field by providing a new perspective on the application of AI in WSNs. They suggest that the conventional models may be significantly improved upon by incorporating intelligent algorithms that adapt and predict, thereby refining the decision-making process within the network's routing mechanism.

In essence, this study provides a precise contribution to the field by demonstrating a tangible improvement over existing protocols through AI-based innovations. It offers a robust argument for the potential of such technologies to revolutionize data communication in WSNs, reinforcing the importance of continual exploration and adaptation in the pursuit of technological advancement within this domain.

5.2 Future Works

Although the present study has achieved its goals, there are several paths for future research that remain open:

- **Algorithmic Evolution:**
  The field of AI and machine learning is continuously advancing, offering newer algorithms that can potentially improve WSN energy efficiency even more. Future studies could explore these algorithms as alternatives or complementary approaches to Genetic Algorithms and Predictive Coding.
- **Addressing Network Delays:**
  As real-time network applications often require low latency, developing innovative strategies such as adaptive routing techniques and optimized packet-forwarding mechanisms will be critical.
- **Holistic Optimization:**
  Besides energy efficiency, future research could consider optimizing other performance metrics, thereby creating a more universally applicable routing protocol.

- **Practical Implementation:** While simulations provide valuable insights, testing the protocol in real-world scenarios would provide the ultimate validation of its efficacy.
- **Adaptive Techniques:** With the dynamic nature of WSNs, implementing adaptive mechanisms that allow the network to reconfigure itself in real-time could be beneficial.
- **Security Considerations:** As WSNs are often used in critical applications, integrating security measures into the energy-efficient routing protocol could be a vital addition.

By systematically exploring these avenues, future work can further refine the energy-efficient routing protocol, thereby making more substantial contributions to WSN technology. In summary, this study not only addresses existing challenges in WSN energy efficiency but also opens up several new dimensions for further research and development.

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