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ETRUST: Enhancing Energy Efficiency in Wireless Sensor Networks Through Trust-Based Clustering and Data Transmission

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Abstract: Wireless Sensor Networks (WSNs) have emerged as a transformative technology with diverse applications across industries, offering benefits such as easy deployment, cost-effectiveness, and enhanced mobility compared to wired networks. This paper delves into the architecture, categories, and operational intricacies of WSNs, focusing on structured and unstructured networks' deployment methods and characteristics. It also addresses the resource constraints inherent in WSNs, including low energy, storage, and processing capacities, which necessitate specialized optimization techniques. The paper proposes a trust based approach for efficient data collection and transmission operation in WSN. The proposed protocol is compared with existing protocol where it demonstrate significant improvements in network stability, and energy efficiency. The proposed protocols showcase enhanced performance, indicating their potential to advance wireless communication systems.

Keywords: WSN, Trust, Residual Energy, wireless communication, Sensor Node

1. Introduction

Wireless sensor networks, or WSNs, have become a paradigm-shifting technology with broad applications in a variety of fields, from industrial automation and control to intelligent infrastructure building. Many built-in benefits, like as easy deployment, less expensive setup and upkeep, and more mobility over conventional wired networks, are what make them so appealing [1]. In theory, wireless sensor networks (WSNs) function as decentralized, infrastructure-less networks that coordinate a chorus of sensor nodes to monitor certain areas and collect vital environmental data. These sensor nodes act as the primary data gatherers, sending the information they have gathered to a sink node or central base station for additional Interestingly, industry estimations from Emerson Process Management highlight the significant cost-saving potential of WSNs, with estimates indicating savings as high as 90% when compared to wired networks [2]. WSNs may be divided into two categories: structured and unstructured networks. These two types of networks have different deployment methods and operating characteristics. Unstructured WSNs are perfect for situations needing long-term monitoring with little supervision since they frequently operate for extended periods of time without human interaction. This is typified by the disorganized deployment of several sensor nodes. On the other hand, structured WSNs offer more control and network performance optimization due to the purposeful, planned deployment of sensor nodes inside the target region. Furthermore, WSNs are distinct from traditional ad hoc networks due to their complex network architecture, wide range of applications, and built-in resource limitations such low energy, storage, and processing capacities [1][3]. Because of its intrinsic complexity, maximizing efficiency and efficacy across a range of deployment circumstances requires specialized procedures and advanced optimization methodologies.

The increasing interest in utilizing wireless sensor networks is due to its operational efficacy and adaptability, especially in essential situations like disaster relief and management in distant or dangerous areas where human participation can be dangerous or impracticable. In this context, WSNs are indispensable instruments for data gathering, analysis, and decision-making in real-time, enabling prompt and well-informed interventions. Beyond crisis management, WSNs are useful in many other fields, such as environmental tracking, agricultural precision farming, healthcare, and smart cities. These fields stand to benefit greatly from WSNs' capacity to extract meaningful insights from massive amounts of sensor data. WSNs provide predictive maintenance, anomaly detection, and resource allocation optimization using advanced data analysis and machine learning algorithms, therefore promoting operational efficiency and sustainability in many industries. Essentially, the attraction of wireless sensor networks is not just their technological capabilities but also their potential to completely transform our understanding of, interactions with, and management of the environment. As we continue to unlock their full potential, WSNs are poised to play an increasingly pivotal role in shaping the future of connected ecosystems and intelligent infrastructure on a global scale.

1.1 Architecture of a Sensor Network

As shown in Figure 1 [4], the architecture of a wireless sensor network (WSN) is divided into three separate layers: the sensor layer, the server layer, and application layer. First up, the sensor layer. Several sensor nodes are arranged in this tier in a deliberate manner to keep an eye on events that occur in the assigned sensing field. These sensor nodes collect information on a range of environmental factors, including air quality, moisture, temperature, pressure, intensity of light, noise pollution, and CO2 and oxygen levels. Then, via wireless communication links at the server layer, the data gathered from the sensor nodes is transmitted and combined at the base station. The base station functions as the focal point for data aggregation and is usually linked to a web server, allowing users to view relevant information remotely. The four main parts that every sensor node in the network has are the processing unit, power unit, communication unit, and sensing unit. The sensing component generates quantifiable signals in reply to changes it observes in the surrounding environment. The processing unit is in charge of processing and analyzing the collected data in order to derive insightful information. Moreover, the communication unit has a transceiver that allows data to be seamlessly transferred over wireless communication channels between various WSN segments. While there are many different wireless communication technologies, IEEE 802.15.4 Wireless Personal Area Network (WPAN) and Bluetooth are more complex and expensive than RFID (Radio-Frequency Identification), which is frequently chosen instead. Furthermore, the RS232 standard can also be used for wireless communication and provides data rates that are similar to those of RFID [1] [3] [4].

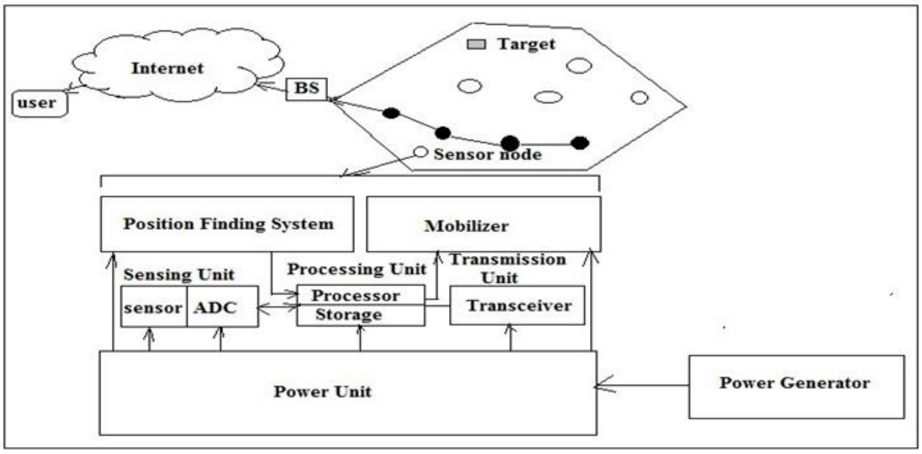

Fig.1 Wireless sensor network architecture [5]

2. Literature Review

Improving the dependability and extending the lifespan of a sensor network are important goals that are achieved by implementing the best energy-saving strategies. In wireless sensor networks (WSN), the land area is partitioned into discrete zones according to their longitudinal separation from the base station (BS). According to [9], this segmentation technique assigns cluster heads (CH) to each region in order to make it easier for data to be transmitted to the BS via a multi-hop communication scheme. This kind of network organization allows for effective data routing and energy consumption, which in turn improves the WSN's overall performance and sustainability.

In [10], a static clustering approach was employed to mitigate system overhead. This involved selecting nodes with the highest available energy (RE) to serve as CH in the network. By increasing the count of CHs within regions, the overall RE of the sensor network (SN) was bolstered, consequently extending the system's lifespan [11].

In [12], the LEACH protocol was proposed, incorporating static based clustering for the election of CH based on maximizing SN RE and minimizing distance from the BS. This methodology aimed to optimize network performance and energy efficiency.

In [13], an algorithm based on minimum spanning trees was introduced for CH selection and data transmission to the BS, utilizing a single-hop communication scheme. This approach aimed to streamline data routing and reduce energy consumption within the network.

In [14], the LEACH protocol was introduced to enhance the CH election process, integrating the K-means based clustering approach for efficient employment of cluster nodes. This optimization strategy significantly improved WSN performance.

In [15], a clustering technique was proposed to organize the SN and implement an effective routing for data transfer to the BS. By partitioning the WSN into distinct regions and selecting CHs on the basis of maximum SN, RE and minimum space from the BS, lifetime of the network and efficiency were notably enhanced.

In [16], node density, distance, energy were utilized as parameters to enhance the life cycle of WSN, aiming to optimize energy utilization and network longevity.

Addressing energy challenges in the LEACH protocol, [17] adjusted the CH formula based on distance and energy considerations, offering a solution to the energy efficiency problem within the network.

[18] employed radius and weight functions to select required candidate CHs within the network, facilitating data transmission to the BS through a multi-hop way. This method effectively minimized energy consumption in the network.

[19] proposed a protocol involving the partitioning of the WSN into equal-sized areas and employing a static oriented clustering mechanism to alleviate operating cost issues. Data transfer to the BS was achieved through a multi-hop scheme, optimizing network efficiency.

Introducing a novel methodology, [20] utilized fusion methods based on ingredient analysis algorithms to mitigate energy challenges within the network, offering a unique approach to energy optimization.

In [21], the authors highlighted issues stemming from unequal energy consumption among nodes and the random CH selection process in the network. They addressed this challenge by implementing an efficient CH election process, resulting in enhanced node energy reserves and extending the WSN's lifespan.

[22] introduced a protocol where CH and non-CH nodes are selected based on the energy reserves of the SN. The node with the highest energy level is designated as the CH, leading to reduced energy consumption within the network and improved overall system execution. The inadequacies in CH selection within the LEACH were identified as a source of various problems.

[23] proposed a trust model aimed at ensuring secure data transmission and mitigating diverse issues within the network.

Building upon this trust model, applied it to secure communication across different layers of the network.

[24] proposed a data merging process based on the trust computed level, aiming to enhance system functioning through informed decision-making.

3. Problem Statement

The core challenge lies in seamlessly integrating Wireless Sensor Networks (WSNs) into data analysis systems, with a focus on optimizing energy usage and maintaining data integrity and trustworthiness. The primary goal is to design protocols that are energy-efficient for data analysis in WSNs, all while ensuring the reliability of the gathered sensor data. This involves tackling obstacles such as managing energy consumption effectively, preserving data integrity, facilitating real-time processing, and establishing and maintaining trust in the system.

4. Proposed Methodology

The proposed approach presents a protocol designed specifically for Wireless Sensor Networks (WSNs), segmenting the network into areas containing two kinds of sensor nodes: advanced nodes with large energy stores and regular nodes with smaller energy stores. There are two phases to this protocol, both of which aim to improve data accuracy and network performance. The protocol's initial phase focuses on allocating sensor nodes among network regions and creating unique thresholds for choosing cluster heads. In order to minimize energy consumption and balance the network load, this phase tries to place advanced and normal nodes in each region in a planned manner.

Subsequently, After the first stage, the protocol moves on to the second, where it leverages a data fusion strategy based on trust functions to improve the accuracy of gathered data. The protocol assesses the reliability and credibility of data coming from different sensor nodes by employing trust functions, and then uses data fusion techniques to combine them. This procedure ensures that the amalgamated data accurately depicts the environmental characteristics seen by the WSN, hence augmenting the general caliber and dependability of the data obtained by the network.

4.1 Trust Function

In this context, the trust function serves to evaluate the reliability of sensor data gathered by nodes within a Wireless Sensor Network (WSN). Let's define the set of sensor nodes as:

S-->{*s*1,*s*2,s3,s4,...,*sn*}, containing the entirety of the network. Suppose '*di'* and '*dj'* represent the data gathered by SNs '*si'* and '*sj'* simultaneously.

The trust degree function is established based on the accuracy of the sensor data. If the precision of SN gerated data '*di'* is greater, its trust computed degree is correspondingly greater compared to other sensor data. Furthermore, if data *di* is trusted by data '*dj'*, it indicates that *di* encompasses all potential degrees for sensor data.

The trust based function's degree can be denoted as:

$$tij=f(|di-dj|)$$

Where:

- *ij* signifies the trust based degree of *di* with regard to degree *dj*.
- *f*(|*di*−*dj*|) is a function that maps the absolute difference between *di* and *dj* to a trust degree value within the range (0 to 1).
- *i*, *j*= 1,2,3,4...,*n* denote the indices of sensor nodes within the network.

This trust function facilitates the evaluation of trustworthiness between pairs of sensor data, aiding in the assessment of data reliability and integrity within the Wireless Sensor Network (WSN).

$$\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix} = T \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \end{bmatrix}$$

$$b_i = a_1 t_{i1} + a_2 t_{i2} + \cdots + a_n t_{in}$$

Bi is a notation for the weight of input data (di) gathered from the SN (si). Although it doesn't denotes the trust degrees of all collected data with regard to di, and tij as the matrix T denotes the trust based degree of di to dj. Ti_1, Ti_2,..., Tin show the real value of di. As a result, the weight matrix B involves a set of not negative matrices A with values a1, a2,...,an, and all of the real values of T.

The technique of combining data from several sources to produce insightful information that is more advanced than what can be produced by a single sensor node is known as data fusion. Enhancing the Quality of Service (QoS) and achieving accurate and dependable data transfer in the Region of Interest (RoI) are the principal goals of data fusion[24][25]. Furthermore, the data fusion procedure reduces energy consumption in the WSN and alleviates data redundancy problems. The data fusion expression is:

$$D_F = \sum_{i=1}^{n} b_i d_i$$

data fusion can be represented as: $D_F = \frac{\sum_{i=1}^{n} a_i d_i}{a_1 + a_2 + \cdots + a_n}$

4.2 Network Model Assumptions

The following presumptions form the basis of the suggested protocol:

1. The network of sensors consists of n nodes are uniformly and randomly distributed throughout a m×n-sized rectangular area.
2. It is considered that the target region is located at a considerable distance from the base station. Based on their coverage probability, nodes in the network may function in one of the p modes: observer, sleep, or active. Nodes that have a coverage probability less than 0.25 are switched to sleep mode. Observer nodes—those that have coverage probability between 0.25 and 0.6—are used to determine how trustworthy other nodes are. Nodes that have coverage likelihood greater than 0.6 function in the active based mode, receiving and sending data.

$$\rho = \begin{cases} \text{active mode} & \text{if} \quad \text{cov}\,(i,j) \geq 0.6 \\ \text{observer mode} & \text{if} \quad 0.25 \leq \text{cov}\,(i,j) < 0.6 \\ \text{sleep mode} & \text{if} \quad \text{cov}\,(i,j) < 0.25 \end{cases}$$

3. The Every sensor node's coverage and sensing model is represented by a circle with radius r, which denotes the region in which the node is capable of detecting and tracking environmental factors.
4. As shown in Figure 1, a heterogeneous network is created with normal and advanced nodes placed in separate regions, R1 and R2, respectively. Higher energy-reserved advanced nodes are positioned in close proximity to the base station and are able to establish direct communication with it. Normal nodes, on the other hand, rely on multi-hop communication to transfer data.

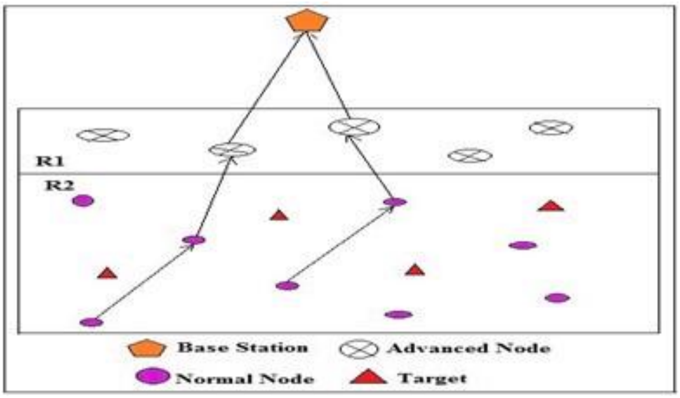

Figure. 1 Proposed network architecture protocol

5. Sensor nodes have the ability to switch between active and sleep modes based on their presence within the coverage area.

5. Simulation and Results

The simulation was performed on Matlab where the network area was defined on a (100 x 100) m^2 area. The nodes are static in nature and the energy of nodes are homogeneous. The number of nodes randomly deployed were 300. The base station of the proposed network architecture was located on coordinate (150, 50). Figure 2 shows the deployed network architecture.

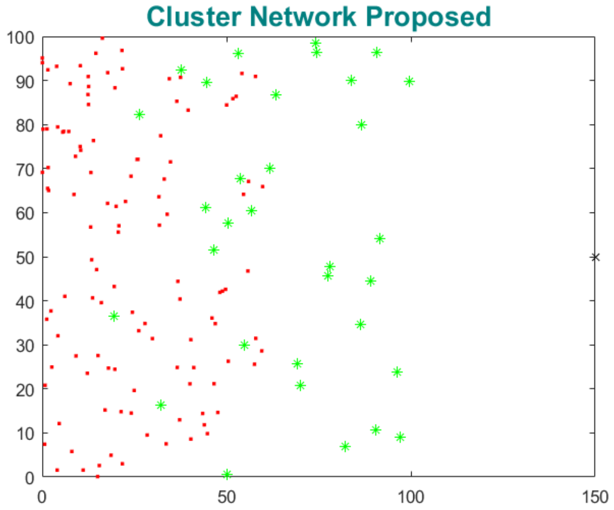

Figure 2: Proposed network deployments

The simulation parameters used in the proposed work is shown on table1.

Table 1. Simulation parameters used in the proposed work

Parameter	Value
Simulation Area	100 square units
Channel type	Wireless communication
Base station Location	Coordinates (150,50)
Energy Model	Battery-powered
Transmission amplifier Efs	10 nanojoules
Transmission amplifier Emp	1.3 picowatts
Data aggregation Energy	5 nanowatts
Transmission Energy ETx	50 nanowatts
Receiving Energy ERx	50 nanowatts

The following results depict simulations of both LEACH and the proposed protocols at a 0.2 probability, representing 2% of the total nodes becoming cluster heads.

Figure 3 illustrates a comparative analysis of dead nodes for 200 nodes over 100 rounds between LEACH and the proposed protocol.

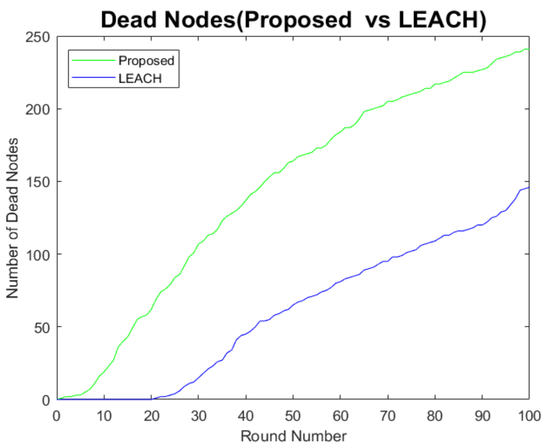

Figure 3 . Dead nodes in the network

Figure 4 shows a comparison of alive nodes for 200 nodes over 100 rounds between LEACH and Proposed Protocol.

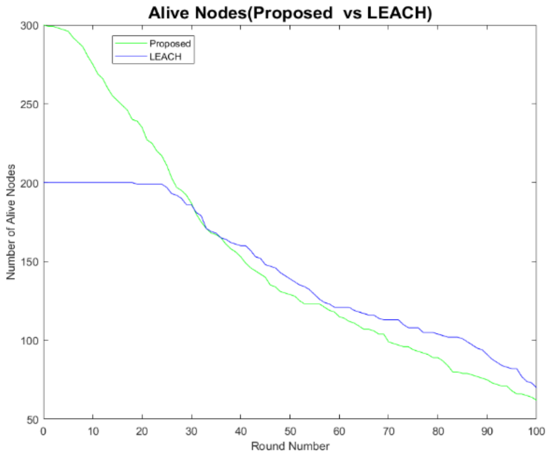

Figure 4 . Alive nodes in the network

Figure 5 displays a evaluation of the number of packets transmitted to the CH for 200 nodes over 100 rounds between LEACH and the proposed protocol.

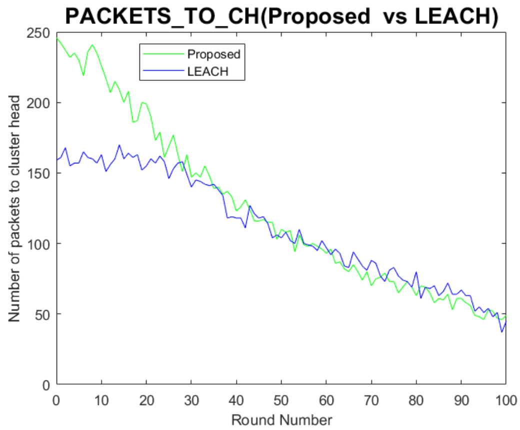

Figure 5 . Packets sent to CH

Figure 6 demonstrates a comparison of the number of packets transmitted to the BS for 200 nodes over 100 rounds between LEACH and the proposed protocol.

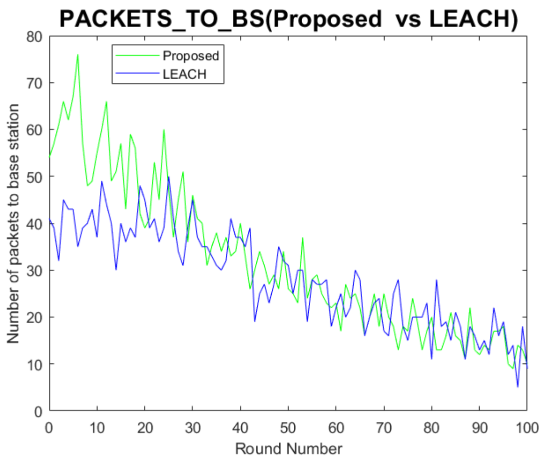

Figure 6 . Packets sent to BS

Figure 7 shows the Average Energy of each node in the proposed protocol vs LEACH protocol.

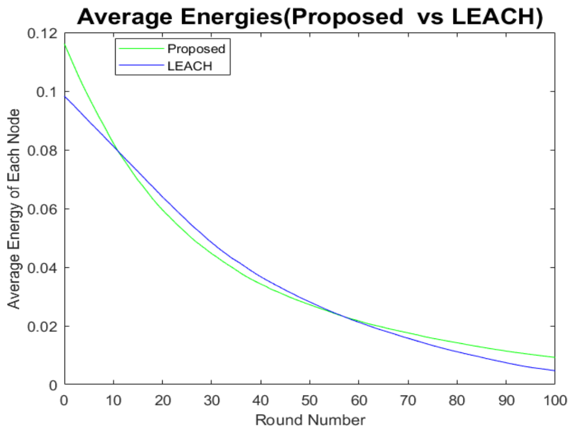

Figure 7. Average Energy consumption in the network

6. Conclusion

The simulations of LEACH and the proposed protocols, with 2% of total nodes as cluster heads, yield significant improvements. Comparing dead and alive nodes, the proposed protocol demonstrates enhanced stability and sustained network activity over 100 rounds. Notably, the comparison of packet transmissions to the cluster head and base station reveals optimized traffic management strategies in the proposed protocol. Additionally, the average energy analysis shows marked efficiency gains, reflecting better resource utilization and prolonged network operation. These findings underscore the proposed protocol's advancements in network reliability, energy efficiency, and overall performance, emphasizing its potential for enhancing wireless communication systems.

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