Design of an Energy Efficient Stable Election Protocol (SEP) for Wireless Sensor Network

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Abstract. *With the rapid growth of Wireless Sensor Network (WSN) applications across domains such as environmental monitoring, smart cities, and healthcare, ensuring energy efficiency has become paramount to extending the network's operational lifetime. WSN nodes are typically resource-constrained, making the design of energy-efficient routing protocols crucial to maintaining stability and functionality. Among the existing protocols, the Stable Election Protocol (SEP) has proven effective in heterogeneous networks due to its ability to manage nodes with varying energy levels. Over time, numerous modifications of SEP have emerged to address its limitations and further enhance network performance. This paper proposes a new energy efficient version of the extended SEP protocol, considering the threshold sensitivity. The heterogeneous node distribution and network energy are modified, and factors are optimally tuned to improve the overall network lifetime. Additionally, the modified absolute distance is proposed for the clustering process. The half ratio of the node scaling is considered for higher-energy nodes. The paper evaluated three cases of the proposed routing protocol, showing a continuous improvement in the stability period.*

***Keywords:* -** WSN, Routing Protocol, SEP, Threshold Sensitivity, Stability Period, Network Lifetime.

Introduction

Today, in all real life areas, a wide variety of sensors are utilized for various control and monitoring purposes [1]. The main characteristics of WSN [2] includes: energy harvesting, ability to cope with node failure, mobility of nodes, heterogeneity of nodes, scalability to large scale deployment, ability to withstand harsh environmental conditions and ease of use [3]. WSNs have various applications in different fields, including precision agriculture, environmental monitoring, vehicle tracking, healthcare monitoring, smart buildings, military applications, and animal tracking [4]. Precision agriculture involves using sensors to collect data that can be used to optimize agricultural practices such as sowing density, fertilizer usage, and predicting crop yields [5]. Environmental monitoring is another important application of WSNs. Sensor networks can be deployed to detect and predict environmental calamities such as earthquakes, floods, forest fires, and volcanic eruptions [6]. Early detection and prediction of these events can help in taking safety measures and minimizing damage. Vehicle tracking using WSNs involves the use of networked cameras and sensors to monitor traffic flow, reduce congestion, track vehicles for traffic violations, and detect illegal activities around critical infrastructure like airports and railway stations [7]. In the healthcare sector, WSNs can be used for monitoring patients' physiological parameters and transmitting the data to healthcare practitioners for analysis and diagnosis [8]. Multi-sensor systems can monitor physical activities, fitness levels, and risk factors like obesity, blood pressure, and diabetes. This technology can contribute to improving health outcomes and extending life expectancy. Smart buildings equipped with WSNs can monitor and control various functionalities based on the building structure and environmental conditions. Real-time monitoring and control systems for household electrical appliances can optimize energy usage and provide flexibility and cost-effectiveness [9]. WSNs also find applications in military settings, where they are used for command, control, communication, intelligence, surveillance, reconnaissance, and targeting systems [10]. The self-organizing and error-tolerant nature of sensor networks makes them valuable tools for military operations. Animal tracking involves attaching sensors to animals to track their movements and locations [11]. This application has various uses in wildlife research, conservation, and management, allowing researchers to study animal behavior, migration patterns, and population dynamics [12].

The purpose of this study is to discuss the different technical issues and difficulties involved in designing WSN networks. Due to the revolutionary developments in the Internet of Everything (IoE), a Virtual Ad-hoc Network (VANET), including the Internet of Things (IoT) in relation to size, operational cost, as well as ease of use the growth of WSN is impacted exponentially [13]. The ultimate goal of this research is to examine the routing strategies employed to create durable and EE- WSN networks, as well as the potential uses for WSN technologies [14].

Today, in all real life areas, a wide variety of sensors are utilized for various control and monitoring purposes. The main characteristics of WSN includes [15]: energy harvesting, ability to cope with node failure, mobility of nodes, heterogeneity of nodes, scalability to large scale deployment, ability to withstand harsh environmental conditions and ease of use [16].

WSNs have various applications in different fields, including precision agriculture, environmental monitoring, vehicle tracking, healthcare monitoring, smart buildings, military applications, and animal tracking [17]. Wireless Sensor Networks (WSNs) have diverse applications. In precision agriculture, they optimize farming practices, including sowing density and fertilizer usage, leading to improved crop yields. For environ-mental monitoring, WSNs detect and predict natural disasters like earthquakes and floods, aiding in timely response and damage mitigation. WSNs enable vehicle tracking by monitoring traffic flow [18], reducing congestion, and enhancing security around vital infrastructure.

II. Literature Review

Large-scale WSNs must frequently be subdivided for effective data collection in order to increase their capacity, energy economy, including load-balancing capabilities [6].The sensor nodes can be uniformly or randomly deployed within the network [7]. If a message is transmitted directly, nodes must expend a lot of energy to send the data collected in terms to a BS which rapidly reduces the energy they have. Data observed is transported from each node to the next along with the BS last, on different paths, to address this issue and increase longevity while consuming less energy.

The aim of all protocols is to provide an extended energy efficient version of the basic SEP-based routing protocol. A highly challenging assignment in WSN design is energy efficient improvement. Therefore, study on this subject is particularly intriguing due to the creation of an energy efficient routing mechanism. This protocol along with countless others like LEACH [13] and its offshoots, SEP [4], I-SEP [2], SEP-V [9], and other variations are improved versions of the SEP protocol. There are many routing protocols that have been designed as modified versions of SPE routing protocol. N. Uniyal et al. [1] has presented the design of the performance enhancing of the basic zonal based SEP routing protocol (EZ-SEP). But it is required to improve the overall life of the network. T. M. Behera et al. [2] proposed a good extension of the SEP to an I-SEP and enhanced stability period. Kumar et al. [3] pro-posed an enhanced threshold sensitive approach for improving the life of the SEP based routing protocol considering energy of nodes. Kumar A. et al. [4] proposed location-based routing. Arafat et al. [5] introduces reinforced learning (RL) for routing. They studied EE protocols that make use of RL. This enables various devices to adjust their energy levels, routing selections, overall mobility, and effectiveness of EER-RL was evaluated. Upasana Sharma et al. [6] have compared the life of the LEACH and the SEP proto-cols and stated the better performance of SEP. Nurlan et al. [7] proposed the extended improved EZ-SEP version of the zone based routing but not feasible in all applications. Rohit D. et al. [8] have considered the distance and the EE both for design of the centralized approach of WSN routing. They stated that incorporating distance with EE may improve performance. The concepts of cooperative communication and the threshold sensitivity approach in WSN are demonstrated in [9 and 10] respectively. Other recent works have been evaluated with other protocols' recommended protocol runtime being lowered and energy usage is minimized. [11, 12] proposed the SEP and DEC protocols. Wenjing et al. [13] have used an RL based optimized approach for WSN routing and extended the life to a range of beyond 2000. Earlier, two decades before Smaragdakis, [14] first introduced the concept of SEP. Most recent approaches have extended the work. Praveen Kumar [15] has proposed the extension of SEP, which has two-tier architecture, and has called SEP-E. This paper has enhanced the performance of this SEP-E. Faisal Shah et al. [16] have presented the zone based extension called Z-SEP considering vertical zones in network. Later, the multilevel heterogeneous approaches of SEP extension are presented in [17 and 18]. Overall, all protocols have aims to improve EE and stability. The overall lifetime of a network is also crucial.

III. Proposed Methodology

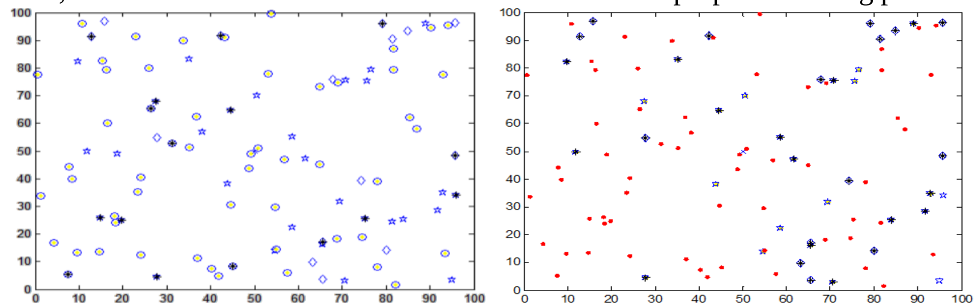
In this work, an improved version of the energy efficient SEP based WSN routing protocol is proposed and designed. The aim is to improve the network lifetime and stability. The stability is defined as the period of the first node died (FND) and lifetime is calculated as the time of all nodes died. The proposed method incorporates energy and distance measures both for clustering the nodes. The modified Canberra_distance (CD) is proposed for the clustering process. The distance measure allows a better CH election process and is defined as;

$$CD = \frac{(abs(S(n).sd - S(n+1).sd))}{(abs(S(n).sd) + abs(S(n+1).sd))} \qquad (1)$$

By stretching the time frame for the WSN to the current LEACH protocol corresponding to the energy advancement, proposed SEP offers a heterogeneous environment. SEP suggested a new timeframe equivalent to $P_{out}\ (1 + m)$ to determine the stable region's optimization.

To choose the CHs, SEP calculated election probabilities according to the initial energy level of every single node. The proposed modified SEP version splits original energy for each cluster with the initial strength of the normal nodes. To account for the extra energy that was included in the overall system, the weighed probabilities for normal intermediate and advanced nodes in proposed method were determined.

The network node distribution and the allocation of all kinds of nodes and CH are represented by 10000 and 5000 rounds respectably in Figure 1 (a) and (b). It can be observed from Figure 1 (b) that even after the 50000 round, 38% of notes are still alive in the network with the proposed routing protocol.



(a) Node allocation on field at 1000 rounds (b) Random distribution at 5000 rounds

Figure 1: WSN random network formations with proposed routing with 100x100 m^2 area and 100 nodes

IV. Simulation Results & Discussion

In this research, the recent SEP-based WSN protocols are evaluated and the energy efficient extension protocol is proposed. During validation, the standard field area of 100x100 using 100 nodes is employed for simulation. Figure 2 illustrates the fundamental validation outcomes for the proposed energy efficient SEP Case 1 routing protocol. During the experiment the nodes energy parameters are optimally steed as m=0.1, b=1. a=3 and c=0.2.it can be observed that the stability period in case 1 is achieved up to 1737 rounds. The standard Euclidean distance (ED) is considered for the study of Case 1. Validation shows improvement over the basic SEP protocol.

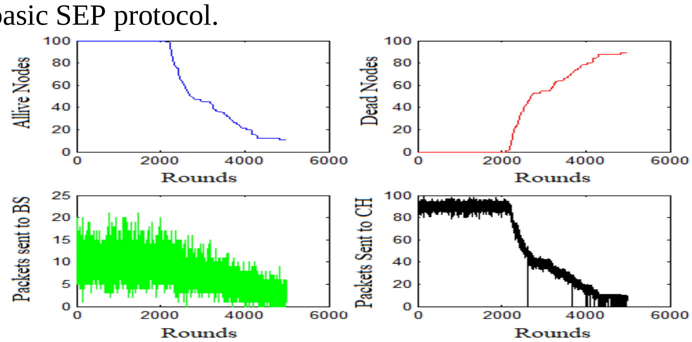


Figure 2: Number of active nodes validation for each round for proposed routing protocol

To enhance the efficiency of the SEP protocol, it is advised to optimally change the energy scaling parameters. In Case 2, the initial energy E0 is set to 0.8. The advanced node and intermediate node energy scaling parameters are stated as a=3, b=2, m=0.15, c=0.3. The ED distance is considered again for the clustering and CH election.

Finally, the modified CD distance is considered for the clustering process and keeping all the optimal parameters as same in Case 2. The CD distance is calculated by the x and y coordinates of the nodes using Eq, (1), and accumulated for the clustering process to use as a distance measure. It is observed that simulation time is slightly increased but using the CD distance measure offers an extended network lifetime, and also improves the number of packets transition significantly.

Figure 3 represents the comparison of the proposed protocol with CD and the Case 1 and Case 2 of optimal parameters with ED for the alive node counts. It can be observed from Figure 3 that the stability period is significantly improved using the proposed methodology. The nearly 11 % improvement over Case 2 and 28 % improvement in Case 1 is offered by the proposed method in terms of stability. There is significant improvement in remaining alive nodes after 5000 rounds is also observed.

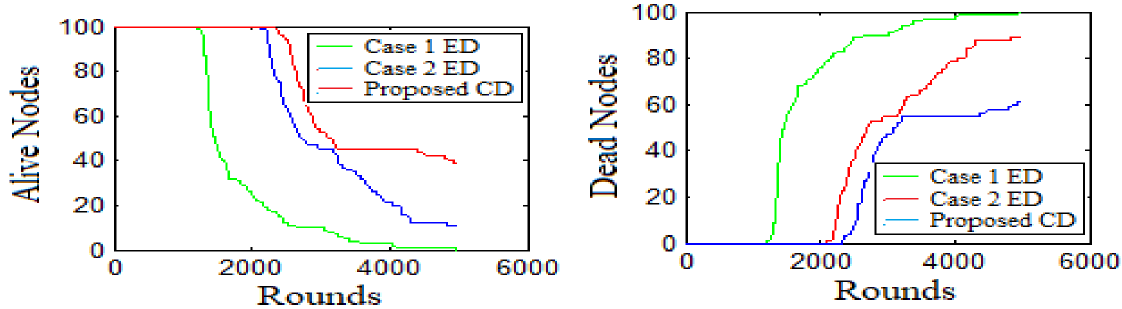


Figure 3: Comparison of Alive nodes and Dead nodes of proposed Routing protocol with Case1 and Case 2 for 100 operating nodes

Similarly, in Figure 3, the respective results of the dead nodes per round are presented for all three cases. It is observed that fewer nodes die for each round using the proposed routing protocol. And after 5000 rounds, only 60% of the nodes die. Figure 5 depicts an examination of the number of packets transmitted to BS for every round of 100 nodes using the EED-ESEP protocol. The continuously higher packet transmission per round is observed using the proposed method.

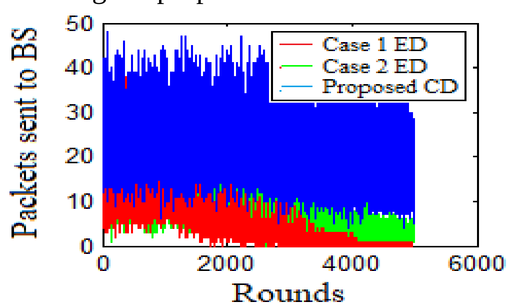


Figure 5: Comparison of number of packets sent to BS for each round for 100 nodes for the proposed routing protocol

The total number of packets transmitted by the different state of the art routing protocols are respectively presented in Figure 6 as bar plot. It can be observed that the total number of packets sent is significantly increased as the last half of rounds good energy stability is observed.

Figure 7 depicts a comparison of various cutting-edge routing protocols with the suggested technique for 100 nodes. The number of alive nodes is plotted against the number of rounds. In the figure, the time of last node death may be seen as an improvement in the overall performance of the system. It can be concluded from the figure that although the stability of the proposed method is less, the overall lifetime is significantly greater and the number of transmitted packets is increased.

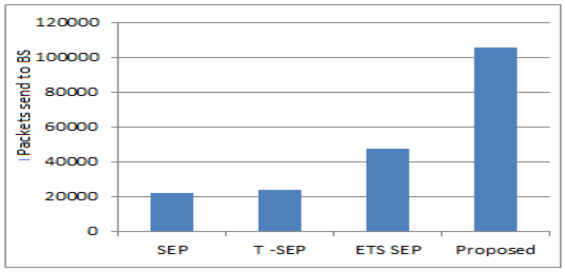


Figure 6: Total packets transition comparison

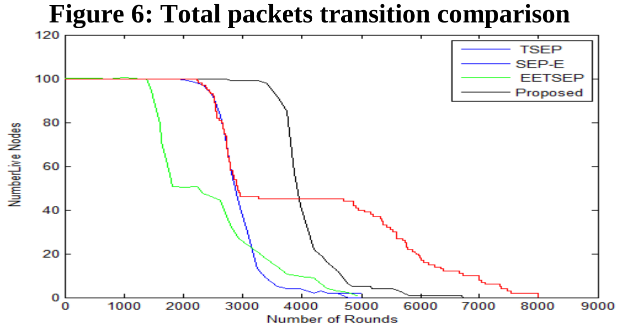


Figure 7: Comparison of the various state-of-art routing protocols with the proposed method for 100 nodes.

V. Conclusion And Future Scope

This work presents an energy-efficient SEP-based routing protocol designed to improve data transmission performance in WSNs. The proposed approach incorporates energy and distance metrics to enhance network efficiency and lifetime. The clustering process utilizes a CD-based distance measure, which significantly extends the network's operational duration. Initially, the protocol was validated using a basic Case 1 scenario with a 1/3 node ratio to demonstrate its energy efficiency. The number of operational nodes was monitored across all rounds, revealing that optimal variable-based routing selection could further enhance network longevity. Remarkably, even after 5000 rounds, 38% of the nodes remained active when the proposed protocol was implemented, indicating a higher likelihood of sustained network operation. The study compared three cases of SEP-based routing. Results showed that the proposed protocol achieved an approximately 11% improvement in stability index over Case 2 and a 28% improvement over Case 1. Additionally, the total number of packets transmitted increased by approximately 2.2 times compared to recent methods, while the network's overall lifetime was extended by around 1200 rounds.

Future work may focus on incorporating threshold sensitivity and advanced optimization methods to further enhance the stability period of the routing system. Optimization strategies could also lead to improved processing speed, enabling more efficient and scalable implementations in next-generation WSN applications.

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