LOPWRCH Protocol for Resilient and Efficient Wireless Sensor Networks

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ABSTRACT

Nodes in Wireless Sensor Networks (WSNs) can operate either statically or dynamically, and this variation directly affects how the network performs. The proposed Low Power Resilient Clustering Hierarchy (LOPWRCH) protocol introduces a likelihood (i.e., probability) based clustering approach that makes the selection of network controllers more adaptable and energy efficient. We evaluate this enhancement in two types of network environments. The first is a standardized setup where nodes continuously transmit sensing data, ensuring constant communication with the Base Station (BS). The second is a more diverse network, where some nodes send data intermittently (static behavior), while others transmit continuously (dynamic behavior). Using Python and libraries like NumPy, SciPy, and SimPy, we ran extensive simulations to test the networks' performance. In the standardized setup, increasing the selection probability to 0.3 led to better data throughput reaching around 15,350 packets in the dynamic case and 11,268 in the static one. In the diverse setup, our approach significantly improved network lifespan, increasing it to about 3,985 cycles versus the 1,608 cycles of the static probability setting.

Keywords-WSN; CLHE; resilient; static

I. INTRODUCTION

WSNs are nowadays commonly utilized in many fields [1]. A WSN involves several measuring instruments that communicate with a Base Station (BS) [2, 3]. WSNs are ad-hoc networks of nodes with limited energy and varying topology and mobility, which affect their performance and lifecycle [4]. One extensively utilized resolution to these encounters is the use of clustering techniques [5]. Clustering algorithms prolong the network's effective lifecycle by selecting Cluster Heads (CLHEs) that transfer the node measurements to the BS [6-9].

Low Energy Adaptive Clustering Hierarchy (LEACH) protocol primarily operates by organizing nodes into clusters and selecting CLHEs through a voting process, which helps in building an efficient network structure [10]. In indoor WSNs, each piece of information goes through several steps, and at each step, it is divided into two parts: one that describes the context or situation, and another that carries the actual data. While handling the contextual information, CLHEs are voted, and clusters are designed. In the solid segment, CLHEs collect and aggregate data from their respective sensor nodes before sending it to the BS [11]. This study proposes a novel framework that employs multiple customized configurations designed for both standardized and diverse WSNs. The framework introduces a flexible likelihood-based mechanism for selecting CLHEs, designed to support both dynamic and static network configurations.

This approach is suitable for applications requiring continuous sensing, such as disaster monitoring in environments like forest fires. Similarly, it is effective in diverse scenarios, such as tracking applications, where the target like a moving individual or an animal navigates through its environment. In such cases, nodes near the target remain active, while others switch to sleep mode to conserve energy. This rigidity is achieved through the proposed probability mechanism, making it versatile for various WSN applications.

II. MODEL METHODOLDY

The LEACH methodology is a widely recognized and efficient routing technique in WSNs for Real-Time Monitoring [12]. It provides an intermediate option between single-hop communication, which has a simple structure but limited network performance, and multi-hop communication, which is more complex but offers extended network coverage [13]. The proposed LOPWRCH operates using a resilient clustering technique where CLHE collection is resolute by a predefined probability value (Prob_v). The network selects this probability to ensure that all nodes (*ND*s) are assigned as CLHEs once per epoch (*ep*), while distributing the assignment evenly across the network. The average number of CLHEs per round (*ro*) is:

$$AvarN_{CLHE}^{ro} = \frac{TS}{Prob_v} \tag{1}$$

$$ep = \frac{1}{Prob_v} \tag{2}$$

$$\sum_{ro=1}^{\frac{1}{Prob_v}} \sum_{i=1}^{n} CLHE_{i,r} = TS \tag{3}$$

where TS represents the total number of sensor nodes, $CLHE_{i,ro}$ is the *r*-th round, and n is the quantity of CLHEs/*ro*. Equation (3) ensures that the overall quantity of CLHEs equals *TS* by the end of an *ep*, applicable during the network's stable period. As nodes deplete their energy and die, the network enters an unstable phase, necessitating an adjustment to (3):

$$\sum_{ro=1}^{ep} \sum_{i=1}^{CLHE} CLHE_{i,ro} = TS.\varphi \tag{4}$$

where $\varphi \in [0,1]$. Since $Prob_v$ is fixed throughout the network's lifetime, certain *ro* may occur without any CLHEs, referred to as Zero Head Rounds (ZEHEROs). As ZEHEROs increase with node failures, network throughput measured by the quantity of packets (PKT) sent to the BS declines because CLHEs are responsible for data transmission. In critical applications requiring continuous sensing, such as disaster monitoring, minimizing ZEHEROs is essential to maintain uninterrupted data collection. Conversely, in applications monitoring static environments, ZEHEROs can extend the network's lifetime by enabling nodes to enter a low energy state, albeit at the expense of throughput. This highlights the significance of ($Prob_v$) which directly impacts throughput and network performance based on application requirements. To address this, this study proposes a resilient probability ($P_{standardized}$) to eliminate ZEHEROs and enhance throughput in standardized environments:

$$P_{\text{standardized}} = \frac{No.\ of\ Alive\ Nodes}{No.\ of\ ro\ per\ ep} \tag{5}$$

For diverse environments, where data vary in type and nature (e.g., tracking a moving target across a large area), a flexible probability is proposed to account for node-level priority. This approach redistributes the load unevenly based on the nature of the environment or data importance:

$$P_{\text{standardized}}^{i} = \frac{pw_i .Prob_v}{x_i \cdot TS} \tag{6}$$

Subject to:

$$\sum_i pw_i = 1 \tag{7}$$

where pw_i is the priority weight [0,1] of the *i*-th node, and x_i represents the proportion of nodes in the *i*-th area of interest [0,1]. This approach ensures optimal performance tailored to both dynamic and static actions in WSNs.

III. PROPOSED MODEL

Two distinct scenarios were designed to assess the controlling of ZEHEROs to suit specific application requirements. The reproductions were realized in Python.

A. Scenario 1: Standardized Environment with Dynamic Actions

In this setup, the WSN is positioned indoors with a standardized atmosphere everywhere and all sensors incessantly diffuse their detecting data packets throughout the period of a dynamic action. The resilient probability ($P_{standardized}$) as distinct in (5) is used to disregard ZEHEROs. This ensures a reliable flow of data from the sensors to the BS. The replication outcomes for this format were related compared to the routine of the standard LEACH protocol.

B. Scenario 2: Diverse Environment with Dynamic and Static Actions

The next setup introduces a unique environment that covers both dynamic and static performance zones. In the dynamic region, sensors operate similarly to those in Scenario 1, continuously transmitting data. However, the static region involves periodic, discrete data transmissions. To cater to the requirements of these two regions, in network lifetime and throughput, a strategic choice of probability value is necessary. In this scenario, the resilient probability as defined in (6) is utilized. This approach adjusts the likelihood of a node on its urgency and the characteristics of the action region. Increasing a sensor's priority boosts its probability of being elected as a CLHE, which enhances its throughput. For example, doubling the probability to 0.3 allows a sensor to serve as a CLHE twice in 15 rounds per epoch (*ropep*), effectively doubling the throughput contributed by that sensor. Conversely, sensors placed in the static mode adopt a demi-sleep approach by lowering their likelihood of CLHE selection. This reduces energy consumption and increases ZEHEROs until an action transforms the static region into a dynamic one, prompting sensors to resume full operation. The outcomes of this simulation were benchmarked against the standard LEACH protocol using both $Prob_v$ and $P_{standardized}$ for comparison. Figures 1 and 2 illustrate the system model flowchart for both standardized and diverse network configurations.

IV. EXPERIMENTAL RESULTS

A. Standardized Setting Setup

A WSN with 1000 nodes, casually distributed over a 1000 m × 1000 m area was simulated to evaluate the performance of the proposed resilient probability mechanism. Each node starts with an initial energy of 0.2 J, and the PKT size is fixed at 9000 bits. As shown in Table I, the resilient probability dynamically increases as nodes deplete their energy and begin to die, effectively minimizing ZEHEROs. Result comparison with fixed probability $Prob_v = 0.2$ are presented in Table II and highlights that resilient probability reduces ZEHEROs by approximately 99.85%, significantly improving the consistency of CLHE formation. Table III illustrates the throughput (*thpt*), where ZEHEROs occupy 50% of the network's lifetime under static probability but only 0.5% with resilient probability is utilized, allowing the PKT quantity guided to the BS to grow from 20 to 35. Figure 3 further reveals a trade-off, where the node time operation (ND_TO) decreases from 3280 to 998 rounds, but throughput improves from 11,120 to 15,350 PKT, demonstrating the resilient probability's effectiveness in enhancing data delivery despite a shorter operational period.

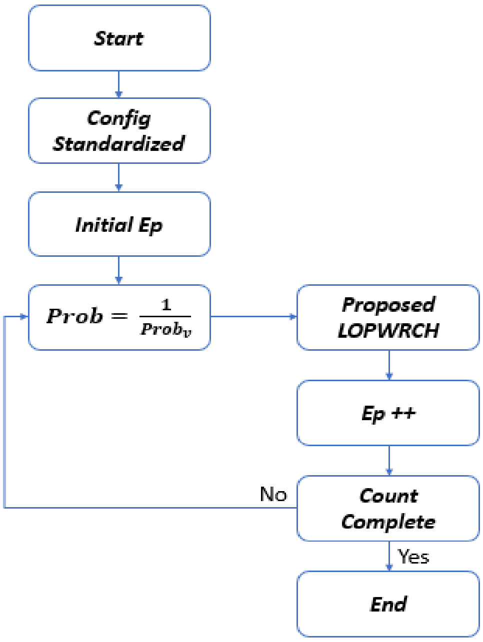

Fig. 1. Standardized WSNs flowchart.

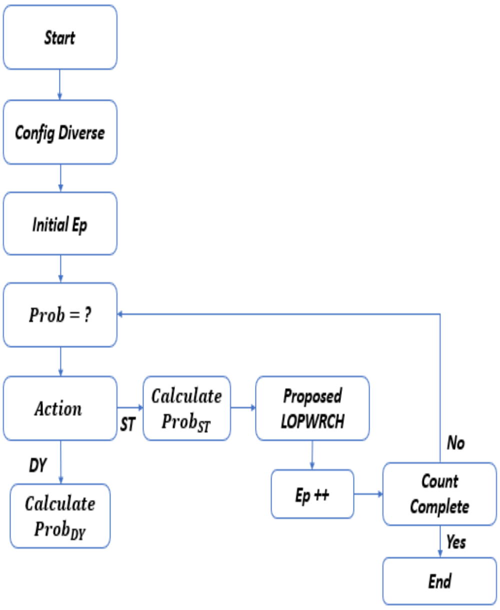

Fig. 2. Diverse WSNs flowchart.

TABLE I. RESILIENT PROBABILITY ACOORDING TO NODE ENERGY

***ro* generation time**	**Probability**	**ND_TO (%)**
0	0.1	100
734	0.1	100
800	0.12	80
1000	0.2	50
1200	0.3	20
1400	0.6	10
1596	1	0

TABLE II. CLHEs PER *ro* DURING GENERATION TIME

CLHE /*ro*	**Static Probability**	**Resilient Probability**
0	1100	1000
2	150	180
4	120	250
6	100	320
8	80	400
10	60	450
12	40	420
14	30	300
16	20	200
18	10	120

TABLE III. PKT NUMBER FORWARDED TO THE BS

PKT to BS / *ro*	**Generation period time**	
	Static Probability	**Resilient Probability**
0	0	0
5	0.2	0.35
10	0.4	0.7
15	0.6	0.9
20	0.8	0.95
25	0.95	0.98
30	0.98	1
35	1	1

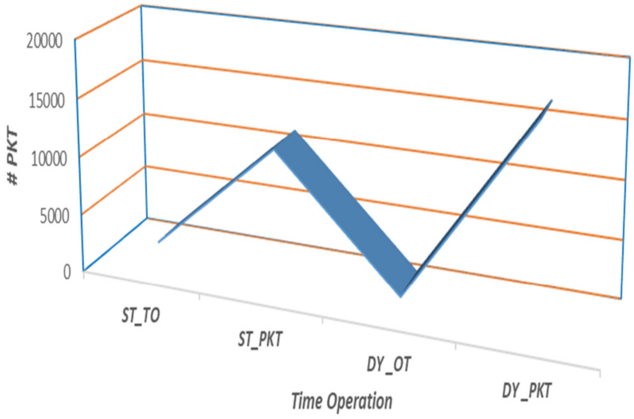

Fig. 3. Throughput for both *DY* and *ST* probability types.

B. Diverse Setting Setup

The WSN beginning the foremost setup is extended to a diverse setting, where actions are distributed disproportionately across the area of interest. This environment consists of two types: dynamic and static. In the dynamic environment, actions occur rapidly and require continuous, fast communication with the BS, which is completed by growing the likelihood of the nodes in this region to enhance their contribution. Conversely, the static environment involves nodes monitoring the area in anticipation of an action, with reduced node activation to conserve energy and extend their lifetime. Each node (ND) is categorized as dynamic (DY) or static (ST) based on a threshold comparison ($z_i \leq thre$), as defined in (8):

$$\mathrm{ND}_{\mathrm{state,i}} = \begin{cases} \mathrm{DY} & \text{if } z_i \geq \mathrm{thr} \\ \mathrm{S} & \text{else} \end{cases} \quad (8)$$

where z_i is a arbitrary amount connected with the *i*-th node and linked with the threshold value *thre*. Node probabilities are assigned using (6), where $ND_d = 0.9$ is a DY node and $ND_s =$

0.3 is an ST node. This distribution means that ND_d account for 90% of the *ep* data, while ND_s contribute 10%. Consequently, ND_d are reselected every 10 rounds and ND_s every 30 rounds. Simulation results in Table IV illustrate the stability period, showing an average of 9 CLHEs per round for ND_d and 20 for ND_s in 11 *ropep*, as per standard LOPWRCH.

TABLE IV. AVG. CLHE PER EP WITH DIFFERENT TS

Environment	**Constancy Period**	**Avg. CLHE/EP**
ST (CL=2, TS=500)	20	20
DY (CL=2, TS=100)	7.7	8.99
LOPWRCH (CL=2, TS=700)	8.5	10.98

Throughput comparison between DY and ST nodes, presented in Figure 4 highlights the effectiveness of diverse probability with DY nodes significantly outperforming the ST nodes.

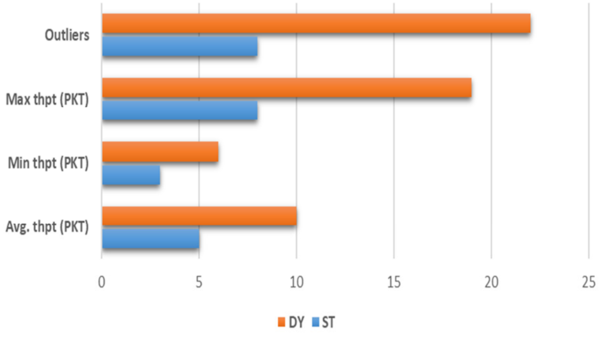

Fig. 4. Throughput comparison.

Further analysis in Figure 5 compares diverse standardized, and fixed probabilities. It was found that varying probability (i.e. likelihood) outcomes lead to consistent stability over time, due to the higher likelihood of ND_d at the network's initialization. Despite this, the diverse probability achieves the longest network lifetime by effectively distributing the load among nodes based on action occurrence. Although fixed and standardized probabilities achieve higher throughput per ep, roughly 75% of these data are redundant as they originate from ND_s monitoring slow or monotonous actions.

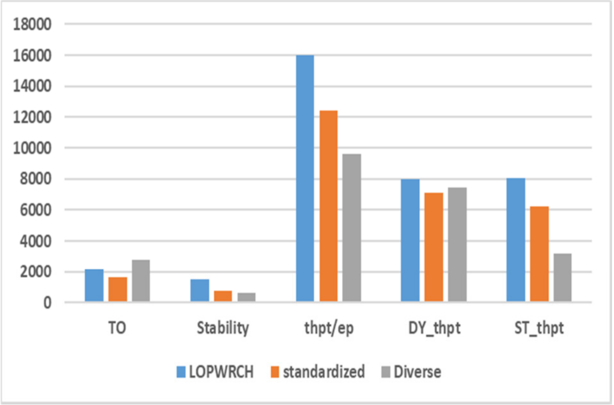

Fig. 5. Comparative result analysis.

V. CONCLUSION

This paper introduces a resilient probability approach for CLHE selection in WSNs, where the probability dynamically adjusts based on the application environment in which the nodes are arranged. In cases with rapidly shifting actions, the probability/likelihood is improved to ensure continuous communication between the WSN and the BS, effectively dropping ZEHEROs. In contrast, in cases with measured actions, nodes enter sleep modes to maintain their energy and prolong network's lifetime. Different setups were considered to evaluate the performance of the proposed resilient probability. In the initial setup, a standardized network with dynamic actions is considered. Simulation results demonstrate that the resilient probability reduces ZEHEROs by 55%, resulting in a 22% increase in throughput. The next setup involves a diverse environment where both ST (slow, repetitive) and DY (fast-changing) actions coexist. The results show that the proposed resilient probability method helps offload the ND_s by leveraging ND_d, reducing redundant data by approximately 85-90%. Additionally, the network lifetime is prolonged by 30% and 80%.

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