Adaptive Probabilistic Protocol for WSN in Different Environments

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***Abstract*—Distinguishing the nature of events in Wireless Sensor Networks (WSNs), whether static or dynamic, determines the type of network action. The classification process is accomplished by adjusting the probability for electing the network head. In this paper, the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol based on the adaptive clustering technique is adopted with two scenarios. In the first scenario, a homogenous environment with a dynamic event is deployed to continuously send the sensing events during the entire period in order to maintain the communication between the base station and the network. Meanwhile, the second scenario deals with heterogeneous environments for static and dynamic events. The static-heterogeneous event is established through sending the data in a discrete manner, while the continuous-heterogeneous event sends the data in a dynamic event. Simulation results using Matlab 2019b indicate that the throughput and lifetime are probability dependent, where increasing the probability value to 0.2 in homogenous networks leads to increased throughput, as it reaches approximately (14402) packets compared to (12029) packets in the fixed probability scenario. In contrast to the heterogeneous network, the lifetime is increased to reach (2806) rounds compared to fixed probability, which achieves (2160) rounds.**

***Index Terms*—Cluster head, LEACH, throughput, lifetime, WSNs**

I. Introduction

In the most recent decade, different applications for Wireless Sensor Networks (WSNs) have been taken into consideration in different fields, including surveillance, habitant observation, and health monitoring in addition to its applications in the fields of science, logistics, military, and medicine [1]. WSNs comprise multiple sensor nodes, which are hardware devices that consist of processing, sensing, communication, and power units [2]. These units are commonly used for sensing, data processing, and communication purposes [3]. These sensors have the ability to sense target area, collect data, and then send them to the Base Station (BS) [4]. However, some requirements are needed for WSNs to operate efficiently with long-lifetime and low-latency transmission and with smooth deployment [5]. It is agreed [6] that the clustering technique is widely used to resolve these limitations, in which the information can be collected and transmitted efficiently with identifying occasions. Fig. 1 shows that the separated clusters are combined to contain multi-nodes including Cluster Heads (CHs), which are responsible for aggregating information from nodes within the cluster and then communicating it to the BS [7].

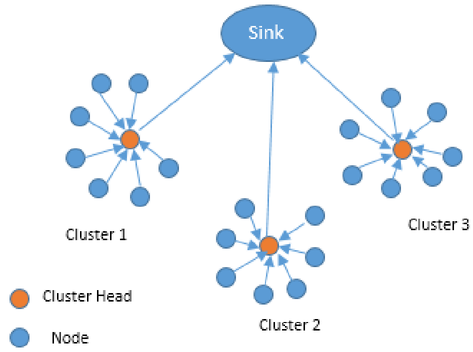

Fig. 1. Clustering in WSN, showing the cluster head within the sensor nodes.

Specific algorithms for this technique are modified, depending on related applications. The clustering algorithms address the related operating lifetime by reducing the data load through repeating the role of the CH among other sensors. This can be achieved by providing the algorithm with the low energy adaptive clustering hierarchy (LEACH) technique [8], which represents a suitable option for accomplishing network endurance. The LEACH technique has been proposed progressively to frame the group and to choose the cluster head node [9].

In data communication, there are a number of rounds for data processing. In each round, there are two phases, including setup and steady phases. In the first phase, the CH election and cluster formation are achieved, whereas in the steady phase the CHs gather information from their native nodes to aggregate it and send it to the base station [7].

In this paper, a new proposed system with two scenarios have been adopted for homogenous and heterogeneous WSNs. Through, selecting an adaptive probability for cluster heads to be compatible with dynamic and static events. The proposed probability can be adopted in some applications where delivering sensing information continuously is critical such as sensing disaster environment like forest fire. Moreover, other applications are heterogeneous in nature such as tracking

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applications. As an example tracking people or monitoring animal behavior etc. In such application, the target is moved through its environment. Accordingly, some nodes need to be active during the target existing in the nearby, while other nodes can be switched to the sleep mode. This can be achieved by employing adaptive probability.

II. Related Works

The LEACH protocol utilizes a hierarchical topology, with which the information is aggregated and then sent to the BS. Many improvements have been made to take control of the disadvantages of the LEACH protocol, therefore studies have been conducted by many researchers and can be summarized as follows:

Atallo *et al*. [10] proposed a modified routing algorithm for the LEACH protocol to minimize energy consumption. The new approach attempts to limit the overhead of choosing cluster heads and forming clusters on each round. Once the first-round clusters are formed, as in the original LEACH protocol, nodes are scheduled to be a cluster head on each round sequentially until two-thirds of their total energy is lost. After that, new scheduling will be held for re-clustering to remove low-powered nodes and dead nodes from the scheduling. The proposed algorithm has been assessed relatively using Castalia 3.3 simulator, and it outperforms the current LEACH protocol.

Amer *et al*. [11] introduced a clustering mechanism for enhancing the LEACH protocol, wherein LEACH is expanded by identifying the distance between the CHs and BS according to the lowest degree of distance in order to increase the lifetime of WSNs in the entire system. Thus, the outcomes explain the capacity of LEACH to upgrade the system lifetime as well as lessening and limiting the use of power.

Ahmed and Ayman [12] presented a new algorithm called Node Ranked–LEACH (NR-LEACH) that improves the performance of the LEACH protocol. This improvement relies upon how to choose CHs so that the energy load of the sensor nodes is dispersed in an adequate manner among all sensor nodes. This is accomplished by utilizing a node rank algorithm, which gives a rank value for all nodes and calculates the path cost in addition to the number of links between nodes to select CHs. This improvement mirrors the real weight of a specific node to be selected as CH, thus overcoming random selection. NR-LEACH gives good performance in terms of energy consumption and network lifetime.

Bilal and Leszek [13] introduced the LEACH-SM protocol, which modified the prominent LEACH by providing energy-saving management and optimal selection of spares. Three main goals have been proposed for LEACH modification: optimal spare selection, management of spsare nodes after WSNs' deployment, and estimating the lifetime of WSNs. LEACH-SM results in satisfaction of these goals and provides the salient features.

Pawan *et al*. [14] proposed SE-LEACH homogeneous network, which is equipped for adjusting the load, ensuring that all nodes dissipate power in a comparative style, since the selection of the best candidate CHs is the utmost requirement. Distance from the BS residue energy node density and power dissipation are considered the selection criteria of CHs. A simulation experiment is performed for two scenarios according to the location of the BS and suitability for the WSN's application. The simulation results show the extension of the stability period for the network.

Jin *et al.* [15] proposed a new method called SMO optimization to solve problems caused as increased computation, poor selection accuracy, and the selection of duplicate nodes for cluster-heads that came from existing cluster-head selection methods for extending the stability and life time of WSNs. Where, SMO looking through a specific location in a continuous environment to retrieves the optimal location. Therefore, the nodes have discrete locations and the aim of the SMO is to locate the optimal feasible samples rather than locations. The experimental results showed that the optimization (SMO) method is higher performance comparing with LEACH_C and PSO_C protocol in term of stability and network life time by average 34.6%, 1.8%, 13.4% and 7.1% respectively.

III. Problem Formulation

The LEACH protocol has been widely adopted as an efficient routing protocol. It provides an intermediate solution between single hop, which has the simplest structure with the shortest lifetime, and multi-hop, which has a complex structure but an extended lifetime compared to others. As previously mentioned, the LEACH protocol is based on the adaptive clustering technique, where the election of CHs is determined by a probability value (p_o). The suitable probability value is chosen by the network operator in such a way that all nodes can be selected as CH once every epoch period to guarantee load balancing between all nodes. Accordingly, the average number of CHs per round ($\mathrm{AV}_{\mathrm{CH}}^{\mathrm{round}}$) and the epoch period can be found as below:

$$\mathrm{AV}_{\mathrm{CH}}^{\mathrm{round}} = N / p_o \tag{1}$$

$$\text{epoch} = 1/ p_o \ (\text{rounds}) \tag{2}$$

$$\sum_{r=1}^{1/p_o} \sum_{i=1}^{c} \mathrm{CH}_{i,r} = N \tag{3}$$

where N is the number of network sensors and $\mathrm{CH}_{i,\,r}$ is the ith elected CH in the rth round and c is the number of CH per round. Equation (3) indicates that the total number of CHs must equal N at the end of each epoch. However, equation (3) is true only for the network stability period. As nodes begin to die, the network operates in an instability period, and equation (3) will be modified to become the following equation:

$$\sum_{r=1}^{1/p_o} \sum_{i=1}^{c} \mathrm{CH}_{i,r} = \propto N \tag{4}$$

where $\propto \in [0,\ 1]$. Since p_o is set before phase one implementation and kept until the end of the network lifetime, some rounds with zero CHs may appear. These rounds will be referred to as Zero Head Rounds (ZHRs). The number of ZHRs will increase as more nodes die. Accordingly, throughput (materialized by the number of packets sent to the base station) will be decreased, since CHs are responsible for transmitting the collected data from each cluster. In other words, BS loses communication with the sensors during ZHRs. This may be evaluated as a problem, especially in some applications, which require continuously sensing the environment. An example of such an application is a disaster region, where an event is fast for a period of time. Therefore, continuous sensing is necessary, and the need to reduce ZHRs is an essential need. Other applications monitor static environments; hence, information is sent periodically at discrete intervals, and the network lifetime is a significant consideration. Therefore, increasing ZHRs helps to extend the lifetime as if the network were going into sleep mode; of course, this will be at the cost of throughput. It can be concluded that Po plays an important role, which is reflected in increasing or decreasing throughput at a certain period based on the application's environment. Accordingly, in this work, an adaptive probability, $P_{\text{homogenous}}$ is proposed, as in (5), to eliminate ZHR and increase throughput.

$$P_{\text{homogenous}} = \frac{\text{No. of Rounds/epoch}}{N \text{ alive}} \tag{5}$$

Moreover, there may be a heterogeneous environment where different data in terms of type and nature are collected from one environment. An example of such an environment would be tracking a target through its movement in a wide area. In such an application, a set of sensors located in the area of interest with the dynamic event can off the load from other sensors located in the static event environment. Accordingly, a flexible probability ($P_{\text{heterogeneous}}$) at the node level is proposed in this work to distribute the load unevenly due to each node priority, as in (6). This priority can be related to the network environment nature or sensing data privilege.

$$p_{\text{heterogeneous}} = \frac{W_i}{m_i N P_o} \tag{6}$$

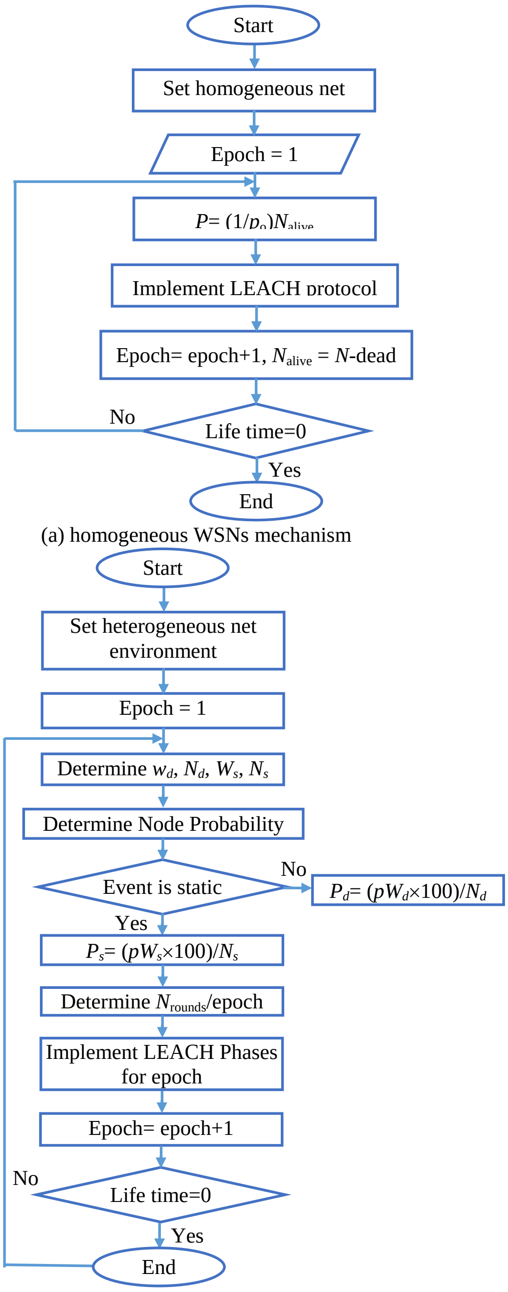
$$\text{s.t. } \sum_i W_i = 1 \tag{7}$$

where w_i is the priority weight [0, 1] of the ith node constrained by the condition in (7). The summation of all environments' priorities must be equal to one. m_i is the percentage of nodes in the ith area of interest [0, 1].

IV. System Model

Two scenarios are assumed to evaluate the effectiveness of adaptive probability in providing flexibility and scalability by reducing increasing ZHRs to meet the requirements of each application, through implemented it using Matlab 2019. In the first scenario, a WSN is deployed in a homogenous environment with the dynamic event. For such an environment, all sensors located all over the network have to transmit their sensing data packets in a continuous manner during the entire period of the event. Hence, adaptive probability ($P_{\text{homogenous}}$ in (5)) is needed to eliminate ZHRs in order to maintain the communication between the BS and the network. The result of this scenario simulation is compared to the LEACH protocol.

A heterogeneous environment is proposed in the second scenario. Such an environment consists of both a dynamic event, as in the first scenario, and a static event in which information is sent periodically in a discrete manner. To meet the requirements of both regions in terms of lifetime and throughput, a judicious decision about the probability value must be considered. Accordingly, $p_{\text{heterogeneous}}$ in (6) is employed for each sensor and determined based on the node priority and the



(a) homogeneous WSNs mechanism

(b) heterogeneous WSNs mechanism

Fig. 2. Flowchart of two scenarios WSNs mechanism: (a) homogeneous WSNs and (b) heterogeneous WSNs.

event area. Increasing a node's priority means increasing its probability of being selected to become a CH per epoch. For example, doubling the probability to 0.2 results in electing the same node twice as CH per 10 rounds (one epoch), thus doubling the throughput gained from this node.

Conversely, the rest of the network's sensors, which are located in the static region, will be entering semi-sleep mode by decreasing the probability, thus increasing the ZHRs until an event occurs and converts the region into a dynamic one. The results of this scenario simulation are compared to the LEACH protocol with p_o and $P_{homogenous}$. Fig. 2 (a) and (b) show the flowchart of system model mechanism for homogeneous and heterogeneous network.

V. Simulation Results and Discussion

A. Homogenous Environment Scenario

In this scenario, a WSN with 100 nodes deployed randomly in 100 m ×100 m is adopted to simulate the network performance with the proposed adaptive probability. The initial node energy equals 0.5 joules, and the packet size equals 4000 bits. Fig. 3 depicts the value of adaptive probability during the lifetime. It clearly demonstrates that as the nodes begin to die, the probability increases to mitigate the ZHRs.

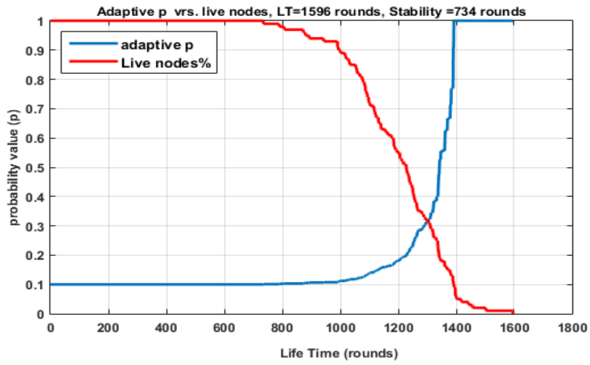
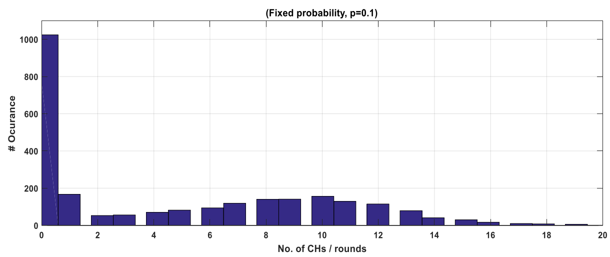
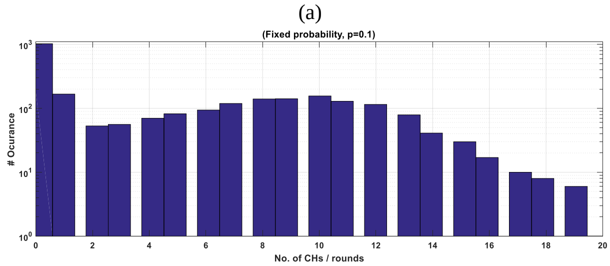


Fig. 3. Lifetime versus adaptive probability.



(a)



(b)

Fig. 4. The number of CHs per round during the lifetime: (a) Fixed probability and (b) Adaptive probability.

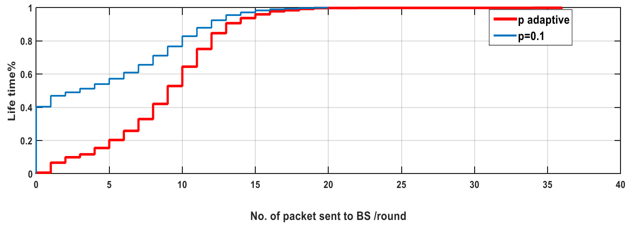


Fig. 5. No. of packets sent to BS for fixed and adaptive probability.

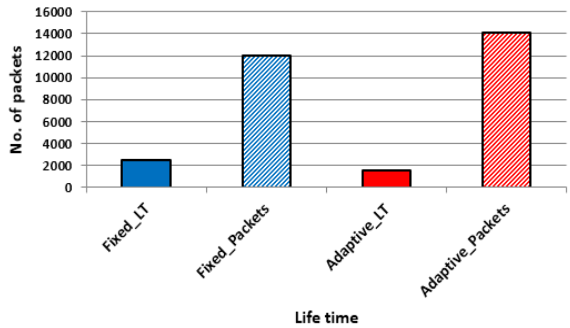


Fig. 6. Lifetime versus throughput for fixed and adaptive probability.

The simulation results using adaptive probability are compared to the same network with fixed probability (p_o=0.1), as shown in Fig. 4 to Fig. 6. Fig. 4 depicts the comparison in terms of the number of CHs per round during the lifetime. The histogram depicts a reduction of ZHRs due to the probability of increasing, where approximately 99% of the ZHRs are eliminated with adaptive probability.

The probability of throughput materialized by the number of packets sent to BS is explained by Fig. 5. It can be seen that 40% of the network lifetime consists of ZHRs in the case of fixed probability. Conversely, in the case of adaptive probability, ZHRs occupy only 0.6% of the lifetime. At the same time, the maximum number of packets sent to BS equals 36 and 20 packets in the case of adaptive probability and fixed probability, respectively.

The results of a comparison in terms of lifetime versus throughput are presented in Fig. 6.

It can be concluded that despite the shortening of the lifetime from 2537 rounds to 1595 rounds, the throughput is increased from 12047 packets to 14108 packets, compared to fixed probability.

B. Heterogeneous Environment Scenario

The WSN from the first scenario is adopted in a heterogeneous environment, where the events occur unevenly over the area of interest. It is assumed that the network area implicates two types of environment. One type of environment is a dynamic environment, where events change rapidly. Such an environment needs continuous and fast communication with the BS. This can be achieved by increasing the probability of the nodes (which are located in this environment) to increase their contributions. The second type of environment is reflected in static events, where the role of nodes is to continuously sense the environment in anticipation of an event occurrence. In such a case, it is important to reduce the nodes' activations by reducing their probability and thus prolonging their lifetime.

This scenario is simulated by a situation where each node is assumed to be dynamic or static according to the below comparison decision:

$$\text{node}_{\text{state},i} = \begin{cases} \text{dynamic}, & \text{if } x_i \geq \text{thr} \\ \text{static}, & \text{else} \end{cases} \tag{8}$$

where x_i is a random number associated with the ith node and compared with a threshold value (thr). Each node probability is determined according to its state and equation (6), where (w_d) is assumed to be the priority weight for dynamic event and equal to (0.8) and (w_s) is assumed to be priority weight for static event and equal (0.2). This indicates that 80% of the epoch data are related to dynamic nodes' sensing data, while static nodes' data contribute only by 20%. Accordingly, the dynamic nodes must be reselected for every (6) rounds, while the static nodes are reselected for every (25) rounds. Fig. 7 depicts the simulation results in the stability period. The epoch is assumed to be (10) rounds, as in the standard LEACH, where the average CH per round equals (10). It can be noticed that using heterogeneous probability results in an average CH per round that equals (8) and (2) for dynamic and static nodes, respectively.

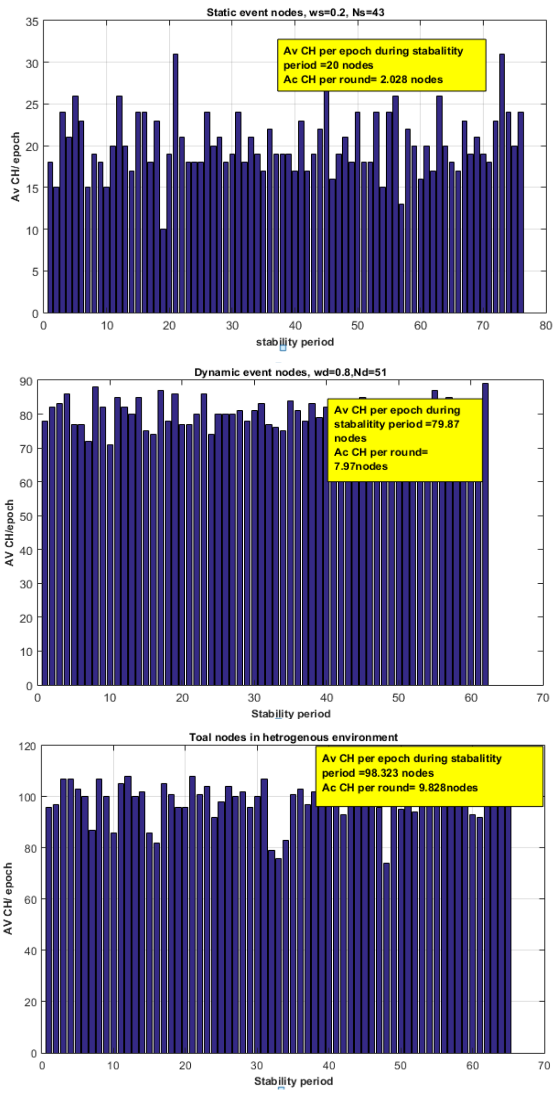


Fig. 7. Stability cycle for static and dynamic environments.

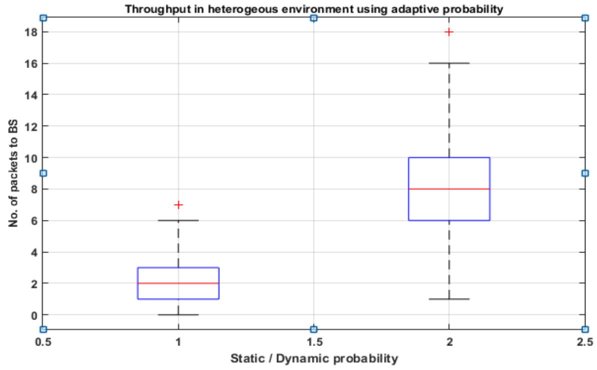


Fig. 8. Static versus dynamic throughput.

TABLE I: QUANTITATIVE ANALYSIS OF HETEROGENEOUS AND HOMOGENEOUS NETWORKS' RESULTS

Characteristic	LEACH	Homogeneous	Heterogeneous
Probability	(P_o) =0.1	$P_{\text{homogenous}}$	$P_{\text{heterogeneous}}$
Lifetime	2160	1679	2806
Stability	745	745	659
Throughput/epoch	12029	14402	11619
Dynamic throughput	5956	7139	9429
Static throughput	6073	7263	2190

The results of a comparison between the dynamic and static nodes' throughput is conducted, and the results are presented in Fig. 8.

These results verify the effectiveness of the proposed probability, where the throughput gained from dynamic nodes is much higher than that gained from static nodes materialized by the boxplot minimum, maximum, and median values. The number of packets delivered to BS during the entire lifetime from dynamic nodes ranges from (1-18) packets/round, with a median equal to (8) packets/round. At the same time, (0-7) packets/round, with a median equal to (2) packets/round, are delivered by static nodes.

The results of a comparison between three heterogeneous networks based on LEACH with fixed probability, homogenous probability, and heterogeneous probability are illustrated in Table I. The following conclusions can be reached:

- Heterogeneous probability results in the shortest stability period, since the probability of that dynamic node is increased at the network initiation as its dynamic event.
- Despite the drawbacks in the previous point, heterogeneous probability achieves the longest lifetime, which is attributable to the load between nodes according to the event occurrence and, thus, the load from the nodes out of event coverage.
- Although the fixed and homogeneous probability outperform heterogeneous probability in terms of throughput per epoch, approximately 50% of these data are considered redundant information, since they are sent from static nodes' monotonous and slow events.

VI. CONCLUSION

In this paper, an adaptive probability for CH selection is proposed. The probability is adaptively changed based on the application's environment where the nodes are deployed. In environments with rapid event changing, the probability is increased to maintain the communication between the WSN and the BS, reducing ZHRs and thus increasing the throughput. Conversely, for slow event applications, the nodes enter sleeping modes to extend the lifetime. Two scenarios are assumed to verify the power of the proposed adaptive probability. The first scenario is represented by a homogeneous environment with the fast and dynamic event. In such a case, the simulation results prove that the proposed adaptive probability can reduce ZHRs by 40%, increasing the throughput by 17% during the entire lifetime compared to standard LEACH. The second scenario is materialized by the heterogeneous environment, where the area of interest is composed of both static (slow and monotonous) events and dynamic (fast-changing) events. The simulation results clearly indicate that the proposed adaptive probability off the load from static nodes by the dynamic nodes reduces the redundant data by about 65-70% compared to standard LEACH and homogeneous cases. Moreover, the lifetime is extended by 30% and 67% compared to standard LEACH and homogenous cases, respectively, due to the saving rounds caused by sleeping mode.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contributions

The research was conducted and written by Aseel Hameed and Siraj Qays. Oras Ahmed was rewritten the research. All authors approved the final version.

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