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Performance Evaluation of Clustered Routing Protocols for Heterogeneous Wireless Sensor Networks

Awatef Chniguir, Tarek Farah, Zouhair Ben Jemaa, Safya Belguith

Abstract—Optimal routing allows minimizing energy consumption in wireless sensor networks (WSN). Clustering has proven its effectiveness in organizing WSN by reducing channel contention and packet collision and enhancing network throughput under heavy load. Therefore, nowadays, with the emergence of the Internet of Things, heterogeneity is essential. Stable election protocol (SEP) that has increased the network stability period and lifetime is the first clustering protocol for heterogeneous WSN. SEP and its descendants, namely SEP, Threshold Sensitive SEP (TSEP), Enhanced TSEP (ETSSEP) and Current Energy Allotted TSEP (CEATSEP), were studied. These algorithms' performance was evaluated based on different metrics, especially first node death (FND), to compare their stability. Simulations were conducted on the MATLAB tool considering two scenarios: The first one demonstrates the fraction variation of advanced nodes by setting the number of total nodes. The second considers the interpretation of the number of nodes while keeping the number of advanced nodes permanent. CEATSEP outperforms its antecedents by increasing stability and, at the same time, keeping a low throughput. It also operates very well in a large-scale network. Consequently, CEATSEP has a useful lifespan and energy efficiency compared to the other routing protocol for heterogeneous WSN.

Keywords—Clustering, heterogeneous, stability, scalability, throughput, IoT, WSN.

I. Introduction

CLUSTERING is considered to be the most proven technique for optimum energy consumption in wireless sensor networks (WSN) as remote monitoring of an area using a large number of sensors with irreplaceable batteries poses a severe problem regarding the network's lifetime [1]. Indeed, with its self-organization nature, WSN must counteract the loss of some sensors without harming the proper functioning of the network. Therefore, it is necessary to extend the period of stability of the network to the maximum possible extent [2]. Besides, WSN, as the first brick of the Internet of Things (IoT), must outperform its shortcomings basically in terms of energy efficiency. Nowadays, researchers focus on this paradigm as it allows us to reach even isolated areas of the world and make appropriate changes. Things become smart, and the computation issue is decentralized. When several WSN are connected to the internet, intelligent sensors' optimal energy efficiency is primordial, mainly when they are usually non-homogeneous in either the amount of energy or functional characteristics [3]. These sensors must consume less and less to extend the lifetime of the network and, therefore, the IoT's stability based on WSN [4]. In this context, a stable election protocol (SEP) was developed using the clustering process. It optimally deals with selecting cluster Heads (CH) based on a weighted probability given the heterogeneity of the nodes. Besides, SEP is the first algorithm that introduced heterogeneity by exploiting the node with extra energy to be elected as CH to balance the power consumption between the nodes to the maximum extent possible. The CH is supposed to ensure data collection in its cluster and then the aggregation and transmission to a base station (BS) using a direct link or multi-hop mechanism. This technique proves its energy efficiency compared to the Low-energy adaptive clustering hierarchy (LEACH) [5]. Thus, several researchers have focused on improving SEP. Among the most significant improvements, the addition of a third layer and the upgrading from a two-level hierarchy to the three-level one can be mentioned. The rest of the paper is organized as follows: the related works are outlined in Section II. Section III describes the energy model. Section IV presents some comparative simulation results. The paper ends with a conclusion.

A. Chniguir, T. Farah, Z. B. Jemaa and S. Belguith are with the Department of information technology and complex systems in National Engineering School of Tunis, University of Tunis El Manar, Tunisia (e-mail: awatefch@gmail.com, frhtarek@gmail.com, zouhair.benjemaa@enit.rnu.tn, safya.belghith@enit.utm.tn).

II. Related Works

A wireless sensor network consists of a large group of sensor nodes controlled by a base station. These are divided into smaller groups called clusters. Every cluster is managed by an elected node named cluster head. CH selection is achieved according to some parameters as it has a direct impact on the network lifetime. Several studies focus on this step called the set-up phase in the pioneer algorithm known as LEACH. This algorithm uses the clustering hierarchy to minimize energy consumption. The CH should be reachable at a minimum cost. It implements a mechanism to enhance network functioning and prolong battery life. CH-aggregate data from a member node in the cluster and transmits them to a remote processing element. Aggregation reduces channel contention, packet collision and improves network throughput under high load. Accordingly, CH reduces energy consumption by scheduling activities in the cluster so the sensor node can switch to low power sleep mode when it is not its turn to transmit. As a result, maximizing the lifespan of the network depends mainly on the CH selection. CHs are chosen through an election process using a decision criterion, usually a metric or a combination of metrics. The

CH selection in heterogeneous clustering is the focus of the present work. Various clustering algorithms for homogenous and heterogeneous wireless sensor networks are found in the literature [6], [7]. However, heterogeneity has recently become the most studied type of network because using nodes with extras of energy is inevitable and beneficial for the survival of the whole network. These advanced nodes have more chances to be chosen as CH since their extra energy rate allows them to properly perform the assigned tasks, such as data collection and aggregation. However, heterogeneity is the only way to make WSN an essential layer for IoT. It does not concern only the unequal level of energy. Furthermore, the impact of heterogeneity characteristics on WSN was analyzed in [8]. The authors ensure that energy heterogeneity is a low-cost solution to prolong the network lifetime.

A. Stable Election Protocol

In 2004, Smaragdakis et al. proposed a protocol based on the pioneer LEACH by introducing heterogeneity consisting of an additional amount of energy in some fraction of the sensor nodes deployed in the field. They kept the two phases of the original protocol: set up and steady phase, and only modified the weighting used to calculate the threshold, which decides whether the node can be a CH or not in the first phase. They considered two-level hierarchies presented by two types of nodes known as normal and advanced nodes. The new heterogeneous setting inserts a new parameter called Epoch, which is the number of rounds that guarantees every node's election in the same cluster as CH. This protocol, which is known as Stable Election Protocol [9], uses the node's initial energy to achieve the computation of the weighted probability for each type of node to be elected as CH. As heterogeneous-aware, SEP provides stability for the network as long as possible. Comparative studies prove that the first node death (FND) occurs much later compared to LEACH.

B. Enhanced Stable Election Protocol

In 2011, Femi & Jeremiah made an extension to SEP by introducing other types of nodes with an intermediate amount of energy by building three-tier energy two-level hierarchical network. This new setting has no upshot on the spatial density of the network. The same number of cluster heads is still obtained in SEP and LEACH, although energy dissipation is more restricted. The enhanced SEP (SEP-E) [10] is more vigorous: It extends the stability period, increases network lifetime and makes a better resource sharing than SEP.

C. Threshold-Sensitive Stable Election Protocol

In 2012, Kashaf et al. suggested another improvement to SEP and SEP-E based on the drawback of the increase in throughput, which can cause a decrease in the network lifetime. Threshold Sensitive SEP (TSEP) [11] was proposed to control the tradeoff between energy efficiency and throughput. Indeed, minimizing energy consumption while keeping a low bit rate despite the network's heterogeneous nature presents a real challenge. TSEP is a reactive protocol that responds immediately to changes in relevant parameters. TSEP uses the three-level node energy introduced by E-SEP and adds two new parameters: a soft and a hard threshold (ST and HT) in a steady phase at the transmission. This new addition serves to control transmission to mini- mize it and therefore reduce energy consumption. Thus, TSEP controls the CH selection by weighted probabilities for normal, intermediate and advanced nodes in the set-up phase then controls the transmission rate in the steady phase by authorizing transmission to the base station when the threshold is reached. This restriction of transmission affects the use of TSEP. The authors realize that it is not suitable for applications where data are required uninterruptedly. TSEP does better than its benchmarks in terms of energy efficiency.

D. Zonal-Stable Election Protocol

In 2013, Javaid et al. stated that SEP could do much better if node deployment is uniform and that the criterion of random distribution decreases its efficiency. Thus, they divided the area into three zones: one zone in the middle for the normal node close to the base station. It responds to two main results detected over all the protocols proposed for clustering hierarchy: First, the nearer to the sink, the less energy the node spends. Second, the more energy the node has, the more likely it is to be assigned as CH to collect and aggregate data. Consequently, the other two zones, which are on the edges of the field, are equipped with advanced nodes allowed to be elected as CH. Normal nodes are there only to sense and communicate their data directly using a single hop because it consumes less energy. Zonal-SEP (ZSEP) is a hybrid routing protocol that improves stability and throughput [12].

E. Enhanced Threshold Sensitive Stable Election Protocol

In 2015, Kumar et al. suggested that the three-level hierarchy can be improved if they consider the residual energy of all the nodes in the cluster in the process of CH selection [13].

F. Dual Cluster Head Routing Protocol

In 2017, Istwal and Verma proposed a dual cluster head routing protocol (DCHRP) [14]. This algorithm outperforms its benchmark (TSEP) about twice as it considers the duality in the cluster head for managing the energy of the cluster heads. This new approach applied to a three-tier heterogeneous clustering demonstrated high efficiency. The number of cluster heads is reduced and therefore, the stability period increases three times compared with SEP. The residual energy and maximum probability from advanced nodes are factors used to select the first CH. The second one is elected from the remaining nodes in the same round and is called SubCH (SCH).

G. Current Energy Allotted Threshold Stable Election Protocol

In 2018, the current energy allotted TSEP (CEATSEP), which uses the current energy allocated to the nodes, was

TABLE I
SEP AND ITS DESCENDANTS

Protocol	Node deployment	Heterogeneity level	Metrics	Benchmark	Year
SEP	Random	2 level	IE	SEP	2004
SEP-E	Random	3 level	IE	SEP	2011
TSEP	Random	3 level	IE	SEP-E	2012
ZSEP	Uniform	3 level	IE	SEP-E	2013
ETSEP	Random	3 level	IE	TSEP	2015
DCHR	Random	3 level	RE	ETSEP	2017
CEATSEP	Random	3 level	CE	TSEP	2018

proposed by Kaur, Sharma and Singh [15]. They perform the best result by including the current energy of each type of node in the threshold that delimits the CH's election. Table I summarizes the studied algorithms.

III. THE ENERGY MODEL AND HETEROGENEITY

The radio dissipations energy model considered in WSN comprises two units: one for transmission and another for reception [7]. Thus, a sensor spends an amount of energy when it transmits data. The energy dissipated for sending L bit message by the radio transmission depends on the distance (d) between transmitter and receiver is presented by (E_{TX}) as mentioned in (1):

$$E_{Tx} = \begin{cases} L * E_{elec} + L * \epsilon_{fs} * d^2, & d \leq d_0 \\ L * E_{elec} + L * \epsilon_{fs} * d^4, & d > d_0 \end{cases} \quad (1)$$

ϵ_{fs} and ϵ_{amp} depend on the transmit amplifier model used []. The energy dissipated per bit to run the transmitter or the receiver circuit is E_{elec}, d_0 is the threshold distance which is computed with (2):

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{amp}}} \quad (2)$$

In the clustering protocol, a sensor can be a CH or not. Therefore, (3) and (4) compute the energy dissipated by respectively a CH (E_{dch}) and a non-CH node (E_{dnonch}).

$$E_{dch} = (\frac{n}{k} - 1).E_{elec} + \frac{n}{k} L.E_{DA} + L.E_{TX} \quad (3)$$

$$E_{dnonch} = L.E_{TX} \quad (4)$$

The total energy consumed (E_{dTOT}) in one cluster will be the sum of both dissipated energies, as mentioned in (5):

$$E_{dTOT} = E_{dch} + \frac{n}{k_{opt} E_{dnonch}} \quad (5)$$

The energy dissipated at every round [13] is described by (6):

$$E_{round} = L.\left(2.n.E_{elec} + n.E_{DA} + \epsilon_{opt}.\epsilon_{amp}.d^4_{toBS} + n.\epsilon_{fs}.d^2_{toCH}\right) \quad (6)$$

Let us first define these parameters:

- P_{opt} = kopt/n: optimal percentage of the CHs,
- K_{opt}: optimal number of construction of clusters,

TABLE II
SIMULATIONS AND PARAMETERS

Parameters	Values
E_{ELEC}	$50nJ/bit$
E_{DA}	$5nJ/bit/message$
ξ_{fc}	$50pJ/bit/m4$
ξ_{amp}	$0.0013pJ/bit/m4$
E_0	$0.6J$
Packet	4000
μ	$\frac{\alpha}{2}$
m	0.1
b	0.2

TABLE III
PROBABILITY TO BE ELECTED AS CH

Nb of hierarchies	Epoch	Normal nodes	Intermediate nodes	Advance nodes
2 levels	$\frac{1}{p_{opt}(1+\alpha m)}$	once	-	$1+\alpha$
3 levels	$\frac{1}{p_{opt}(1+\alpha m+b\mu)}$	once	$1+\mu$	$1+\alpha$

- α: additional energy factor in the advanced nodes,
- μ: additional energy factor in intermediate nodes,
- m: fraction of the nodes selected as advanced nodes,
- b: fraction of the nodes selected as intermediate nodes,

Then consider

- Energy for normal nodes E_0,
- Energy for advanced nodes $E_{adv} = E_0.(1+\alpha)$,
- Energy for intermediate nodes $E_{int} = (1+\mu)$, where $\mu = \frac{\alpha}{2}$.
- Total Energy $E_T = n.E_0(1 + m.\alpha + b.\mu)$

Accordingly, residual energy depends on the base station's distance (BS), but P_{opt} does not depend on the field dimensions.

IV. SIMULATIONS AND ANALYSIS

At first, we define the network model used in all studied protocols as:

- The base station is in the center of the field
- BS is static and not energy limited
- Nodes are not mobile
- Nodes are uniformly distributed
- 10 percent of sensors are advanced nodes
- 20 percent of sensors are intermediate nodes
- One cluster head is elected per cluster.

Table II summarizes the Energy Model parameters used during the simulations.

1) Heterogeneity Scheme: SEP introduces a new parameter called Epoch that guarantees stability in the network. Epoch is defined as the number of rounds equal to $\frac{1}{p_{opt}}$ for each node that will be CH for at least once (TableIII).

In a heterogeneous network, the CH is elected with a weighted probability specific to each type of node. Thus, the node that reaches the threshold can be elected as CH. However, every node belonging to a specific type must refer to its threshold estimated by its level of energy thus allowing

TABLE IV
TWO LEVEL HETEROGENEITY SCHEME

Nodes	Probability $p_i =$	Threshold $T(s_i) =$
Normal	$\frac{p_{opt}}{(1+\alpha m)}$	$\begin{cases} \frac{p_{nmr}}{1-p_{nmr}\left(r mod \frac{1}{p_{nmr}}\right)} & if s_{nmr} \in G' \\ 0 & otherwise \end{cases}$
advanced	$\frac{p_{opt}(1+\mu)}{(1+\alpha m)}$	$\begin{cases} \frac{p_{adv}}{1-p_{adv}\left(r mod \frac{1}{p_{adv}}\right)} & if s_{adv} \in G' \\ 0 & otherwise \end{cases}$

TABLE V
THREE LEVEL HETEROGENEITY SCHEME

Nodes	Probability $p_i =$	Threshold $T(s_i) =$
Normal	$\frac{p_{opt}}{(1+\alpha m)}$	$\begin{cases} \frac{p_{nmr}}{1-p_{nmr}\left(r mod \frac{1}{p_{nmr}}\right)} & if s_{nmr} \in G' \\ 0 & otherwise \end{cases}$
Intermediate	$\frac{p_{opt}(1+\mu)}{(1+\alpha m)}$	$\begin{cases} \frac{p_{int}}{1-p_{int}\left(r mod \frac{1}{p_{int}}\right)} & if s_{int} \in G' \\ 0 & otherwise \end{cases}$
Advanced	$\frac{p_{opt}(1+\mu)}{(1+\alpha m)}$	$\begin{cases} \frac{p_{adv}}{1-p_{adv}\left(r mod \frac{1}{p_{adv}}\right)} & if s_{adv} \in G' \\ 0 & otherwise \end{cases}$

advanced nodes and then intermediate nodes to be elected most times as shown in Tables IV andV where i refers respectively to nmr, int and adv for normal, intermediate and advanced nodes.

*2) **1st Scenario: Fixed Number of Nodes and Variable Additional Energy Parameter** α:* Performance evaluation of clustered routing protocols depends on the relationship between the size of the network, both small or large scale and the percentage of the number of advanced nodes calculated by the parameter α. In order to outline the effect of the additional energy parameter on the lifetime of sensors, a comparison of the number of dead nodes with a different value of parameter α is conducted (Fig. 1). The total number of sensors is fixed to 100. As a result, the optimal number of constructions of CH in one cluster is k_{opt}=10 and p_{opt}=0.1. Therefore, the additional energy factor between advanced and normal nodes (α) is variable. First, 10% of the populations are considered as advanced nodes as α =1. Then, the number in order to evaluate the behavior of the sensors is incremented. Assuming that CH will be elected from advanced nodes which will conserve energy in most sensors and maximize the the network's lifetime.

The obtained results show the effectiveness of our method. The stability period (SP), known as the networks period of the process until the death of FND, is much longer when α is incremented. Hence the importance of prolonging this period as much as possible. The process of CH selection is performed with a weighted probability that depends on the whole number of sensors. When sensors start to be off, this probability will not be true. These algorithms do not reflect the realistic behavior over the stability period. Then, SP and FND must be considered as effective parameters. Moreover, it can be concluded that three-tier-hierarchy heterogeneity increases the network's lifetime when we compare the SP of our benchmark

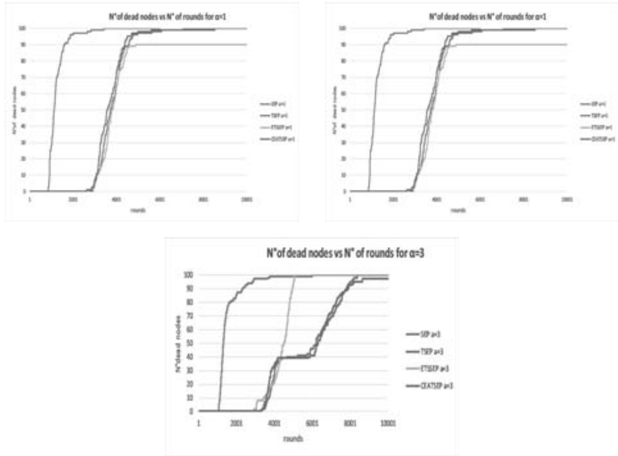

Fig. 1 Number of Dead Nodes for $alpha$=1(a), $alpha$=2(b) et $alpha$=3(c)

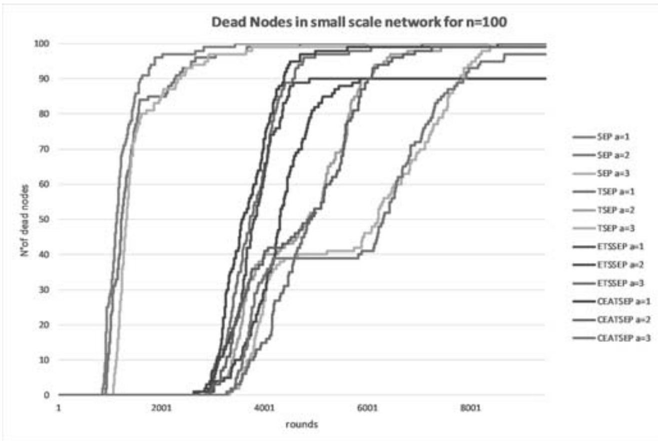

Fig. 2 Stability Period in a small scale network (n = 100)

SEP and that of TSEP. A complete view of SEP and its descendants in terms of Dead Nodes for different heterogeneity values is presented in Fig. 2. Therefore, CEATSEP with the additional factor of current energy multiplied by each type of node's threshold outperforms the behavior of its antecedent TSEP. Furthermore, the number of packets sent to the base station known as throughput is much better. Sensors must send data using a low rate so that less energy is consumed in the transmission, which maximizes the network's lifetime. As can be seen in Fig. 3, CEATSEP improves the behavior of TSEP and corrects. In this scenario, the variation of α increases the stability period, as illustrated in Fig. 4.

*3) **2nd Scenario: Variable Number of Nodes and Fixed Additional Energy Parameter** α:* The first scenario shows that for α = 3, the best results in terms of SP are reached. Then, the additional energy parameter is set, and the number of nodes is incremented to be applied in a large-scale network. SEP is scalable as it does not need any knowledge of the position of each node in the network [7].

The second scenario's main objective is to deal with scalability as the number of sensors in the same field is increased. Then, the optimal number of CH constructions as it depends on the number of nodes becomes k_{opt} = 33. The

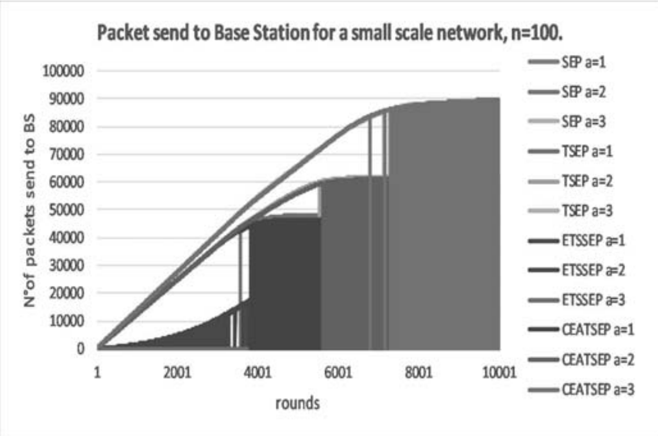

Fig. 3 Throughput for small scale Network

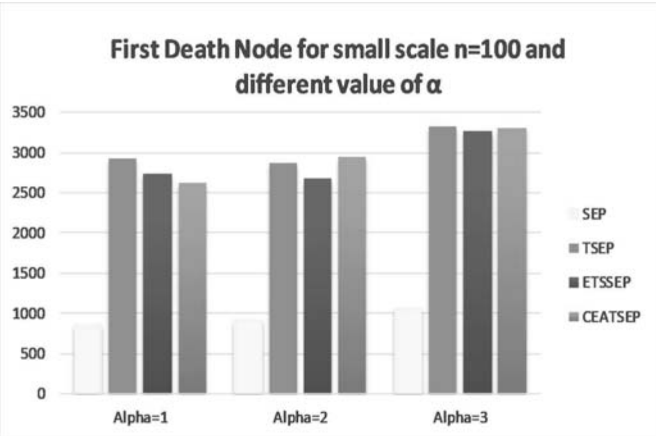

Fig. 4 The First Node Death for different values of α and n = 100

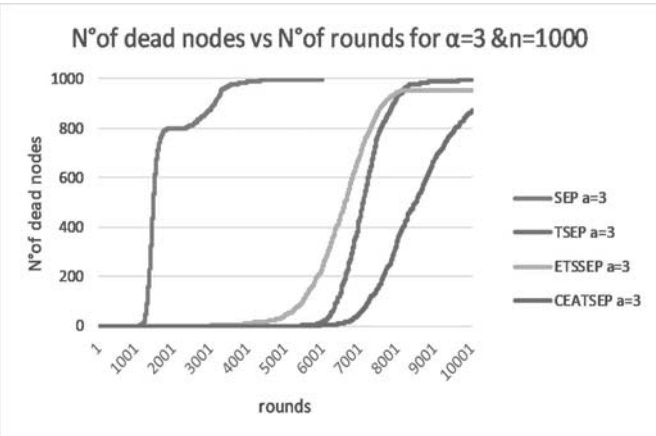

Fig. 5 Number of Dead Nodes for large scale Network

percentage of CH increases (P_{opt} = 0.03 for n = 1000). Fig. 5 shows the number of Dead Nodes for α=3 in the case of a large-scale network. We take as example n equals 1000.

As mentioned above, FND delimits the Stability Period. Here, in the second scenario, the second scenario aims at dealing with the effect of the incremented number of nodes on SP. Basically, at each round, the rate of dissipation energy

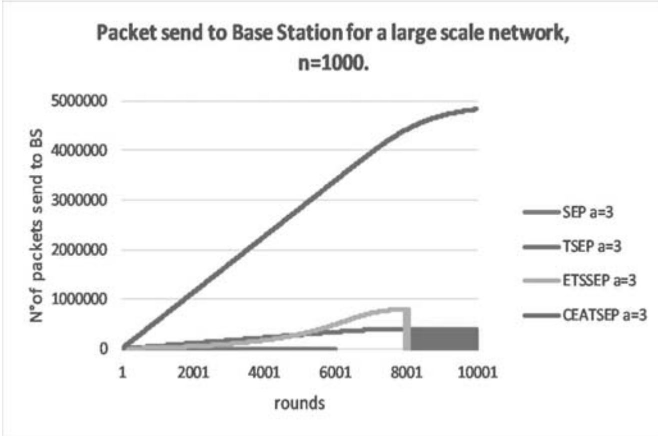

Fig. 6 First Death Node in a small scale network (n = 100)

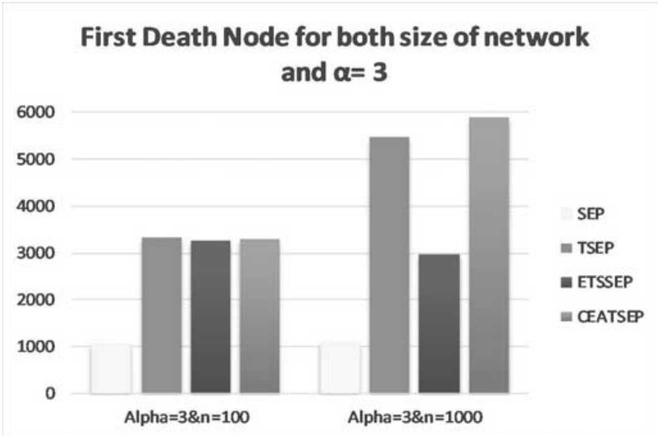

Fig. 7 First Death Node in a large scale network (n = 1000)

is computed considering the energy used in the aggregation phase for each kind of node. Then, the current energy is the remainder from the total energy and the dissipated energy. However, the residual energy is used in Enhanced TSEP as a parameter. To increase the lifetime, upgraded SEP protocols append two new parameters to the threshold probability affected to every level of heterogeneity [12], [14]. This modification aims to balance the consumption of nodes well. Advanced nodes are elected more often than intermediate and normal nodes, as CH consumes more energy. The process of the selection of CH depends on the residual energy in ETSSEP and the current energy of every type of node in its successor CEATSEP [14]. Simulations achieve adequate performance, the deployment of three-level heterogeneity fulfills objectives by increasing the longevity and throughput (Fig. 6). Hence, this work focuses on the consequence of the variation of the heterogeneity factor. Increasing has a beneficial impact on the lifetime of the WSN. The performance comparison of the studied clustered heterogeneous protocols is presented in Fig. 4 and Fig.7 if we consider the Stability Period as a decision metric.

V. Conclusion

Three clustering protocols, namely TSEP, ETSEP, CEATSEP, and their benchmark SEP were implemented and simulated considering two scenarios. The first one was for detecting the best heterogeneity scheme and the second to deal with scalability. After analyzing the results, it can be concluded that using current energy as a factor to the threshold of a three-tier heterogeneity scheme positively impacts energy efficiency. From the multiple runs with different parameters of heterogeneity, it can be proven that CEATSEP increases the period of stability as the first node death delimits it. Furthermore, in large-scale networks, we observe that the death of the first node occurs much later. As heterogeneous-aware, SEP's enhanced version provides stability essentially for a dense network.

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