Performance Evaluation of a Zone-based Three-level Heterogeneous Clustering Protocol for WSNs

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Abstract — This paper proposes a zone-based three-level heterogeneous clustering protocol (ZB-TLHCP) for heterogeneous WSNs. In ZB-TLHCP, the sensor field/region is divided into zones where super, advance, and normal nodes are deployed uniformly and randomly. The performance of the proposed ZB-TLHCP system is compared with that of zonal-stable election protocol (Z-SEP), distributed energy efficient clustering (DEEC), and threshold-based DEEC (TDEEC) protocol by varying the number of super and advance nodes, their energy levels for the fixed sensor field, and the total number of nodes. Matlab simulation results revealed that the proposed ZB-TLHCP solution performed better than Z-SEP, DEEC, and TDEEC protocols, as it increased the instability period, prolonged the network's lifetime, and achieved higher throughput values.

Keywords — clustering, heterogeneous, network lifetime, stability period, zone-based WSN

1. Introduction

Wireless sensor networks (WSNs) comprise numerous self-governing, low-energy, lightweight, densely deployed sensor nodes communicating via the wireless medium [1]. WSNs are widely used in the military, various industries, in environment protection schemes, in multimedia, as well as in underwater, home control/automation, forest fire detection, transportation, logistics, monitoring, parking slot management, biomedical, health and other settings [2], [3]. Due to the dense deployment of sensor nodes, WSNs provide more information and collect data to the mutual collaboration of nodes, thus ensuring more accurate and comprehensive results. The field deployment of sensor nodes defines the communication architecture of sensor networks [4]. These nodes collect information from the physical medium and transmit it to the base station (BS) in multi-hop or single-hop transmission processes. Sensor node architecture [4] consists of four modules: a power unit, a processing unit, a transceiver unit, and a sensing unit, as shown in Fig. 1. The sensing unit comprises an analog-to-digital converter (ADC) and a MEMS sensor. Sensors sense data in the analog form, and ADC converts it into digital data for further processing. The processing unit consists of a storage block and a computational unit, processing the digital data received from the sensor and store it based on the requirements of a specific application. The transceiver unit either transmits or receives the data through the communication medium. The power unit supplies energy to all the modules. Along with these four modules, there is a GPS-based location-finding system and a mobilizer for establishing mobile communications.

Sensor nodes within the network are deployed in harsh environments, where battery replacement is expensive and human entry is discouraged [4]. This makes the sensor nodes power-constrained, emphasizing the need for efficient energy utilization. The BS is assumed to have a sufficient power supply in any wireless sensor network communication architectures. The clustering technique is an effective solution to reduce the sensor node's energy consumption in WSNs [5] (Fig. 2). The nodes are organized into clusters and each cluster chooses one node to serve as its cluster head (CH). Within the specified TDMA schedule, CH gathers data from cluster nodes. After performing data aggregation and integration, the information is transferred, in a single-hop or with the use of multi-hop communication, to the BS. At the BS, this data is uploaded to the Internet, making it accessible to end-user [5]. The remaining sections are structured as follows. Section 2 discusses related research work concerned with the proposed protocol. Section 3 discusses the implementation steps. Simu-

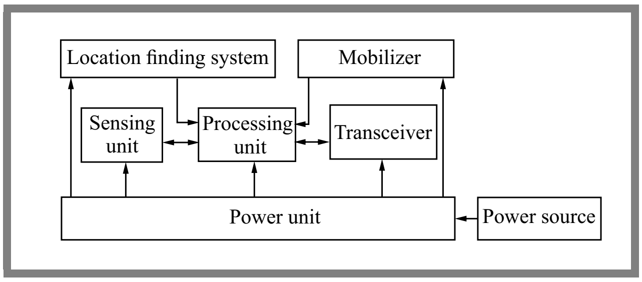

Fig. 1. Sensor node architecture.

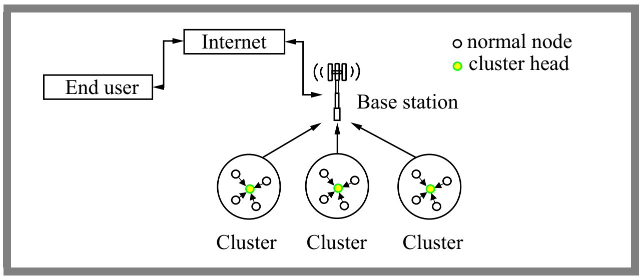

Fig. 2. Clustering architecture in WSN.

lation results and related discussions are presented in Section 4. In Section 5, a conclusion based on the findings and outcomes of the proposed protocol is presented, along with the suggested direction of future research.

2. Related Work

Homogeneous and heterogeneous clustering networks are the two main types of WSNs that need to be taken into account when considering the amount of energy used. All sensor nodes deployed within a homogeneous clustering network have the same level of energy, while nodes in a heterogeneous clustering network are deployed with different energy levels.

2.1. Homogeneous Clustering Protocols

A low energy adaptive clustering hierarchy (LEACH) protocol was developed by Heinzelman *et al.* [6] for homogeneous WSNs. LEACH is considered a benchmark for the various clustering algorithms in WSNs. In this protocol, each node behaves, at least once, as a CH. Data transfer from nodes to the BS is divided into two phases: the setup phase and the steady phase. During the setup phase, sensor nodes are grouped into a cluster by choosing one node to serve as their CH. Each node randomly selects a number between 0 and 1 and compares it with the threshold value. If the chosen number is below the threshold, the node acts as the CH. In the steady state, the CH gathers information from cluster nodes, performs data aggregation and fusion, and transmits it to the BS. In terms of functionality, LEACH increases stability period and network lifetime by distributing energy load among all sensor nodes, unlike in conventional protocols.

Farman *et al.* in [7] presented an improved grid-based hybrid network deployment (IGHND) approach for grid-based WSNs. In IGHND, data transfer from nodes to the BS is achieved by selecting a zone head (ZH) and by developing topology phases. During the topology development phase, if the number of nodes in a zone falls below the lower threshold, then the nodes in that zone will be combined with those in an adjacent zone, based on density and distance. A zone will be divided into sub-zones if the node count rises above the upper threshold. In the ZH selection phase, distance from the zone's center point, distance from neighboring nodes inside the zone, residual energy of a node, number of times a node has undergone ZH, and whether a node is merged parameters, are considered for ZH selection. Using this scheme, the IGHND prolongs network lifespan and increases network stability in IoT-based WSNs.

Singh *et al.* [8] proposed the LEACH – uniform size clusters (LEACH-USC) protocol, being an improved version of the balanced cluster size Formation (BCF) protocol. The BCF protocol achieves balanced cluster size formation in two phases: the initial cluster formation phase and the rescue phase. In this method, the CH selects and forms balanced clusters in the initial cluster formation phase. In the rescue phase, nodes not clustered join nearby clusters as normal nodes. Instead of a rescue phase, the LEACH-USC protocol uses a cluster refurbishment phase as the second phase, in which excess nodes from large clusters are joined with other clusters as the second-best choice of the CH.

Kumar *et al.* [9] introduced a divide and rule sectorization (DRS) scheme for homogeneous WSNs to reduce the energy-hole creation problem. The DRS scheme divides the sensor field into sectors and inner circle regions. These sectors, in turn, are divided into segments and nodes are deployed in these segments uniformly. The three-tier communication model transfers data from the node to the BS by dynamically selecting forward nodes. The DRS scheme increases the network's lifetime by reducing the amount of energy consumed by nodes and provides better stability than existing protocols.

2.2. Heterogeneous Clustering Protocols

In paper [10], Verma *et al.* presented a new cost and sub-epoch-based stable energy-efficient clustering (CSSEEC) protocol for heterogeneous WSNs. The CSSEEC protocol uses a cost function to reduce the energy consumption of sensor nodes and a modified sub-epoch to balance energy among the nodes. The CSSEEC protocol ensures better network lifetime, network throughput, and stability period than existing protocols. Rawat *et al.* [11] proposed an energy-efficient heterogeneous clustering protocol, a two-level network model consisting of normal and power nodes. To select the appropriate CH, the residual energy of the node, total network energy and initial node energy are introduced into the threshold equation. The model reduces the amount of energy consumed by the nodes, prolongs network lifetime, and increases network throughput in comparison with existing protocols.

In [12], Faisal *et al.* described the Z-SEP protocol, a variation of the SEP protocol based on zones. SEP is a two-level heterogeneous clustering protocol comprising advance and normal nodes. Advance nodes are equipped with extra energy levels compared with normal nodes. In Z-SEP, the sensor field is divided into zone 0 and two head zones. Normal nodes are deployed only at zone 0 and send he sensed data directly to the BS, while advance nodes are deployed in both head zone 1 and head zone 2, uniformly and randomly. These data is sent to the BS using the CH. Z-SEP offers a longer network life and a longer stability period compared with existing protocols. Khan *et al.* [13] proposed the advanced Z-SEP (AZ-SEP) protocol, an enhancement of Z-SEP. In the AZ-SEP protocol, zone 0 nodes send data to the BS in a single-hop, while nodes in head zone 1 and head zone 2 transfer data to the BS in a multi-hop transmission. CHs in head zone 1 or head zone 2 transfer data to the nearby CH in head zone 1 or head zone 2, respectively. The AZ-SEP protocol optimizes average energy consumption and increases the stability period and network throughput compared to existing protocols.

Rowayda *et al.* [14] introduced the hybrid IoT (Hy-IoT) protocol for IoT applications, where the sensor field is divided into two regions: superior and regular. The superior region consists of higher energy nodes, while the regular region consists mainly of normal nodes and includes a minority of higher energy nodes. The superior region uses the LEACH protocol for CH selection, while the regular region uses the SEP protocol. The Hy-IoT protocol prolongs the network lifetime and increases its throughput and instability period compared with existing protocols.

A two-level heterogeneous clustering protocol in which the sensor field is divided into two regions is proposed by Abidi *et al.* in [15]. Normal nodes are deployed in region 1, near the BS, and advance nodes are deployed in region 2, far from the BS. Nodes in region 1 do not participate in the CH selection process, and directly send information directly to the BS. Nodes in region 2 participate in CH selection and send information to the BS through selected CHs. The proposed protocol gives a better network lifetime, stability period, and network throughput compared with the Z-SEP protocol.

Chithra *et al.* [16] researched an energy-efficient concentric circular clustering protocol (EECCCP). Three concentric circular zones make up the sensor field in EECCCP. The nodes are deployed in three zones: normal, advance and super. Nodes in normal and super zones submit data directly to the BS, while nodes in advance zone sent data to the BS using the clustering technique. The proposed protocol increases network lifetime and throughput compared with existing protocols. Tyagi *et al.* [17] introduced a lifetime extended multi-level heterogeneous routing (LE-MHR) protocol with k-levels horizontal heterogeneity. In LE-MHR, data transmission is divided into two stages: cluster formation and data transmission stage. These are similar to the setup and steady phases of the LEACH protocol. The authors presented four theorems for implementing the LE-MHR protocol. Several advanced nodes were implemented at each level of the network's hierarchy. The proposed protocol was simulated by varying energy heterogeneity parameters and initial energy values. The results reveal that LE-MHR enhances stability period, network lifetime, and ensures better distribution of cluster heads compared with existing protocols.

Alsafi *et al.* [18] and Qureshi *et al.* [19] presented a comparative performance analysis of distributed energy efficient clustering (DEEC), Developed DEEC (DDEEC), extended DEEC (EDEEC), and threshold-based DEEC (TDEEC) protocols. All these protocols follow a similar pattern in transferring data. If the nodes are close to the BS, relative to the nearby CH, the data is transferred directly to the BS. Otherwise, nodes clustered near the CH transfer data to their respective CH. The

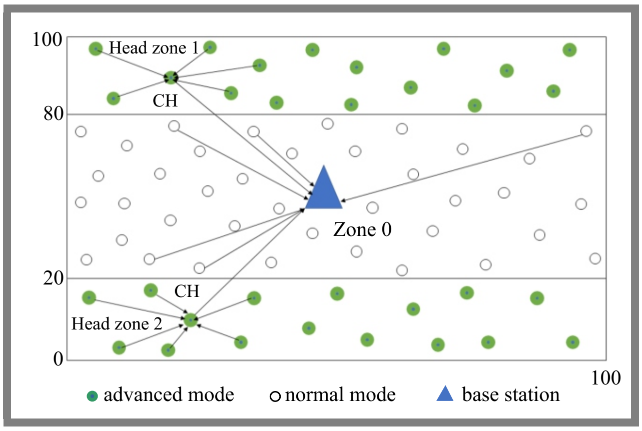

Fig. 3. Z-SEP network communication model.

DEEC and DDEEC protocols are designed for multi-level networks. In the DEEC protocol, advance nodes continue to punish energy consumption even after their energy level becomes low, compared with the normal node. EDEEC and TDEEC are designed for three-level networks comprising normal, advance, and super nodes. By incorporating residual and average energy levels in the current round into the threshold value equation, the performance of the EDEEC protocol was improved. TDEEC outperforms all other protocols in terms of network throughput, lifetime, and stability period.

3. Proposed Heterogeneous Clustering Protocol

TDEEC is a three-level heterogeneous clustering protocol consisting of normal, advance, and super nodes. These nodes are placed randomly in the sensor field. In the Z-SEP protocol, the sensor field is split into three regions, zone 0, head zone 1, and head zone 2, as depicted in Fig. 3. Only zone 0 has normal nodes deployed which communicate directly with the BS. Advance nodes are randomly and uniformly distributed in head zones 1 and 2, and these transfer data to the BS through the elected CH in either head zone 1 or head zone 2. From Fig. 3, the following conclusions can be drawn:

- Normal nodes in zone 0, close to the CH in head zone 1 or head zone 2, but far from the BS, only send data to the BS. As a result, normal nodes far from the BS consume more energy and perish quickly;
- Advance nodes are deployed only in the lower and upper parts of the sensor field, so normal nodes in the left- and right-hand parts dissipate more energy than those in the lower and upper parts of the sensor field.

Considering the problem formulated above, the following approach has been implemented to increase the network's lifespan and reduce node energy consumption:

- Instead of two-level networks, three-level networks are used for a longer network lifetime;
- Making normal nodes in zone 0 participate in cluster formation by considering nodes that are closer to the CH than the BS, only clustered into respective CH cluster formation;
- Making zones on each side of the sensor field and deploying high-energy nodes in the corners of the sensor field instead of the sides of the sensor field helps balance energy consumption.

By putting all these solutions together, we proposed a new zone-based three level heterogeneous clustering protocol (ZB-TLHCP) for energy optimization in WSNs.

3.1. Network Model

As shown in Fig. 4, the sensor field is split into nine zones, based on the distance from the BS. We assume that n_zone will end at d_0 distance from the BS. All normal nodes are deployed in n_zone only, all advance nodes are deployed uniformly in a_zone 1 ... 4 and super nodes are deployed

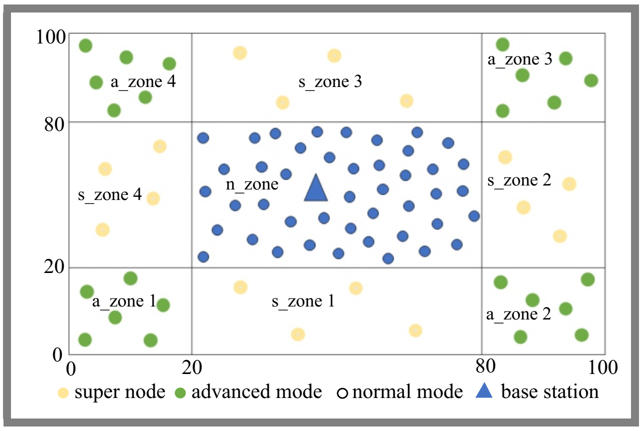

Fig. 4. ZB-TLHCP network model.

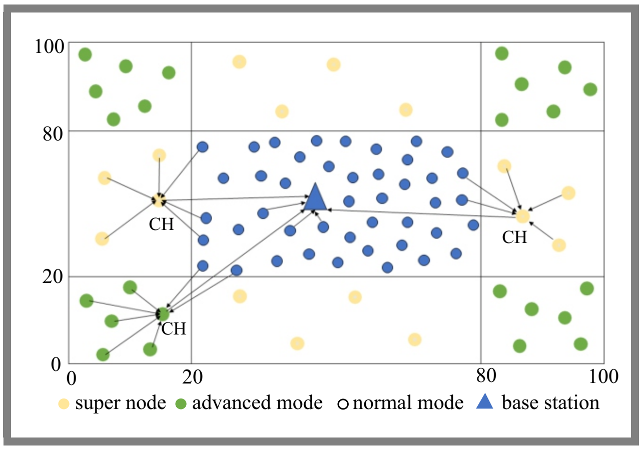

Fig. 5. ZB-TLHCP communication network model.

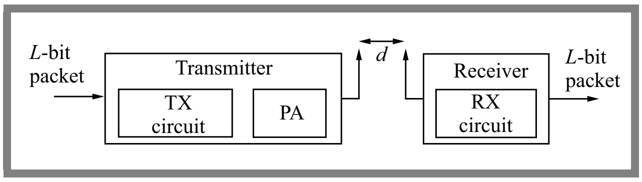

Fig. 6. The radio energy model for WSN.

uniformly in s_zone 1 ... 4. Nodes from n_zone will not participate in the CH selection phase. In the cluster formation phase, all nodes in n_zone calculate the distance from CHs and the BS. If the node is close to the BS, data packets are sent directly to the BS. Otherwise, the nodes join the nearby cluster's CH. Nodes not located in n_zone and not selected as CH join the nearby CH, as shown in Fig. 5.

3.2. Radio Energy Model

During data transmission, the sensor node consumes energy [19]–[21], as shown in Fig. 6. The energy required by a sensor node to send an L-bit message over distance d is:

$$E_{TX} = \begin{cases} L \times E_{elec} + L \times \varepsilon_{mp} \times d^4, & d \geqslant d_0 \\ L \times E_{elec} + L \times \varepsilon_{fs} \times d^2, & d < d_0 \end{cases}, \tag{1}$$

where E_{TX} is the energy consumed by the transmitter, E_{elec} is energy consumed during the transmission by the companion device, ε_{mp}, ε_{fs} are multipath and free space amplification factors, respectively, and $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$ is the threshold distance.

The energy needed by a sensor node to receive an L-bit message is:

$$E_{RX} = L \times E_{elec} \,, \tag{2}$$

where E_{elec} is receiver circuit energy consumption.

The amount of energy left after either transmission or reception of the L-bit message is called residual energy E_R and is given by:

$$E_R = E_{TOTAL} - (E_{TX} + E_{RX}) \,. \tag{3}$$

In the proposed protocol, regular nodes have an energy level of E_0, while advance nodes have an additional energy level of a. Super nodes are equipped with an extra energy level of b, such that $a < b$. The total initial energy of the network is:

$$\begin{aligned} E_{TOTAL} &= N(1-m)E_0 + N\,m(1-m_0) \\ &\times (1+a)E_0 + N\,m\,m_0(1+b)E_0 \end{aligned}, \tag{4}$$

where N is the total number of nodes, m_0 is the share of super nodes and m is the share of advance nodes. After CH selection and cluster formation, all nodes send data packets are sent to the BS as one round.

The energy consumption in one round is:

$$\begin{aligned} E_{Round} &= 2L\,N\,E_{elec} + N\,E_{DA} + k\,\varepsilon_{mp} \\ &\times d_{toBS}^4 + N\,\varepsilon_{fs}\,d_{toCH}^2 \end{aligned}, \tag{5}$$

where E_{DA} denotes the data aggregation energy, k is the number of clusters in the current round, d_{toCH} is the distance between cluster member nodes and the CH, and d_{toBS} is the distance between the nodes and the BS, such that:

$$\begin{gathered} d_{toCH} = 0.765\,\frac{M}{2} \,, \\ d_{toBS} = \frac{M}{\sqrt{2\pi k}} \,, \\ K_{opt} = \sqrt{\frac{N}{2\pi}} \cdot \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \cdot \frac{M}{{d_{toBS}}^2} \,. \end{gathered} \tag{6}$$

In Eq. (6), M denotes the sensor field size, K_{opt} is an optimum number of clusters for efficient energy consumption ($k = K_{opt}$). The total maximum rounds for WSNs can be estimated using Eqs. (4) and (5):

$$R = \frac{E_{TOTAL}}{E_{Round}} \,. \tag{7}$$

In order to identify which CH is best in a given round of iteration, the probability of threshold $T(S_i)$ is introduced. If the probability threshold $T(S_i)$ is exceeded, the node is chosen as the CH for that round.

$$T(S_i) = \begin{cases} \frac{P_i}{1-P_i(r\%\frac{1}{P_i})} \cdot \frac{E_{i(r)}}{E(r)}, & S_i \in G \\ 0, & \text{otherwise} \end{cases}, \tag{8}$$

where r is the current round, P_i is the probability used for CH selection and G is the collection of nodes that have not been chosen as CHs in previous $1/P_i$ rounds.

$$P_i = \begin{cases} \frac{P_{opt} \cdot E_i(r)}{1+m(a+m_0 b).\bar{E}r}, & S_i \in \text{normal node} \\ \frac{P_{opt} \cdot (1+a)E_i(r)}{1+m(a+m_0 b).\bar{E}r}, & S_i \in \text{advance node} \\ \frac{P_{opt} \cdot (1+b)E_i(r)}{1+m(a+m_0 b).\bar{E}r}, & S_i \in \text{super node} \end{cases}. \tag{9}$$

In Eq. (9), $E_{i(r)}$ is residual energy, P_{opt} is the reference value of the average probability of P_i, $E\bar{(}r)$ stands for the estimated energy that acts as standard reference energy for each node and is equal to:

$$\bar{E}(r) = \frac{1}{N} E_{TOTAL}\left(1 - \frac{r}{R}\right). \tag{10}$$

The algorithm for the proposed ZB-TLHCP protocol is given as Algorithm 1.

Algorithm 1. Pseudo code of the proposed ZB-TLHCP protocol

Initialize sensor network parameters
Initialize population and energy for each sensor node
Sensor nodes deployment
for $r = 0$ to maximum rounds **do**
  Check nodes' eligibility to become CH using mod$(r, round\,\frac{1}{P}) == 0$
  Calculate average energy $\bar{E}(r)$ of network in current round using Eq. (10)
  Check status of each node alive or dead.
  for $i = 1$ to N **do**
    if $\bar{E}(r)$ **then**
      Allot P_i respectively using Eq. (9)
    if $E_R > 0$ **then**
      $temp_{rand}$ → node assume some random value between 0 to 1
      if node not in n_zone & $temp_{rand} \leqslant T(S_i)$ **then**
        N node considered as CH
      end if
    end if
    end if
  end for
  for $i = 1$ to N **do**
    if $E_R > 0$ **then**
      if node in n_zone **then**
      Node check distance from BS and CH
      if node near to BS **then**
        Data directly sent to BS
      else node is clustered to near CH and sends data to that respective CH
      end if
      if node not in n_zone & not selected as CH **then**
        Node is clustered to near CH and sends data to that respective CH
      end if
      end if
    end if
  end for
end for

4. Results and Discussion

We simulated our model by considering the parameters given in Tab. 1. Four performance parameters are considered:

Tab. 1. Parameters used for simulation.

Parameters	Notation	Value
Number of nodes	N	100
Transmit or receive energy	E_{elec}	50 nJ/bit
Initial energy	E_0	0.5 J
Data aggregation energy	E_{DA}	5 nJ/bit/message
Multipath loss constant	ε_{mp}	0.0013 pJ/bit/m^4
Free space loss constant	ε_{fs}	10 pJ/bit/m^2
Data packet size	L	4000 bits
Network size	M	100×100 m^2
Probability	P_{opt}	0.1
Maximum rounds	R	100,000

– **Stability period** – Time from when networks become active to when the first node runs out of energy,
– **Instability period** – Time from the first node dying to the last node running out of energy, or the entire network collapsing,
– **Network lifetime** – Time from when a network becomes active until the final node runs out of energy or the entire network collapses,
– **Throughput** – The overall network data transmission rate. The rate of data transmission from nodes to the BS as well as from CHs to the BS.

By altering the number of advance nodes and super nodes, as well as their energy levels for given N and m value, we could examine overall performance.
The proposed model is simulated for the following four cases:
– Case 1: $m = 0.3, m_0 = 0.2, a = 1.2, b = 2$,
– Case 2: $m = 0.4, m_0 = 0.3, a = 1.3, b = 2.5$,
– Case 3: $m = 0.5, m_0 = 0.4, a = 1.5, b = 3$,
– Case 4: $m = 0.6, m_0 = 0.5, a = 1.6, b = 3.2$.

We simulated the model ten times, and then averaged the results.

4.1. Matlab Simulation Results

In case 1, DEEC, Z-SEP, TDEEC [18], and ZB-TLHCP comprise 70 normal nodes, each with an energy level of E_0. In the DEEC protocol, 30 advanced nodes are considered, each with the energy level of $(1 + rand \times 1.2) \times E_0$. In Z-SEP, 30 advance nodes have an energy level of $2.2E_0$. In TDEEC and ZB-TLHCP, 24 advance nodes are simulated, each with the energy level of $2.2E_0$ and six super nodes, each with the energy level of $3E_0$.
According to Fig. 7a, the longest stability period of the network (in descending order) is achieved by: Z-SEP, ZB-TLHCP, DEEC, and TDEEC. The order for the network lifetime is: ZB-TLHCP, TDEEC, Z-SEP, and DEEC (Fig. 7b). From Fig.

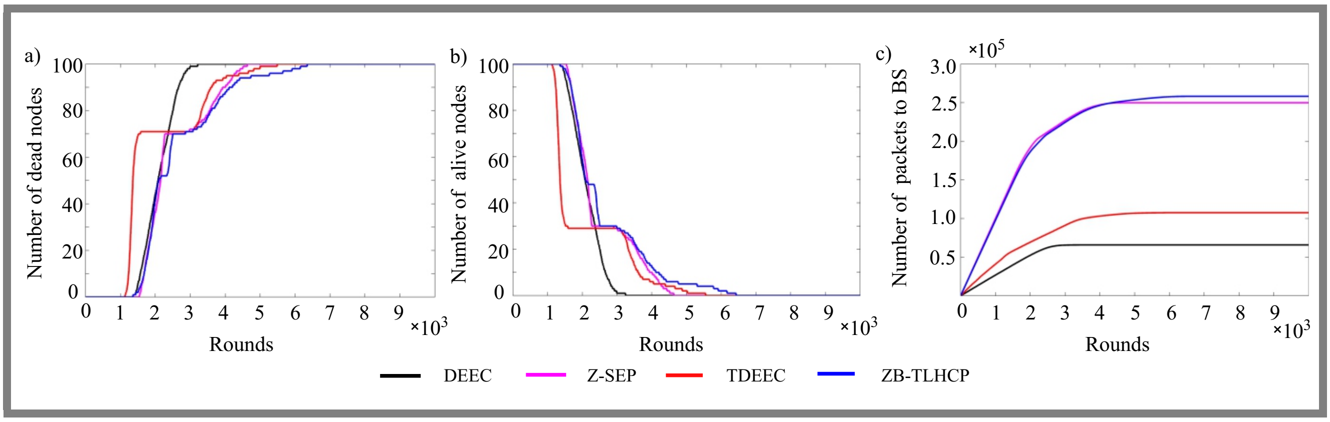

Fig. 7. Simulation results for case 1: a) stability period, b) network lifetime, and c) throughput.

7a and Fig. 7b, we can say that the results concerning network instability period are: ZB-TLHCP, TDEEC, Z-SEP, and DEEC. The throughput of the network is, in descending order: ZB-TLHCP, Z-SEP, TDEEC, and DEEC (Fig. 7c).

In case 2, it is assumed that DEEC, Z-SEP, TDEEC, and ZB-TLHCP have 60 normal nodes, each with an energy level of E_0. In the DEEC protocol, 40 advanced nodes, each with the energy level of $(1 + rand \times 1.3) \times E_0$ are simulated. In Z-SEP, 40 advance nodes have an energy level of $2.3E_0$, while in TDEEC and ZB-TLHCP, 28 advance nodes, each with the energy level of $2.3E_0$ and 12 super nodes, each with the energy level of $3.5E_0$ are considered.

According to Fig. 8a, the longest stability period of the network (in descending order) is: Z-SEP, ZB-TLHCP, DEEC, and TDEEC. From Fig. 8b, the order for network lifetime is ZB-TLHCP, TDEEC, Z-SEP, and DEEC, while results concerning instability period of the network are, in descending order: ZB-TLHCP, TDEEC, Z-SEP, DEEC (Fig. 8a-b). The throughput of the network is, in descending order: ZB-TLHCP, Z-SEP, TDEEC, DEEC (Fig. 8c).

The results for case 3 are as follows. DEEC, Z-SEP, TDEEC [18], and ZB-TLHCP have 50 normal nodes, each with an energy level of E_0. In the DEEC protocol, there are 50 advanced nodes, each with the energy level of $(1 + rand \times 1.5) \times E_0$. In Z-SEP, 50 advance nodes have an energy level of $2.5E_0$. In TDEEC & ZB-TLHCP, 30 advance nodes are simulated each with the energy level of $2.5E_0$ and 20 super nodes, each with the energy level of $4E_0$.

According to Fig. 9, the longest stability period of the network is achieved by Z-SEP, ZB-TLHCP, DEEC, and TDEEC. The results for the network lifetime are: ZB-TLHCP, TDEEC, Z-SEP, and DEEC, while those concerning the instability period of the network are: ZB-TLHCP, TDEEC, Z-SEP, DEEC. From Fig. 9c the one can see that the order related to the highest throughput of the network is: ZB-TLHCP, Z-SEP, TDEEC, DEEC.

In the last simulated case 4, DEEC, Z-SEP, TDEEC, and ZB-TLHCP have 40 normal nodes, each with an energy level of E_0. In the DEEC protocol, 60 advanced nodes are analyzed, each with the energy level of $(1 + rand \times 1.6) \times E_0$, while in Z-SEP, 60 advance nodes have an energy level of $2.6E_0$. In TDEEC and ZB-TLHCP protocols, 30 advance nodes, each with the energy level of $2.6E_0$ and 30 super nodes, each with the energy level of $4.2E_0$.

From Fig. 10 we can conclude the that the longest stability period of the network is achieved by Z-SEP, ZB-TLHCP, DEEC, and TDEEC. The sequence for network lifetime is: ZB-TLHCP, TDEEC, Z-SEP, and DEEC and the results related to instability period of the network are: ZB-TLHCP, TDEEC, Z-SEP, and DEEC. The network throughput is, in descending order: ZB-TLHCP, Z-SEP, TDEEC, and DEEC.

4.2. Overall Analysis

Here, by increasing the number of advance and super nodes and their energy levels, we examine the performance of the proposed protocol by combining all results in one figure. The results shown in Fig. 11a indicate that the stability period remain almost at the same level as the number of advance nodes and super nodes, as well as their energy levels, increase. In case 1, the proposed ZB-TLHCP protocol offers an improvement in stability period of 2.25% and 22.81% over DEEC and TDEEC protocols, respectively, and an improvement in instability period of 61.63% over the Z-SEP protocol.

In case 2, the proposed ZB-TLHCP provides an improvement in stability period of 22.82% over the TDEEC protocol and an improvement in instability period of 222.84% and 90.15% over DEEC and Z-SEP protocols, respectively. In case 3, the proposed ZB-TLHCP solution offers an improvement in stability period of 5.97% and 26.49% over DEEC, and TDEEC protocols, respectively, as well as an improvement in instability period of 99.15% over the Z-SEP protocol.

In case 4, the proposed ZB-TLHCP offers an improvement in stability period of 1.36 % and 37.75% over DEEC and TDEEC protocols, respectively and an improvement in instability period of 106.30% over the Z-SEP protocol. In all four cases, ZB-TLHCP ensures higher better when compared with TDEEC, while lacking in terms of stability when compared with Z-SEP. Among these, Z-SEP performs better than ZB-TLHCP, DEEC, and TDEEC protocols. Due to the high network lifetime, the instability period of all protocols is increasing.

According to the results shown in Fig. 11b, the network lifetime of all protocols increases with a higher number of ad-

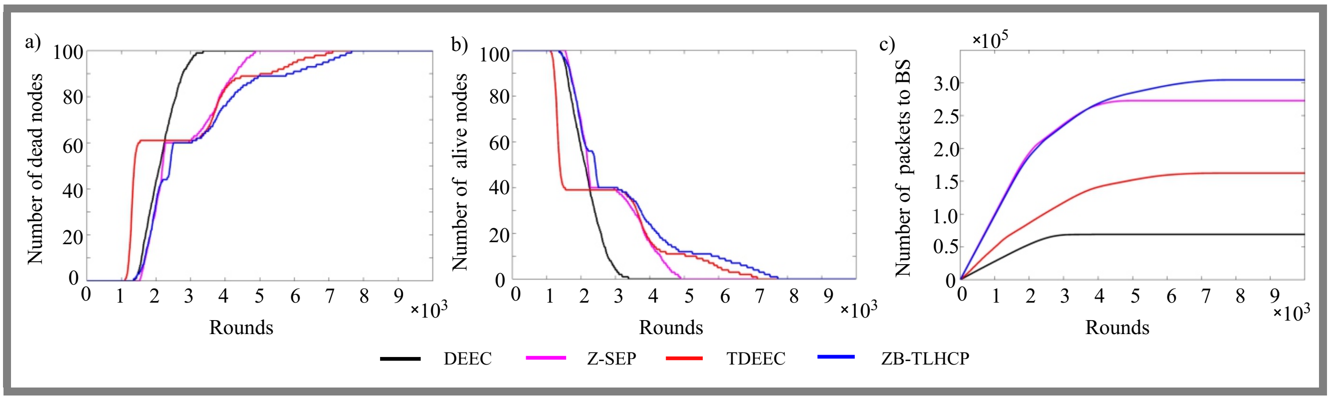

Fig. 8. Simulation results for case 2: a) stability period, b) network lifetime, and c) throughput.

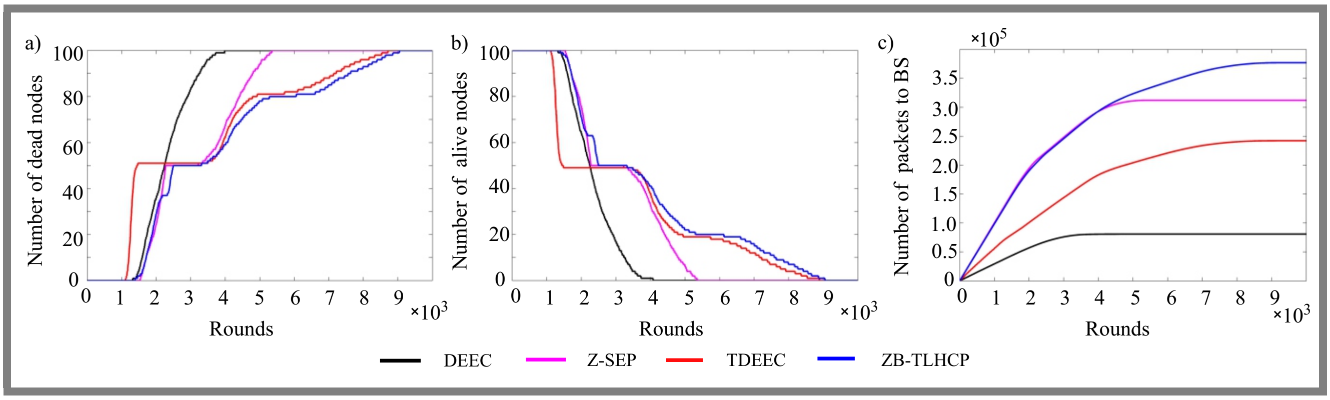

Fig. 9. Simulation results for case 3: a) stability period, b) network lifetime, and c) throughput.

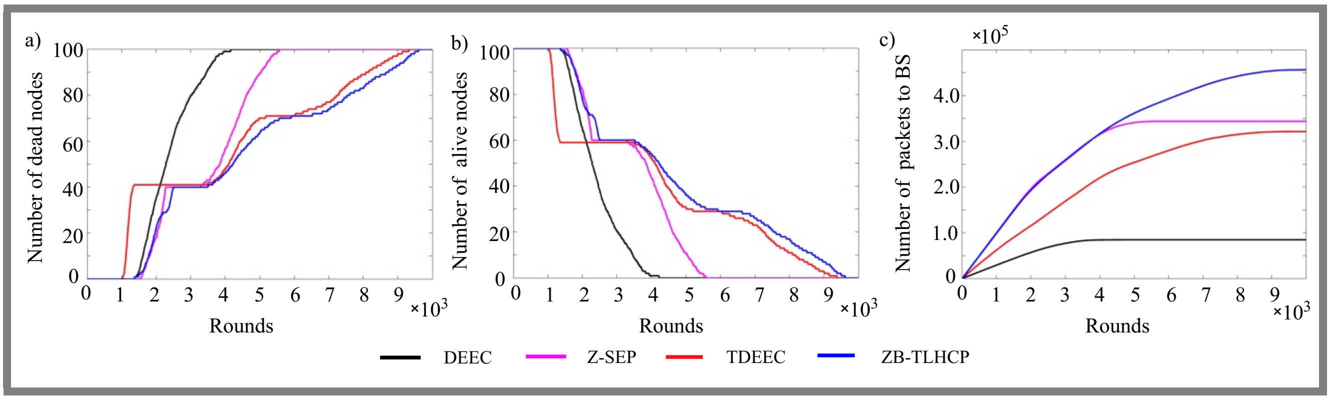

Fig. 10. Simulation results for case 4: a) stability period, b) network lifetime, and c) throughput.

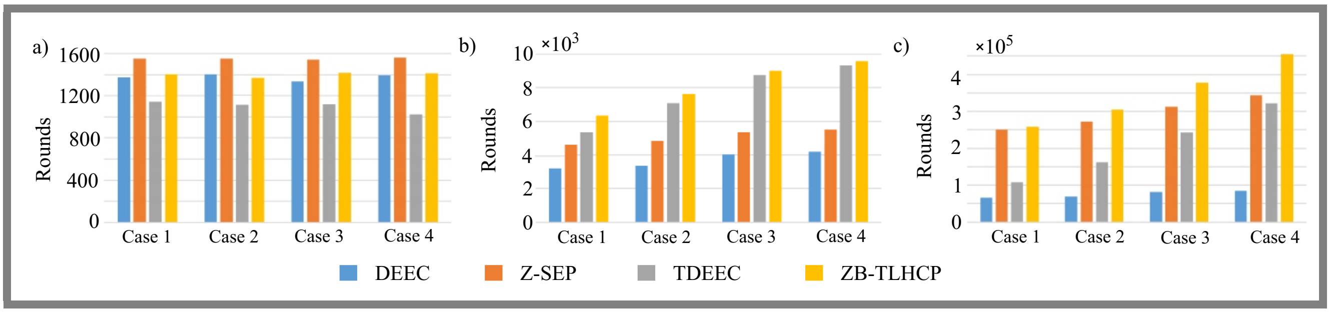

Fig. 11. Overall analysis of DEEC, Z-SEP, TDEEC, and ZB-TLHCP protocols for: a) stability period, b) network lifetime, and c) throughput.

vance nodes and super nodes and their energy levels. In case 1, ZB-TLHCP provides an improvement of 98.21%, 37.62%, and 18.56% over DEEC, Z-SEP, and TDEEC protocols, respectively. In case 2, ZB-TLHCP ensures and improvement of 128.29%, 57.49%, and 8.01% over DEEC, Z-SEP, and TDEEC protocols, respectively. In case 3, ZB-TLHCP offers an improvement of 123.59 %, 68.26%, and 2.97% over DEEC, Z-SEP, and TDEEC, respectively. In case 4, ZB-TLHCP achieves an improvement of 129.21 %, 73.60%, and 2.85% over DEEC, Z-SEP, and TDEEC, respectively. Hence, ZB-TLHCP achieves the longest network lifetime compared to DEEC, Z-SEP, and TDEEC, in all four scenarios.

Figure 11c, shows that the network throughput increases along with the number of advance nodes, super nodes, and their energy levels. In case 1, ZB-TLHCP provides an improvement of 292.64%, 3.30%, and 140.26% in throughput compared to DEEC, Z-SEP, and TDEEC, respectively. In case 2, ZB-TLHCP guarantees and improvement of 341.49%, 11.62%, and 87.56% in throughput compared to DEEC, Z-SEP, and TDEEC, respectively. In case 3, ZB-TLHCP ensures an improvement of 366.27%, 20.78%, and 55.66% in throughput compared to DEEC, Z-SEP, and TDEEC, respectively.

In case 4, ZB-TLHCP offers an improvement of 438.92%, 32.76%, 41.98% in throughput compared to DEEC, Z-SEP, and TDEEC, respectively. Hence, ZB-TLHCP has the highest throughput compared to DEEC, Z-SEP, and TDEEC in all four cases.

5. Conclusions and Future Work

This paper proposes a heterogeneous clustering protocol for WSNs, known as ZB-TLHCP. It divides the sensor region into zones, based on distance from the BS. Sensor nodes are deployed uniformly and randomly within the zone. The proposed model is simulated by varying the number of super and advance nodes and their energy levels for four different cases. The results reveal that the proposed protocol prolongs the network lifetime and increases the instability period and network throughput. In the future, this protocol can be integrated with nature-inspired algorithms [21], [22] to further enhance the effectiveness of the proposed protocol.

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