TEZEM: A new energy-efficient routing protocol for next-generation wireless sensor networks

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Abstract
The design and implementation of energy-efficient routing protocols for next-generation wireless sensor networks is always a challenge due to limited power resource capabilities. Hierarchical (clustering) routing protocols appeared to be a remarkable solution for extending the lifetime of wireless sensor networks, particularly in application-aware (threshold-sensitive) and heterogeneity-aware cluster-based routing protocols. In this article, we propose a protocol, namely, Threshold-based Energy-aware Zonal Efficiency Measuring hierarchical routing protocol. It is a heterogeneity-aware and threshold-based protocol that provides a better solution to existing problems in next-generation wireless sensor networks. During execution, the Threshold-based Energy-aware Zonal Efficiency Measuring hierarchical routing protocol splits the entire network area into several zones to manage network traffic efficiently. In the first step, Threshold-based Energy-aware Zonal Efficiency Measuring hierarchical routing protocol is designed for a homogeneous network where the initial energy of all the nodes is the same. Thereafter, we bring in heterogeneity in the Threshold-based Energy-aware Zonal Efficiency Measuring hierarchical routing protocol execution environment to optimize its energy consumption. By investigating the performance of the various numbers of divisions, it is proved that the Threshold-based Energy-aware Zonal Efficiency Measuring hierarchical routing protocol with 9 zonal divisions has higher stability and throughput. The performance of the proposed Threshold-based Energy-aware Zonal Efficiency Measuring hierarchical routing protocol is compared with those of Stable Election Protocol, Low-Energy Adaptive Clustering Hierarchy, Modified Low-Energy Adaptive Clustering Hierarchy, and Gateway-Based Energy-Efficient Routing Protocol through computer simulations. Simulation results verify the improved performance of the proposed Threshold-based Energy-aware Zonal Efficiency Measuring hierarchical routing protocol in terms of network stability, lifetime, and throughput.

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Introduction

Recently, tremendous development in various wireless communication technologies such as multiple-input multiple-output (MIMO), V2X (vehicle-to-everything), channel-coding, and green-communication has provided a road map toward the evolution of next-generation energy-efficient communication networks. In a few years, the demand for wireless sensor networks (WSNs) in future platforms is also projected to increase exponentially, allowing many wireless devices to work freely for newer applications with unlimited power infrastructure. Sensor networks have been widely utilized in many applications such as health monitoring, security, temperature, humidity, fire, smoke, automatic doors, vibrations, and seismic events because they can sense data with high accuracy.

Sensor networks, especially WSNs, created foundations for a remarkable technological advancement by enabling the efficient management of resources in critical situations. WSNs consist of multiple wireless nodes with limited power resources spread randomly in a specified region, and they can be stationary or mobile. With recent technological advancements, the applications of WSN have increased significantly, but it also has to confront energy-constraint problems due to limited battery sources. Therefore, the selection of an efficient routing algorithm is a major concern for the reliable transmission and reception of packets with specific information. Hence, the routing scheme must ensure minimum energy consumption to increase the lifetime of a network.

Nodes consume a huge amount of energy during the transmission of data and in the sensing environment. A node can accomplish about 800 internal operations with the same amount of energy required to send one single transmission, which shows that more energy is consumed during data transmission than sensing. The conventional methods to conserve energy are as follows:

- To design and utilize an energy-efficient (EE) routing protocol for data forwarding;
- Node’s state scheduling (Active, Sleep, Idle);
- Adjusting the transmission range of nodes if possible;
- By preventing collisions, extra listening, and overhearing.

Typically, a sensor node is a small device with limited power capacity, comprised of few key components. These components include the sensing part which acquires data through sensors, followed by the processing of data in the control system and storage, that is, memory tasks. Next is the communication subsystem, which transmits and/or receives data to and/or from other linked devices, and last but not least is a power source supply to provide energy to execute desired operations. The power source is usually a limited capacity battery. Therefore, the power outage in any critical node is a severe protocol failure. The point of concern is that battery recharging might be impossible due to random deployment of nodes in a hostile environment or unapproachable catastrophic areas for obtaining the necessary information. Therefore, to achieve the situation-specific requirements where sensor nodes might be required for months or even years, the nodes must have sufficient and persistent lifetime capabilities. The above scenario is a challenge for researchers to improve and elongate the lifetime of a node.

The energy constraint in nodes can be overcome by using external surroundings, for example, solar cells. However, what we normally observe is a non-continuous behavior in external power sources. Hence, an energy buffer is required to mitigate this problem. Nevertheless, energy is always a critical resource to be utilized carefully and wisely in WSNs.

The hierarchical protocols tend to be more effective in managing the failures. Cluster-based (hierarchical) protocols that are proposed to improve the energy efficiency of a designated network area can undergo data aggregation. The localized algorithms are more stable compared to centralized ones and can attain high throughput. The clustering introduces the concept of Cluster Head (CH) selection from the nodes, which has to spend more power than other node members for that particular period. The data from the micro-sensor node are transmitted to the CHs, which then transmit that data to the receiver or base station (BS) away from the field. Existing hierarchical routing protocols such as
In this article, we design a protocol, named Threshold-based Energy-aware Zonal Efficiency Measuring hierarchical routing protocol (TEZEM), which is based on the concept of energy-aware zone routing. Initially, we consider that sensor nodes are randomly spread across the sensor field and are stationary. Then, the TEZEM achieves multiple zones by splitting the network area into equal parts. Each zone works as a cluster having a reference point (RP) in the center which assists in the efficiency calculation of distributed nodes. In each round, the highest energy node from each zone is selected as a CH, hence resulting in balanced CH selection. The performance of the proposed TEZEM protocol is studied with numerical simulations, and comparisons with other protocols are made. Simulation results show that TEZEM yields a longer stability period, improves node survival rate, provides high throughput, and extends network lifetime. In addition, TEZEM achieves key objectives such as balanced and even clustering, heterogeneity awareness, application awareness, load balancing CH selections, and an equal number of CHs per round.

The remainder of this article is structured as follows. In section “Related works,” several conventional routing protocols in WSNs are briefly reviewed. Section “Radio model of WSN” explains the radio model of WSNs. Section “TEZEM” provides the network model for TEZEM. The complete working of the proposed routing protocol TEZEM and its network model with simulation results is given in section “Simulation results.” Section “Performance analysis” describes the reason for using the optimal number of zones. Finally, concluding remarks are given in section “Conclusion and remarks.” In addition, the abbreviations used in the article are given in Table 1.

**Related works**

In the recent past, a significant development can be seen in WSN routing protocols. These protocols are based on application requirements and network structure. But few implications must be considered while mounting WSN routing protocols. Nevertheless, the most essential element is the energy efficiency of sensors that directly affect the network’s lifetime.

In recent years, several EE routing protocols for WSNs have been proposed. Among them, the clustering routing protocols show significant performance in optimizing energy costs for both homogeneous and heterogeneous networks. In the cluster-based routing method, nodes arrange themselves in hierarchical structures. Within a cluster, there is a CH that performs the role of data collector and aggregator. The CH reduces the amount of energy consumed by nodes to transmit data to the BS/sink. The most initially proposed hierarchical/clustering routing protocol for WSNs is LEACH, which has adopted a mechanism called dynamic clustering to prolong the network lifetime. In this mechanism, the node by some probability elects itself to become CH and afterward broadcasts its status to the whole network. All the members in the cluster forward the collected information to their CH, which then transmits it to the sink, so CH utilizes more energy than a non-CH node. Every node in the network will get a chance to become CH within the network lifetime. The major drawback of LEACH is the imbalanced distribution of CHs and massive energy consumption because of direct transmission from nodes to BS. Moreover, the early death of nodes makes the LEACH unstable. To overcome these problems and drawbacks, LEACH-Centralized (LEACH-C) was proposed.

In LEACH-C, the CHs are selected by BS using the mechanism of centralized CH selection. In every round, the BS receives the information from each node present in the network about its current location and its remaining energy. After getting the required information, the BS computes the network’s average node energy. After energy calculation, BS only spots those as qualified CH nodes whose energy is higher than the average calculated energy of all the nodes. Then it uses a simulated annealing algorithm to reduce the objective function with the help of candidate nodes. The algorithm applies some set of rules to minimize the energy of data transmission between non-CH and CH nodes. The drawbacks of LEACH-C include the repeated cluster formation overhead and the energy and information wastage due to fixed round time.

PEGASIS is an upgradation of LEACH and a chain-based protocol. In this protocol, each node just communicates with its close neighbor to give and take the information. The data gathered from the surroundings move from node to node and get fused. Finally,
Table 1. The list of symbols and their definitions.

| Abbreviations | Explanation                        |
|---------------|------------------------------------|
| Adv           | Advertisement                      |
| APTEEN        | Adaptive Periodic TEEN             |
| Assreq        | Association Request                |
| Bc            | Broadcast                          |
| BCDCP         | Base-Station Controlled Dynamic    |
|               | Clustering Protocol                |
| BS            | Base Station                       |
| CCS           | Concentric Clustering Scheme       |
| CEEC          | Centralized Energy-Efficient       |
|               | Clustering                        |
| CH            | Cluster Head                       |
| CV            | Cluster Sensing Value              |
| Data_pkt      | Data Packets                       |
| DEEC          | Distributed Energy-Efficient       |
|               | Clustering                        |
| DWEHC         | Distributed Weight-based Energy-    |
|               | efficient Hierarchical Clustering  |
| EE            | Energy Efficient                   |
| EECS          | Energy-Efficient Clustering Scheme |
| EEUC          | Energy-Efficient Uneven Clustering |
| e_eff         | Energy Efficiency of a Node        |
| e_init        | Initial Energy of All Nodes        |
| HEED          | Hybrid Energy-Efficient Distributed |
| LEACH         | Low-Energy Adaptive Clustering     |
|               | Hierarchy                          |
| LEACH-C       | LEACH-Centralized                  |
| LEACH-VF      | LEACH with Virtual Force           |
| M-GEAR        | Gateway-Based Energy-Efficient     |
| MOD-LEACH     | Modified-LEACH                     |
| non_ch        | Non-CH nodes in a zone             |
| NSP           | Network Settling Phase             |
| NTP           | Network Transmission Phase         |
| PANEL         | Position-based Aggregator Node     |
| PEGASIS       | Power-Efficient Gathering in Sensor Information Systems |
| RP            | Reference Point                    |
| Rp_zone       | Reference Point in Every Zone      |
| SEP           | Stable Election Protocol           |
| SN            | Sensor Node                        |
| SNR           | Signal-to-Noise Ratio              |
| TDMA          | Time Division Multiple Access      |
| TEEN          | Threshold-Sensitive Energy-Efficient Sensor Network |
|              | Efficiency Measuring               |
| TEZEM         | Threshold-based Energy-aware       |
|               | Zonal Efficiency                   |
| TL-LEACH      | Two-Level Hierarchy LEACH          |
| TTDD          | Two-Tier Data Dissemination        |
| UCS           | Unequal Clustering Size            |
| VGA           | Virtual Grid Architecture          |
| WSN           | Wireless Sensor Network            |

In Manjeshwar and Agrawal, a TEEN protocol is presented which is a clustering protocol, designed to target the abrupt changes in the sensing attributes like temperature. The nodes keep sensing the environment but consume less energy than the proactive networks because the data transmission is less frequent and highly controlled because of two thresholds. The data are transmitted on demand, which can reduce energy consumption. The APTEEN, which is an extension to TEEN, is a hybrid protocol that alters the threshold values exercised in TEEN as per the application type and users' requirement. There is a query system in APTEEN which deals with three different types of queries, which are on-time queries, historical queries and persistent queries. Another routing protocol is SEPL, which focuses on advanced nodes in a network that are furnished with excessive energy resources. This protocol enhances the stability region but decreases the throughput and lifetime of the network. A clustering protocol Hybrid Energy-Efficient Distributed (HEED) is proposed in Younis and Fahmy, for EE routing. HEEC has a non-random CH selection criteria which are different from LEACH. The cluster formation is based on a hybrid combination mechanism of two different parameters. The first parameter depends on residual energy and the other parameter depends on the communication cost of the cluster. The main advantages include distributed clustering and high-energy conservation, whereas the main drawback is the significant network overhead. Authors in Ding et al. presented Distributed Weight-based Energy-efficient Hierarchical Clustering (DWEHC), which is also distributed the same as HEED. The main merits of DWEHC are the balanced distribution of CHs and just a few assumptions in the CH selection process. The shortcomings include single-hop communication, which results in high-energy consumption and message overhead. In Loscri et al., the authors introduced Two-Level Hierarchy LEACH (TL-LEACH), which is an extension of the LEACH algorithm. The TL-LEACH employs different techniques to accomplish energy efficiency and better robustness and scalability. This protocol is also based on two-level clustering which helps to reduce transmission distance with the employment of fewer nodes. The drawback of TL-LEACH is that it follows dual-hop routing only for the information transmission from the source to the BS, so it is not applicable to long-range communications. In Soro and Heinzelman, the Unequal Clustering Size (UCS) model is used for network establishment to ensure the balanced consumption of energy. The UCS model has significance in WSN research because it has the attribute of being the first unequal model for clustering. It has a mechanism to manage the sizes of different clusters. With the help of its two-layer model and multi-
hop communication technique, it reduces the transmission distance, thus reducing the overall energy utilization. Energy-Efficient Uneven Clustering (EEUC)\(^4\) is a competitive algorithm based on localized competition for the electing CHs. For every node, there is a predefined range, which becomes smaller as the node gets near to the BS. This algorithm is vital in conserving energy as in the steady-state phase it uses multi-hop routing based on communication cost. The main disadvantage of this algorithm is the overhead because it performs clustering and data aggregation in each round. In Muruganathan et al.,\(^4\) the authors have introduced Base-Station Controlled Dynamic Clustering Protocol (BCDCP), a centralized hierarchical protocol in which the BS can accomplish complex computations. Because of the centralized algorithm, BCDCP is robust and more scalable to large networks. A low-power protocol based on the Two-Tier Data Dissemination (TTDD) method is introduced in Luo et al.,\(^4\) which ensures efficient delivery of information from several sources to several mobile BSs. The routing method in TTDD uses a geographic routing which is based on the grid of cells. Rather than inactively anticipate queries from the BSs, SNs can proactively create a structure to generate the forwarding data. TTDD can be employed for event detection in WSNs with random traffic. The authors Qing et al.\(^4\) introduced the DEEC protocol, which is based on the footsteps of LEACH and SEP. A probability-based mechanism is established in this protocol to select CHs and to calculate the ratio of average energy and the residual energy of every node in the network. DEEC is somehow more similar to SEP as it accustomed every node’s rotating epoch to its energy. Energy-Efficient Clustering Scheme (EECS) presented by Ye et al.\(^4\) uses the EE clustering method which benefits the application related to periodical data gathering. Similar to the LEACH protocol, it also divides the network into multiple clusters and also adopts the same single-hop communication mechanism. Dynamic size clustering based on the distance of cluster from the BS is performed in EECS.

In order to overcome the energy constraints in PEGASIS, a chain-based scheme called Concentric Clustering Scheme (CCS) has been presented in Jung et al.\(^4\) The location-based performance enhancement is the main idea behind this scheme to enhance the network lifespan. Uneven distribution of nodes and not considering residual energy for the election of CH are the main drawbacks of this scheme. There are some scenarios in WSNs where the diameter of the network expands beyond a certain limit, which results in a huge distance between CH and BS. The simple LEACH protocol which is based on single-hop communication between CHs and BS is not suitable in this scenario. So to address this problem, an extension of the LEACH variant, multi-hop LEACH, is proposed in Xiangning and Yulin,\(^4\) which is a distributed multi-hop routing protocol that uses the same CH election criteria and the cluster formation scheme as LEACH protocol. A position-based protocol Position-based Aggregator Node Election (PANEL)\(^4\) is proposed to highlight position-based EE routing in WSNs. The main advantages of PANEL are that it guarantees load balancing and it supports asynchronous applications, which make it distinctive from other clustering protocols. A block cluster-based protocol named LEACH with Virtual Force (LEACH-VF) is proposed in Awad et al.\(^4\) This protocol unites the LEACH with two different kinds of virtual forces: one is called the attractive force and the second is called the repulsive force. The first one is employed to push the nodes toward the CH, and the other one is exercised to push the overlapping nodes far from each other. In CEEC,\(^4\) authors proposed a multi-level heterogeneous network model. CEEC is the enhancement of SEP, and the main feature of this protocol is that it allows multi-hop inter-cluster communication. The network in CEEC is equally divided into three regions, and nodes with the same energy levels are placed in the same region. The main goal behind the development of CEEC was to enhance the stability and network lifetime by achieving the optimal number of CH in each round. The centralized routing in CEEC helps to maintain better control over network operations. Another protocol MOD-LEACH, which is a novel modification of LEACH, is proposed in Mahmood et al.\(^4\) This protocol can also be utilized for efficiency enhancement. It conserves energy utilization by replacing CH after every first round and amplifying the transmitting power levels for intra-cluster and CH to BS communication. In this protocol, CH is only replaced when its energy drops below a certain threshold level, thus resulting in the reduction of routing traffic. Furthermore, MOD-LEACH also implements for soft and hard thresholds to consume performances of the protocols considering energy utilization and throughput. M-GEAR\(^4\) is an energy-aware multi-hop protocol. This protocol uses a gateway node to reduce the energy utilization of a sensor network. In this protocol, the whole network is divided into local regions. Every region uses a unique communication hierarchy. Direct communication topology can be seen in two regions and then further these regions are sub-divided into clusters that implement a multi-hop communication hierarchy.

To address the shortcomings in the previous protocols such as LEACH,\(^4\) LEACH-C,\(^4\) PEGASIS,\(^4\) SEP,\(^4\) CEEC,\(^4\) MOD-LEACH,\(^4\) and M-GEAR,\(^4\) a novel routing protocol TEZEM is proposed, which we will thoroughly discuss in sections “TEZEM” and “Simulation results.” A comparison of the above-discussed clustering protocols is also done in Table 2.
Radio model of WSN

The radio model adopted for TEZEM is simple and similar to LEACH\textsuperscript{19} as shown in Figure 1. The energy dissipation values in the radio model show the energy utilization by the hardware for transmission, reception, and aggregation of the required data. The total electronic energy dissipated per bit ($e_{\text{elec}}$) to run the transmitter or receiver electronics is equal to the energy dissipated in terms of transmit electronics ($e_{\text{tx-elec}}$) and the energy dissipated in terms of receive electronics ($e_{\text{rx-elec}}$), so $e_{\text{elec}} = e_{\text{tx-elec}} = e_{\text{rx-elec}} = 50$ J per bit, and to attain satisfactorily Signal-to-Noise Ratio (SNR), the transmitter amplifier dissipates 100 pJ/bit/m$^2$.

The radio expands energy to transmit $k$-bit data over a distance $s$ using the radio model, as follows

$$e_{\text{tx}}(k, s) = e_{\text{tx-elec}}(k) + e_{\text{tx-amp}}(k, s)$$

$$e_{\text{tx}}(k, s) = \begin{cases} e_{\text{elec}} \times k + e_{\text{fs}} \times k \times s^2 & \text{if } s < s_0 \\ e_{\text{elec}} \times k + e_{\text{amp}} \times k \times s^2 & \text{if } s \geq s_0 \end{cases}$$

In equation (2), the amplifier energy expenditure for one bit, $e_{\text{amp}}$, depends on the distance from the sender to the receiver and the acceptable bit error rate. For the free-space transmission, $\gamma = 2$, $e_{\text{fs}}$ is denoted as $e_{\text{fs}}$. For multi-path fading channel, $\gamma = 4$, $e_{\text{fs}}$ is denoted as $e_{\text{amp}}$, and $s_0$ is used as the distance threshold, which can be obtained as $s_0 = \sqrt{(e_{\text{fs}})/(e_{\text{amp}})}$. In order to obtain k-bit data, the radio utilizes energy which is as follows

$$e_{\text{tx}}(k) = e_{\text{tx-elec}}(k) = e_{\text{elec}} \times k$$

Consider $m \times m$ (m$^2$) area with $n$ randomly spread nodes that are homogeneous and have equal processing capabilities. Also assume to have a centralized BS, and the BS and the deployed nodes are fixed. Finally, the distance $s$ from any node to CH is less than or equal to $s_0$, and then the energy consumed by the CH node during intra-zone communication will be

$$e_{\text{CH}} = \left(\frac{n}{Z} - 1\right) e_{\text{tx-elec}} \times k_c + \frac{n}{Z} \times k_c \times e_d + \frac{e_{\text{tx-elec}} \times k_A + e_{\text{fs}} \times k_A \times s_{\text{toBS}}^2}{2}$$

where $Z$ indicates the optimal number of zones, $n$ shows the total number of nodes, $k_c$ denotes data bits obtained from all nodes in a zone, $k_A$ denotes aggregated data bits, $e_{\text{fs}}$ is the data aggregation cost per bit, and $s_{\text{toBS}}$ is the distance to BS and is normally expressed as

$$s_{\text{toBS}} = 0.765 \frac{m}{2}$$

The energy consumption by the non-CH nodes of a particular zone can be stated as

$$e_{\text{non-CH}} = \left(\frac{n}{Z} - 1\right) e_{\text{tx-elec}} \times k_c + e_{\text{fs}} \times k_c \times s_{\text{toCH}}^2$$

where $s_{\text{toCH}}$ indicates the distance among CH and its members within a zone. The overall dissipated energy in each round in a zone throughout transmission is

$$e_{\text{zone}} = e_{\text{CH}} + e_{\text{non-CH}}$$

As $Z$ represents total zones in the entire network, the total energy consumption can be calculated simply by substituting the values of equations (4) and (6) into equation (7) as follows

$$e_{\text{zone}} = \left(\frac{n}{Z} - 1\right) e_{\text{tx-elec}} \times k_c + \frac{n}{Z} \times k_c \times e_d + \frac{e_{\text{tx-elec}} \times k_A + e_{\text{fs}} \times k_A \times s_{\text{toBS}}^2}{2} + \left(\frac{n}{Z} - 1\right) e_{\text{tx-elec}} \times k_c + e_{\text{fs}} \times k_c \times s_{\text{toCH}}^2$$

In this section, we propose a novel EE routing protocol, namely, TEZEM which is aimed to achieve successful energy management and threshold-based communications for better stability period, network lifetime, and throughput. Energy can be managed by bringing heterogeneity in the TEZEM execution environment. Therefore, TEZEM can be termed as the heterogeneity-aware hierarchical protocol. In this distributed hierarchical routing protocol, CH selection is based on the decision of each node, so every node has an equal opportunity to become a CH.

WSN transmission model

WSN mainly consists of unattended tiny sensor nodes with limited power spread over a region termed as the sensor field, as given in Figure 2. These nodes sense essential information from the surroundings and transfer it to the BS. To accomplish the energy management, heterogeneity is brought in the network where TEZEM
| Routing protocols | Type | Cluster scalability | Scalability | Energy-efficiency | Homogeneous | Hop-count | Algorithm complexity | Distributed/ Centralized | Delivery delay | Mobility |
|-------------------|------|---------------------|-------------|-------------------|-------------|-----------|---------------------|--------------------------|----------------|---------|
| LEACH19           | Hierarchical | Better            | Limited     | Low                | Yes         | Single     | Low                 | Distributed              | Very small   | Fixed   |
| LEACH-C21         | Hierarchical | Better            | Limited     | High               | Yes         | Single     | High                | Centralized             | Small         | Fixed   |
| PEGASIS22         | Hierarchical | Limited            | Limited     | Low                | N/A         | Multi      | High                | Distributed              | Very large    | N/A     |
| TEEN23            | Hierarchical | Good               | Better      | Moderate           | Yes         | Single     | Very High           | Distributed              | Small         | Fixed   |
| AP-TEEN24         | Hierarchical | Limited            | Limited     | Low                | N/A         | Multi      | Moderate           | Both                     | Moderate      | Fixed   |
| SBP25             | Hierarchical | Good               | Better      | Very high          | Yes         | Multi      | Moderate           | Distributed              | Moderate      | Fixed   |
| BCDCP42           | Hierarchical | Good               | Limited     | Low                | Yes         | Single     | Low                 | Distributed              | Small         | Fixed   |
| TTDD43            | Hierarchical | Very Good          | Limited     | Low                | No          | Single     | Moderate           | Both                     | Moderate      | Fixed   |
| DEEC44            | Hierarchical | Good               | Better      | High               | No          | Single     | Very High          | Distributed              | Very large    | Fixed   |
| EECS45            | Hierarchical | Good               | Limited     | Moderate           | Yes         | Multi      | Moderate           | Distributed              | Small         | Fixed   |
| UCS46             | Hierarchical | Limited            | Limited     | Low                | No          | Single     | Moderate           | Distributed              | Small         | Fixed   |
| Multi-hop LEACH47 | Hierarchical | Very Good          | Very Good   | Very high          | Yes         | Multi      | High               | Distributed              | Small         | Fixed   |
| PANEL48           | Hierarchical | Low                | Limited     | Moderate           | Yes         | Single     | High               | Distributed              | Moderate      | Fixed   |
| LEACH-VF49        | Hierarchical | Good               | Limited     | Moderate           | Yes         | Single     | Moderate           | Distributed              | Very small    | Fixed   |
| CEEC50            | Hierarchical | Good               | Good        | High               | No          | Multi      | High               | Distributed              | Moderate      | Fixed   |
| MOD-LEACH26       | Hierarchical | Good               | Good        | High               | No          | Multi      | High               | Distributed              | Moderate      | Fixed   |
| M-GEAR27          | Hierarchical | Better            | Good        | High               | Yes         | Multi      | Moderate           | Both                     | Small         | Fixed   |

LEACH: low-energy adaptive clustering hierarchy; LEACH-C: LEACH-centralized; PEGASIS: power-efficient gathering in sensor information systems; TEEN: threshold-sensitive energy-efficient network; AP-TEEN: adaptive-TEEN; SEP: stable election protocol; HEED: hybrid energy-efficient distributed; DWEHC: distributed weight-based energy-efficient hierarchical clustering; TL-LEACH: two-level hierarchy LEACH; UCS: unequal clustering size; EEUC: energy-efficient uneven clustering; BCDCP: base-station controlled dynamic clustering protocol; TTDD: two-tier data dissemination; DEEC: distributed energy-efficient clustering; EECS: energy-efficient clustering scheme; CCS: concentric clustering scheme; PANEL: position-based aggregator node election; LEACH-VF: LEACH with virtual force; CEEC: centralized energy-efficient clustering; MOD-LEACH: modified-LEACH; M-GEAR: gateway based energy-efficient routing protocol.
is implemented. The CH selection is based on the sole decision of nodes.

Network model of TEZEM

In TEZEM, the nodes are randomly distributed in the whole area, without considering any deployment scheme. Although it is a difficult task to deploy nodes in WSN, this problem can be solved by splitting the entire area into various equal zones. In this section, we present the network model of TEZEM.

The network model of TEZEM is very efficient and distinctive. Initially, nodes \((n = 100)\) are randomly dispersed over the entire network and are stationary as shown in Figure 3(a). Primarily, the nodes are considered to be homogeneous, that is, equal energy levels.

Zonal division–based model

Initially, all nodes are randomly deployed in the region. The whole network area is then equally distributed into nine zones \((z = 9)\). In this model, every zone is referred to as a cluster, and all zones will get some quantity of nodes as depicted in Figure 3(b).

The exact amount of nodes in each zone cannot be predicted until the placement of sensor nodes is completely done. Finally, an RP is placed in the mid of each zone as illustrated in Figure 4. The purpose of RP is to act as a key element for calculating the energy efficiency of all nodes.

In every round, a single CH is selected from each zone. This zonal division–based energy calculation helps the distributed processing network criteria. The number of network divisions should be carried out with utmost consideration to manage the network traffic efficiently. The equal division of the entire network into distributed clusters (zones) assists in balancing the net-
work traffic and reducing network load. The required data are forwarded by the nodes of each zone to their CH, which then transmits that information to the Sink. The zones are heterogeneous, which implies that an unequal number of sensor nodes are present in each zone. In our proposed protocol, we introduce the idea of equalized or balanced CHs, that is, CH in every round from each zone. The total number of CHs during the entire simulation period will remain fixed until the whole cluster/zone is dead. The optimal CHs per round can be computed as follows

\[
CH_{opt} = n \times p_{opt}
\]  

(11)

\[
p_{opt} = \frac{Z_{eq}}{n} = \frac{9}{100} = 0.09
\]  

(12)

Inserting this value into equation (11), we have

\[
CH_{opt} = 100 \times 0.09 = 9
\]  

(13)

The above equation gives us the value of optimal CHs in each round, which is 9.

**Threshold-sensitive energy-efficient routing protocol**

Like other routing protocols, TEZEM is also divided into certain rounds. The round processing period is decided and designed by the network designer as per the network application and environment. Besides this, every round is segregated into two phases, namely, Network Setting Phase (NSP) and Network Transmission Phase (NTP). The CH selection and cluster formation take place in NSP; however, the main communication is done in the NTP in which nodes from each zone forward data to their CHs, and then CHs transmit that information to the Sink. In TEZEM, shorter NSP results in maximum throughput. The proposed TEZEM-based clustering is explained in Algorithm 1.

NSP. NSP is an initialization phase in which CHs are selected and clusters are generated. In TEZEM, clusters (regions) are formed first and CHs are designated

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**Algorithm 1.** Proposed TEZEM-Based Routing.

**INITIALIZE**

1: Identify total nodes \( n \); // \( n=100 \)
2: Regulate total rounds \( r \); // \( r=3000 \)
3: \( c_{eq}(s) = e_0; // s=1,2,...,n \)

(i) NETWORK SETTLEMENT PHASE (NSP)

4: do //run and repeat for total rounds (\( r \))
5: \( r=\text{rand}(0,1); //\)nodes randomly deployed
6: \( XY=[x_m/3,y_m/3]; //\) Zones formation by x-axis and y axis division in 3 parts
7: \( \text{clusters/zones}(z)=9; // 9 \) equal zones generated
8: for \( i=1: z \)
9: \( \text{Plot}((RP_{zone})=((xzi)/2,(yzi)/2)); //\) for mapping reference points
10: end for
11: for \( j=1: nz \)
12: calculate \( ee_{eff}(nz) \)
13: max=\( ee_{eff}(nz) \); //highest energy efficient node in each zone
14: if \( (\text{max}(sz).e_{init}(sz)) \) then
15: \( \text{CH}_{max}(sz) = \text{TRUE}; //\) node become a CH
16: else
17: \( \text{CH}_{max}(sz) = \text{FALSE}; //\) node will not be a CH
18: end if
19: if \( \text{CH}_{max}(sz) = \text{TRUE} \) then
20: \( \text{remain fix for one whole round} \)
21: Bc (adv); // broadcast CHs advertisement
22: \text{Assreq(nonch)}; //association request by non-CH nodes
23: \text{join } (ID_{nonch}); // non-CH nodes attach with CH within the zone
24: cluster/zone(z); //cluster formation is done in each zone
25: end if
26: end for

(ii) NETWORK TRANSMISSION PHASE (NTP)

27: If \( (CV(sz) > \text{threshold}) \) then // temperature is taken as a threshold
28: Receive (DataPKC(fromnonch)), //receive information packets from member nodes
29: Aggregate (DataPKC(fromnonch)), //aggregate data received from associate nodes
30: TransToBS (DataPKC(fromnonch)),//compress and transmit received information
31: else if (TimeSlot=TRUE) then
32: TransToCH (DataPKC(fromnonch)), //send out sensed information
33: else
34: No-comm Mode (nonch) = TRUE; //no communication between nodes
35: end if
36: end if
37: one round ended
38: END

---

**Figure 4.** Zonal topology with fixed reference points.
afterward. This technique is remarkable as well as beneficial because the entire network in TEZEM is divided only once, and cluster (zone) creation is carried out for a complete network lifetime. So, there is no need to bring in the association phase again. Thus, it results in the shortening of NSP and prolongation of NTP. The distributed CH selection-based clustering routing protocols, working on the phenomena of random CH selection, tend to be very ineffective and less efficient in some situations, hence resulting in a shorter lifetime of SNs. TEZEM adopts a unique method for CH selection, which is based on the energy efficiency calculation technique for normal nodes and present zone CHs

\[
\eta_{\text{eff}} = \left( \frac{\varepsilon_{\text{res},n}}{\min\left(\text{dis}_{\text{node,RP}}\right)} \right) \times \left( \frac{1}{\min\left(\text{dis}_{\text{node,BS}}\right)} \right) \quad (14)
\]

Here, \(\varepsilon_{\text{res},n}\) is the average residual energy of the nodes in a zone, \(\min(\text{dis}_{\text{node}})\) is the distance between node and RP, and \(\min(\text{dis}_{\text{node,BS}})\) is the distance between node and BS. As in our case, the initial energy of the nodes is the same, and after the first round, nodes in each distributed zone will give their residual energy information to the BS. We can calculate the average residual energy of the normal nodes in each round in every zone which is as follows

\[
\overline{\varepsilon_{\text{res},n}}(R) = \frac{1}{n_{\text{nz}}} \times \sum_{i=1}^{n_{\text{nz}}} \varepsilon_{\text{res},n}(R) \quad (15)
\]

where \(R\) is the current round, and \(n_{\text{nz}}\) represents the total number of normal nodes in the zone.

By using equation (14), the energy efficiency of all the nodes in the region can be determined. The most efficient node will be designated as CH. The above equation will be applied to every zone to elect the CH in each round. The NSP operational flow is depicted in Figure 5.

**NTP)**. In NTP, nodes initially start sensing the environment at first, to perform particular tasks as shown in Figure 5. Nodes do not transmit information until the threshold value is achieved. In this scheme, the temperature is considered as a threshold that is set to 180. Now let’s elaborate how this threshold will act in this scenario. A continuous Current sensing Value (CV) can be achieved from the first till maximum rounds (3000). So when the CV is greater than or equal to 180 (CV \(\geq 180\)), it implies that the attribute set parameter reaches its threshold, and the sensor node moves to the transmitter and transmits the detection information. This information is stored in an internal variable named the sensed value in the sensor node. The nodes send the information to their zonal CH, not to the CHs of neighboring zones. This will assist in extending the network lifetime because by this we can limit the intra-cluster communication range. Information is then transferred from nodes to CHs and subsequently CHs aggregate this received data to form a Time Division Multiple Access (TDMA) super-frame. After the creation of super-frames, data compression is done by CHs, and to accomplish this, objective multiple signal processing method is utilized by CHs. CHs will reduce the final information through the process of data aggregation and compression. Finally, these compressed data are transferred to the BS. This is how the BS will get the information from all the zones. More significantly, a single round contains sole NSP and several transmissions to BS. The BS can control information sensing and transmitting, which can be achieved by outlining various thresholds and allocating different times according to the required information and network life cycle.

**Simulation results**

TEZEM is compared with SEP, LEACH, MOD-LEACH, and M-GEAR for the performance and efficiency evaluation. From the simulation results, we can easily conclude that TEZEM is a good candidate for EE routing as it prolongs network lifetime and stability and enhances the total throughput. Moreover, it decreases the overall energy utilization and optimizes the amount of CHs.

**Simulation parameters**

In the scenario of our proposed work, 100 nodes \((n = 100)\) are randomly deployed over a 100 m² network area along with a fixed BS positioned at (50, 50). Figure 3 displays the arrangement of nodes deployed randomly for evaluation. Each simulation uses a different sample of randomly deployed nodes. The simulation results are enlightened in the following subsection. The simulation parameters along with their values are given in Table 3, employed for simulating SEP, LEACH, MOD-LEACH, M-GEAR, and TEZEM.

**Performance metrics**

Before explaining the simulation results, it is necessary to define some performance metrics based on which the performance of the proposed protocol will be evaluated. The metrics are defined as follows as given in Zagrouba and Kardi and Liu et al.
Network lifetime: It can be described as the period from the beginning of the operation till the last sensor node of the network dies.

Stability/Instability period: There are two adjoining sections of a network lifespan. The first section, which starts just from the beginning of the network operation and continues till the death of the first sensor node, is termed as the Stability period. The second section, which starts just after the death of the first node till the last sensor node dies, is called the Instability period.

Number of CHs per round: The CHs are selected from the nodes present in each zone in every round. The number remains consistent in each round until and unless all the nodes present in a zone are dead.

Throughput (Packets to CHs/Packets to BS): The total amount of data packets sent from the nodes to CHs and also the packets received by BS from the CHs are termed as throughput. If the protocol achieves a prolonged network lifetime, it can send more packets, which ultimately increases the throughput of the network.
Table 3. Simulation parameters.

| Parameters                          | Value                        |
|------------------------------------|------------------------------|
| Amount of nodes deployed (n)       | 100                          |
| Distribution of nodes              | Randomly                     |
| Total simulation rounds            | 3000                         |
| Network size                       | 100 m²                       |
| Number of zones                    | 9                            |
| BS position                        | Located at (50,50)           |
| Initial energy of node             | 0.5J                         |
| Energy dissipation during reception ($e_{rx-elec}$) | 50 nJ/bit                   |
| Energy dissipation during transmission ($e_{tx-elec}$) | 50 nJ/bit                   |
| Data packet                        | 4000 bits                    |
| Transmit Amplifier ($e_{rx-amp}$)  | 100 pJ/bit/m²                |

BS: base station.

Simulation results

In this sub-section, to analyze the performance and behavior of the proposed TEZEM, the existing well-known clustering routing protocols LEACH, SEP, MOD-LEACH, and M-GEAR are used in the comparison. The MATLAB simulation tool is used to carry out the performance evaluation of TEZEM. The nodes are regarded as static nodes and are randomly deployed in a 100 m² region. The number of nodes is fixed to 100 and a total of 3000 rounds are considered for simulation.

In Figure 6, a comparison of dead nodes versus the total number of rounds is given. Results demonstrate that the TEZEM has a prolonged lifetime in comparison with the previously proposed protocols. The stability time of TEZEM is significantly greater compared to LEACH, SEP, MOD-LEACH, and M-GEAR, which is the major achievement of our proposed model. Taking into consideration the total rounds, we can observe that the stability period of LEACH, SEP, MOD-LEACH, M-GEAR, and TEZEM is 33%, 30%, 34%, 36%, and 40%, respectively. The higher stability in TEZEM is achieved because of the well-planned distribution of the nodes and better mechanism of cluster formation in TEZEM. The first node in TEZEM dies after around 1250 rounds compared with that of LEACH, SEP, MOD-LEACH, and M-GEAR, which are 980, 910, 1000, and 1050 rounds, respectively. As the rounds progress, the final standing node of LEACH, SEP, MOD-LEACH, and M-GEAR dies after around 1275, 2100, 1500, and 1540 rounds, whereas TEZEM extends it to 3000 rounds. It can also be seen that in TEZEM the nodes do not start to die rapidly as it happens with the other four protocols. The network lifetime of the proposed protocol is 56%, 26%, 48%, and 47% greater than that of LEACH, SEP, MOD-LEACH, and M-GEAR, respectively.

SEP, MOD-LEACH, and M-GEAR, respectively. The main objective of designing any EE routing protocol in WSN is to maximize the lifetime of a network keeping in view the Quality of Service (QoS). In Figure 6, the evaluation of the network lifespan of TEZEM is done by using a comparison of dead nodes versus the total number of rounds. Results demonstrate that the TEZEM has a prolonged lifetime in comparison with the previously proposed protocols. As the network lifetime shows the nodes standing from the start till the last alive node, it can be observed in Figure 6 that as the rounds progress, the final standing node of LEACH, SEP, MOD-LEACH, and M-GEAR dies after around 1275, 2100, 1500, and 1540 rounds, whereas TEZEM extends it to 3000 rounds. It can also be seen that in TEZEM the nodes do not start to die rapidly as it happens with the other four protocols. The network lifetime of the proposed protocol is 56%, 26%, 48%, and 47% greater than that of LEACH, SEP, MOD-LEACH, and M-GEAR, respectively.
Figure 7 demonstrates the comparison of stability and instability period of TEZEM. The two periods of the compared protocols can be seen in the form of two adjoining parts of the total network lifetime. The stability time of TEZEM is significantly greater and best compared to LEACH, SEP, MOD-LEACH, and M-GEAR, which is the major achievement of our proposed model. Taking into consideration the total rounds, we can observe that the stability period of LEACH, SEP, MOD-LEACH, M-GEAR, and TEZEM is 32.7%, 30.3%, 33.3%, 35%, and 41.7%, respectively. The higher stability in TEZEM is achieved because of the well-planned distribution of the nodes and better mechanism of cluster formation in TEZEM. From Figure 7, we can also observe another important feature of TEZEM in terms of the instability period. In comparison with other protocols, the instability period of TEZEM starts later and the nodes do not die instantly. The first node in TEZEM dies after around 1250 rounds compared with that of LEACH, SEP, MOD-LEACH, and M-GEAR, which are 980, 910, 1000, and 1050 rounds, respectively. So this shows that TEZEM can survive longer in the field and can sense the environment and keep sending information as long as possible. A comparison of the stability period with network lifetime is also given in Figure 8.

Figure 9(a) and (b) shows the number of CHs per round. From the graphs, it can be seen that TEZEM accomplishes an optimal number of CHs in each round, whereas in LEACH, SEP, MOD-LEACH, and M-GEAR, an uncertainty can simply be observed as their CH selection criteria are based on a distributed algorithm that generates random CHs. The efficient CH selection in TEZEM is achieved by the formation of zones and static clustering. The formation of equalized zones helps in the selection of the fixed number of CHs in each round, which results in network lifetime prolongation and stability enhancement and makes TEZEM perform better compared with other distributed routing protocols. It can also be observed that due to uncertainty the CHs of LEACH, SEP, MOD-LEACH, and M-GEAR fluctuate rapidly, which badly affects the performance of these protocols and the packets which have to be received by the BS from CHs.

It is evident from the studies conducted on routing protocols that if the protocol has a longer lifetime, the nodes can send more packets to the CHs and BS and has higher throughput. Figure 10(a) and (b) shows the simulation evidence that TEZEM performs much better in terms of maximum data packets transmitted from nodes to CHs and from CHs successfully to BS. The results also highlight that compared with LEACH, SEP, MOD-LEACH, and M-GEAR, the proposed TEZEM ensures about 88%, 82%, 91%, and 90% extra packets from nodes to CHs and about 87%, 84%, 85%, and 24% extra packets from CHs to BS, respectively. Due to the even number of CHs and static clustering in the TEZEM protocol, its throughput is considerably higher than the other four protocols. Thus, it can be concluded that the throughput of TEZEM is much higher than that of LEACH, SEP, MOD-LEACH, and M-GEAR.

Performance analysis

The concept behind the zonal division is to operate the network traffic efficiently. Initially, the deployment region is evenly distributed in zones, which helps in balancing the network and reducing traffic load. Each node within a zone sends the information (data) to its CH and then that CH transmits that information to Sink. The zones are heterogeneous, which implies the fact that in every zone the number of nodes may differ. In the proposed protocol, we have introduced the concept of balanced CHs, and each zone in each round will have sole CH. The amount of CHs like the number of zones is static throughout the simulation time until and unless the whole cluster is dead.

Hence, the question arises that why 9 equal zones are used instead of 4, 6, or 12 in TEZEM. Because it is observed from the previous research on EE routing protocols that if we consider 100 x 100 m of network size with 100 nodes, ideally the number of CH per round should be almost equal to 10 because the network lifetime, scalability, and efficiency are subject to the formation of optimal number and position of CH. Thus, the development of several clusters should be optimal for prolonging the life of sensor networks. The optimal CHs in each round are computed as

\[ CH_{opt} = n \times p_{opt} \]  

where \( n \) is the number of CHs and \( p \) is the desired percentage of CHs per round. In our case, \( p \) is calculated as 0.09 above by using equation (10), so the desired number of CHs per round will be \( n \times p = 100 \times 0.09 = 9 \). In TEZEM, we considered nine zones that are very near to the ideal value which
the researchers considered while proposing previous protocols. That is why we divided the network into 9 parts, not 12 or 6 or 4, to get the ideal number of CHs in each round.

To witness the impact of 9 zones on the network performance, whether it is effective or not, we divided the whole region into 12, 6, and 4 equal zones as shown in Figure 11(a)–(c) to check the system performance in diverse scenarios.

Figure 12(a) infers that the 9-zonal distribution attains better stability in comparison with 12, 6, and 4 divisions. In 9 divisions, the first node dies at around 1250 rounds, while in 12, 6, and 4 divisions, the nodes started to die at around 1200, 700, and 600 rounds, respectively. If the total number of zones is taken into account, it can be observed that the CHs per round also decrease, which is not per ideal condition. Furthermore, the traffic burden will also increase on these CHs because of being less in number. This may influence the performance and stability of the whole network. Figure 12(b) shows the total number of CHs selected in each round.

Figure 13(a) depicts that 9 zonal divisions ensure about 10%, 20%, and 35% additional packets to CHs.
Figure 11. Network topology: (a) 12 zones, (b) 6 zones, and (c) 4 zones.

Figure 12. Total amount of dead and CHs/round: (a) total number of dead nodes/round and (b) total amount of CHs/round.
from nodes. Figure 13(b) illustrates that the throughput of 9 divisions is notably greater compared to 12, 6, and 4 divisions in stable and unstable regions. It can be seen from the graph that 9-zone topology guarantees about approximately 40%, 120%, and 170% extra packets to the BS from CHs in contrast with 12, 6, and 4 zonal topologies, respectively. The throughput of 9 zones is also greater than the other three zones because of the efficient CH selection. Hence, it is concluded that dividing the region into 9 zones will yield higher throughput in contrast to 12, 6, and 4 zones. The summary is given in Table 4.

### Table 4. Comparison of zonal divisions.

| No. of divisions | Stability | CHs/Round | Throughput |
|------------------|-----------|-----------|------------|
| 4                | Better    | Stable    | Better     |
| 6                | Good      | Stable    | Good       |
| 9                | Very Good | Stable    | Excellent  |
| 12               | Good      | Stable    | Very Good  |

It can be seen from the graph that 9-zone topology guarantees about approximately 40%, 120%, and 170% extra packets to the BS from CHs in contrast with 12, 6, and 4 zonal topologies, respectively. The throughput of 9 zones is also greater than the other three zones because of the efficient CH selection. Hence, it is concluded that dividing the region into 9 zones will yield higher throughput in contrast to 12, 6, and 4 zones. The summary is given in Table 4.

### Conclusion and remarks

To address the core challenges like reduction in power consumption in next-generation WSNs, the clustering routing protocols can be a vital solution, dividing the network into well-distributed clusters. This article proposed an EE hierarchical routing protocol called TEZEM for WSNs. The main purpose is to enhance network efficiency by improving the CH selection process by distributing the entire network division into several zones. TEZEM is a very effective and efficient method for CH selection as it guarantees an equal number of CHs in each round. The performance evaluation and simulation results demonstrate that TEZEM maximizes the lifetime of the network, throughput, and stability compared with previously proposed clustering protocols such as SEP, LEACH, MOD-LEACH, and M-GEAR. In addition, several simulations are conducted to show the impact of zonal division on TEZEM performance and the significance of dividing zones into nine equal parts. Results depict that 9 zonal divisions have greater stability and throughput in comparison with 4, 6, and 12. Many possible directions still need to be investigated in the field of WSNs. As future work, we will validate the efficiency of the proposed protocol in real scenarios such as monitoring physical or environmental conditions of large agricultural lands, sensor-based transportation systems, and battlefield monitoring. Besides, seeking unique CH selection methods to improve the network performance is also our future work. We will also extend the field size (300 m² and 1000 m²) with 300 and 1000 nodes, respectively, and observe the impact of field size on the performance of TEZEM.

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