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RESEARCH ARTICLE

Robustness Performance Analysis of OEERS Clustering Technique for Heterogeneous Network Models

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Abstract

Objectives: To design an Optimized and Energy Efficient Routing Scheme (OEERS) for heterogeneous wireless sensor networks. **Methods:** In OEERS algorithm the cluster head selection is done with the probability values based on available energy levels along with optimal cluster counts and node distance from base station. Hence, nodes with higher energy and located near to base station have higher probability to be selected as cluster head (CH). **Findings:** In this work, analysis for OEERS has been executed to prove the robust network performance for the designed sensor network in a multi-level heterogeneous environment in terms of key network parameters such as Arrival of Dead Nodes in various stages, Number of Packets Transmitted to Base Station, Number of Dead Nodes during Each Round, Residual Energy during Each Round, Dissipated Energy during Each Round, etc. Besides this, comparative analysis has also been performed to showcase the out performance of the OEERS technique over the DL-LEACH scheme.

Keywords: Cluster Head; Alive node; Advance and master nodes; Network Lifetime; Heterogeneous Wireless Sensor Network

1 Introduction

Wireless sensor networks (WSNs) have been popularly applied to monitor our environmental changes and events. When a sensor detects the occurrence of an event, it produces event packets and delivers it to notify the corresponding sinks, from which system administrators can realize the real situation of the monitoring environment and then react properly[(1)].Enabled by advances in intelligent systems, distributed signal processing and wireless communication technologies, and motivated by military and civil applications, WSNs recognized a new generation of a multi-functional sensor able to capture various types of environmental and physical conditions and characterized such as floods, fires, earthquakes, acoustic, agricultural, seismic, visual, health monitoring, thermal, security, and surveillance, etc by their low battery, low data processing capacity, small size and ability to move around and organize themselves into a network[1–4].

Wireless sensor networks (WSNs) are composed with large number of tiny nodes with different characteristics such as self-organizing, broadcast communication in short-ranges and routing in multi-hop. These tiny nodes equipped with many capabilities, support for radio implementations, processing, and high sensitivity, and deployed in remote areas to monitor, gathering data, and transmit the useful information about certain phenomena desired to monitor in that area, from any node to the desired destination. The deployment of sensor nodes be usually done in different modes, uniformly, randomly, or linear depending on applications and objectives. The general source of power in sensor networks is batteries; and this limitation in WSNs makes energy consuming as a most challenging matter. So, the most important challenge in WSNs is power consuming. Usually sensors distributed in unreachable area; if one of the sensors depletes its energy, replacing the batteries becomes complicated or impossible in some cases, and energy holes emerge. Moreover, the sensor node energy reduced during radio implementations. Therefore, in WSNs routing role an important issue and suitable election of effective routing protocols can preserve energy and extend network lifetime[5].

In addition, the sensor networks are comprised of plenty of nodes deployed in the field to communicate the data from an incredibly inaccessible far-off region along with the transmission of their subsequent reports headed towards the sink. An efficient design of a network with improvised network performance parameters is much essentially required during network design. Hence, the direct communication among the deployed sensor nodes and hence to the accessible base station (BS) is not sanguine and realistic. The conventional and classy scheme to resolve this issue is to split up the whole sensor network area into a variety of clusters and then selection of a node among the available cluster nodes as cluster head (CH)[6].

In this study, the author has worked upon the realization and robustness analysis of the Optimized & Energy Efficient Routing Scheme (OEERS) proposed in[7] to enable the salient network features such as energy efficiency, enhanced network lifetime, and elevated data transmission rates in heterogeneous surroundings. The heterogeneous network is consisting of the nodes deployed with a variety of energy levels rather than the equal energy level nodes attributed as suggested in current research ongoing such as DL-LEACH[8], MAC-LEACH[9], and O-LEACH[10]. The Optimized & Energy Efficient Routing Scheme (OEERS) proposed in[7] makes extensive use of the concept of heterogeneous energy distribution to avail the strategy of cluster head rotation derived from the probability distribution which is in turn function of the distance from the base station and residual energy of the corresponding deployed node. Moreover, in the OEERS scheme, the cluster head selection was derived from the threshold value which was inherently based on the residual node energy, the initial node energy, and distance of a node from the corresponding base station, and the probability of the node getting elected. The analysis of various network performance parameters based on the variety of network design parameters in the heterogeneous environment along with different network fields has been carried out in this work to prove the superiority of the OEERS scheme.

The rest of the paper is planned as follows. Section 2 briefly presents the related work in wireless sensor networks. Section 3 explains the OEERS network and energy model along with critical network design parameters in brief. Section 4 presents the analysis of the OEERS technique along with the comparative analysis. Sections 5 present the conclusion of the paper.

2 Related Work

On a broader classification level, the sensor networks are classified into two major categories namely homogenous wireless sensor network (with extensive use of homogeneous clustering technique) and heterogeneous wireless sensor network (with extensive use of heterogeneous clustering technique). Since battery performance in terms of energy savings together with network lifetime is key network performance parameters. Hence, designing an energy-efficient heterogeneous wireless sensor network is a challenging task owing to the complex energy distribution and configuration. Furthermore, the hierarchical routing technique is rooted in the concept of the division of the complete sensor network area into various small clusters along with the optimal selection of monitoring cluster heads (CHs) in heterogeneous network constraints the other network parameters. One of the most primitive hierarchical routing schemes for homogenous networks proposed was Low Energy Adaptive Clustering Hierarchy (LEACH)[11].

Furthermore, ample numbers of research have been carried out to design an energy-efficient wireless sensor network[12–14]. Furthermore, because the data broadcasting and data sinks are the segments with one of the most energy-consuming, for this reason, the energy cutback is one of the most significant as the key network performance parameter for designing optimized sensor networks[15]. A variety of both homogeneous and heterogeneous networks based on hierarchical clustering techniques have been proposed motivated and learned from the traditional and primitive LEACH algorithm. MODLEACH[16], HEED[17], PANEL[18], EEMC[19], EE-LEACH[20], Enhanced Centralized LEACH (ECLEACH)[21], EHA-LEACH[22], DEEC[23], TEEN[24], ACH2[25] etc. are few elegant and quite familiar examples of routing schemes.

Table 1 presents a comparative analysis of various versions of LEACH discussed and surveyed. The basic idea for selection of cluster head and functionality for these protocols along with their pros and cons are listed in this table. They are arranged in chronological order in this table. The selection of protocol depends on the choice of network performance parameters such as cluster formation, selection of cluster head, cost effectiveness, scalability, network lifetime, throughput, mobility, energy efficiency, complexity etc.

Table 1. Comparisonof Different Hierarchical Routing Schemes

Routing Scheme	Description	Advantages	Disadvantages
LEACH	CH selection is done using threshold-based probability. Single hope communication and used for homogeneous networks.	Delay is less Low complexity Cost effective	Poor scalability Not energy efficient Moderated stability and load balancing Poor lifetime
PEGASIS	CH selection is done randomly. Single hope communication with multi-level hierarchy and used for homogeneous networks.	Good lifetime Moderated energy efficiency	Delay is large Low stability High complexity Moderated load balancing
MOD-LEACH	Both inter and intra cluster communication take place by using two particular types of signal amplification	Low overhead Energy efficiency is better good load balance	High complexity Different signal amplification and synchronization
P-LEACH	Cluster center is taken as the node with maximum energy. Empirical prediction-based clustering scheme.	Energy efficiency is very high better lifetime Superior stability	Extremely high overhead and complexity
EE-LEACH	Conditional probability and use of Gaussian distribution scheme. Spatial density is useful for CH selection.	Energy efficiency is good, better lifetime High data rates	High overhead and complexity Low data integrity
CL-LEACH	Threshold value and residual energy for the deployed node is input. Uses relay nodes.	Energy efficiency is very high good load balance better lifetime	High overhead and complexity Poor data rates Less throughput
TEEN	Data is sent from lower-level cluster head to next level cluster head. Works on soft and hard threshold.	Very good lifetime Energy efficiency is good High stability	High complexity Poor scalability Calculation of dual threshold
DEEC	Custer head is selected by ratio of residual and average energy. Works in multi-level heterogeneous networks.	High stability Better lifetime Lower complexity	Moderated energy efficiency Advanced nodes die rapidly
EHA-LEACH	Maximizing the minimum conserved energy. CH Selection is based on energy consumption and energy harvesting capacity.	Energy efficiency is very high good load balance High throughput	Very high overhead and complexity Higher cost
DL-LEACH	Nodes are segregated based on distance. Direct communication between nodes and gateway if less distance without CH.	Less complexity and moderated overhead Good load balance	Moderated data rates Inferior network lifetime
COG-LEACH	During selection of cluster head, number of idle channels is used as weight to evaluate the probability	Better lifetime High throughput High scalability	High complexity Bad load balancing Energy efficiency is low
V-LEACH	Vice cluster head selection along with cluster head. If cluster head is dead VCH acts as CH.	Energy efficiency is very high good load balance	Low scalability High overhead and complexity
O-LEACH	Nodes which are not under regulation of any cluster head are named as orphan nodes.	Energy efficiency is very high Good load balance Better coverage	High overhead and complexity Less throughput
MAC-LEACH	Puts a restriction over number of cluster heads getting selected under CH advertisement.	Energy efficiency is very high good load balance High throughput	High overhead and complexity

3 Proposed Work

OEERS Network and Energy Model

The designed network clustering technique has been carried out for an arbitrary network field area of m x n dimensions with N number of sensor nodes deployed at random. Furthermore, these deployed nodes are treated as immobile through the duration of network simulation. These deployed sensor nodes are responsible for data broadcasting to one of the nearest base stations in closed network cluster proximity. In addition to this, the base station coordinates are again arbitrary and hence can be considered whether inside or outside the sensor network dimensions. Moreover, the designed sensor network area is categorized in diverse segments designated as clusters. Each cluster corresponds to a special sensor node recognized as cluster head (CH). Since the designed network is heterogeneous hence nodes are attributed to three different energy levels to enable the functionality as a three-level heterogeneous network.

As discussed in [7], in the designed three-level heterogeneous network, there are three different categories of sensor nodes of diverse node energy levels. Normal nodes with normal energy level E_o, Advanced nodes with the moderated energy level of additional 'α' times energy that is $E_o(1+\alpha)$ and master nodes with the highest energy level of additional 'β' times energy means $E_o(1+\beta)$. The fraction of nodes assumed to be advanced nodes are m_o and a fraction of nodes assumed to be master nodes are n_o. As a result, the preliminary energy sum for the designed three-level heterogeneous network is represented as in equations (1) and (2).

$$E_{total} = N(1-m_o)E_o + Nm_o(1-n_o)(1+\alpha)E_o + Nn_o(1+\beta)E_o \qquad (1)$$

$$E_{total} = NE_o(1+m_o(\alpha+n_o\beta)) \qquad (2)$$

Furthermore, the network energy model in conjunction with 'l' bit message broadcasting and sink for the communication distance of 'd' is given by equations (3 to 5) along with the relevant network parameters in equations (6 to 9) as presented in [7].

$$-$$

$$E_{round} = l\left(2*N*E_{diss} + N*E_{DA} + N*\varepsilon_{fs}*{d_{toCH}}^2 + C*\varepsilon_{mp}*{d_{toBS}}^4\right) \qquad (4)$$

$$E_{RX} = l*E_{diss} \qquad (5)$$

$$d_{toCH} = \frac{m}{\sqrt{2\pi C}} \qquad (6)$$

$$d_{toBS} = 0.765*\frac{m}{2} \qquad (7)$$

$$C_{opt} = \sqrt{\frac{N}{2\pi}}*\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}*\frac{m}{{d_{toBS}}^2} \qquad (8)$$

$$d_o = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \qquad (9)$$

OEERS Technique Network Flow

OEERS technique is a kind of threshold derived technique that incorporates four major network parameters namely distance of the specific node from the corresponding base station, residual energy of the corresponding node, cluster count, and existing residual energy of the designed wireless sensor network with the purpose of selection of cluster head (CH) for the given heterogeneous surroundings. The generic flow of the presented OEERS algorithm is shown in Figure 1.

Let us one of the given deployed sensor nodes of the network N_k, $(k = 1, 2, \ldots, N)R_k$ is the number of rounds carried out to perform the selection of cluster head (CH). Hence, using the basic probability theory the optimal probability (P_{ost}) of cluster head selection for a general homogeneous network is given by equation (10). Furthermore, for the given number of rounds, the average cluster head selection probability is given by P_k is calculated using equation (11).

$$P_{opt} = \frac{1}{R_k} \tag{10}$$

$$P_k = \frac{1}{R_k} \tag{11}$$

In addition to this, $E_{Avg}(i)$ represents the i^{th} round average residual energy which is presented in equation (12). For this reason, based on the cluster counts and available energy in the specific round; the essential and the critical probability value is presented in equation (13). Based on these network parameters, the threshold calculation is done as presented in equation (14) as presented in [7]. Furthermore, the average nodal probabilities of all three types of deployed nodes along with the corresponding threshold values and the frame-based total energy consumption are referred directly from the work presented in [7].

$$E_{avg}(i) = \frac{1}{N} * \sum_{k=1}^{N} E_k(i) \tag{12}$$

$$P_k(i) = P_{opt} * \frac{E_k(i)}{E_{avg}(i)} \tag{13}$$

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4 Result and Discussions

The OEERS algorithm implementation and entire analysis have been carried out using MATLAB (MATrix LABoratory) software with MATLAB codes. In addition to this, the corresponding network design parameters are presented in Table II. For the designed wireless sensor network, total numbers of 100 sensor nodes are deployed at random in various analysis network areas such as 100 x 100 m^2, 150 x 150 m^2, 200 x 200 m^2, etc. On the other hand, the base station (BS) can be located capriciously at any place but for straightforwardness, ease of analysis, and to maintain generality base station has been placed at the center of the designed sensor network area. In addition, with the intention of a robust analysis of the OEERS technique the heterogeneous network parameters such as several master and advanced nodes; energy multiplication factors, etc. are further assorted to analyze the performance of the designed network for a 100 x 100 m^2 network area with five different cases.

Analysis of various network performance parameters such as the round number for the arrival of first dead node, round number for the arrival of tenth dead node, round number for the arrival of all dead nodes (No alive nodes), number of data packets transmitted to base station throughout the network simulation time has been presented in Figure 2 to Figure.5 for five different cases namely

CASE-A (α = 0.5, β = 0.5, m_o = 1.5, n_o = 3)
CASE-B (α = 0.3, β = 0.3, m_o = 1.1, n_o = 2.5)
CASE-C (α = 0.4, β = 0.4, m_o = 1.3, n_o = 2.75)
CASE-D (α = 0.6, β = 0.6, m_o = 1.7, n_o = 3.25)
CASE-E (α = 0.7, β = 0.7, m_o = 1.9, n_o = 3.5) and tabulated in Table 2.

In addition, the comparative analysis based on the above-discussed network parameters for the OEERS algorithm and DL-LEACH scheme discussed in [8] has been performed. The comparative analysis is shown in Figure 6 to Figure 9 and

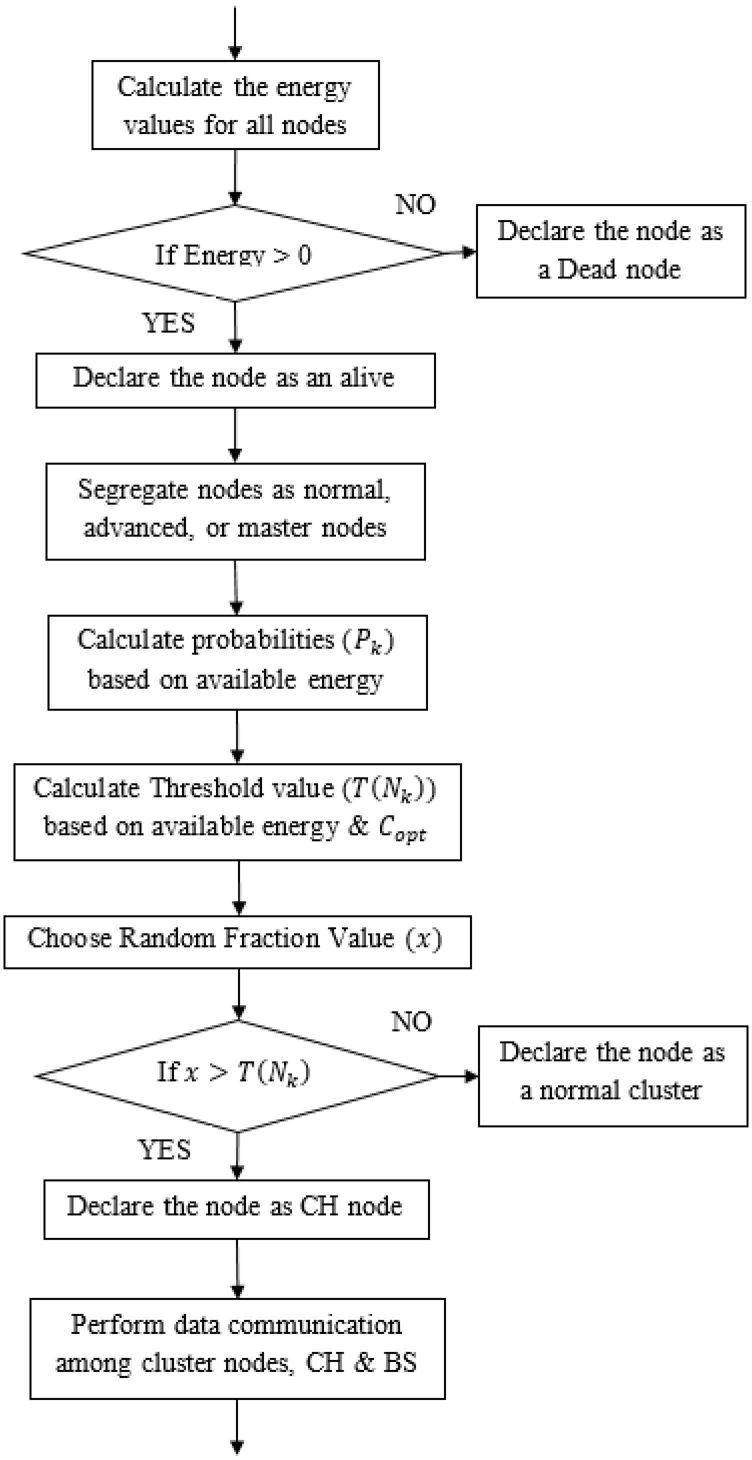

Fig 1. Flowchart of Proposed Work

Table 2. General Network Design Parameters

Parameter	Value
Area of Network	100m x 100m
Number of Sensor Nodes	100
Initial Energy of Normal Node (E_o)	0.5 J
Dissipation Energy during transmission (E_{TX})	50nJ/bit
Dissipation Energy during Reception (E_{RX})	50nJ/bit
Data Aggregation Energy (E_{DA})	5nJ/bit/message
Amplification factor for Free Space (ε_{fs})	10pJ/bit/m^2
Amplification factor for Multi-path (ε_{mp})	0.0013pJ/bit/m^4
Message Size	500 Bytes
Optimal Probability (P_{ost})	0.1
Maximum Number of Rounds (R)	15000

Table 3. Analysis of Various Network Parameters for Different Case Studies

Network Parameters	CASE-A	CASE-B	CASE-C	CASE-D	CASE-E
Round # (Arrival of First Dead Node)	1357	1326	1306	1315	1345
Round # (Arrival of Tenth Dead Node)	1690	1634	1634	1660	1834
Round # (Arrival of All Dead Nodes)	9869	8731	9324	10845	12127
Number of Packets Transmitted to BS	410583	276486	332628	490001	599096

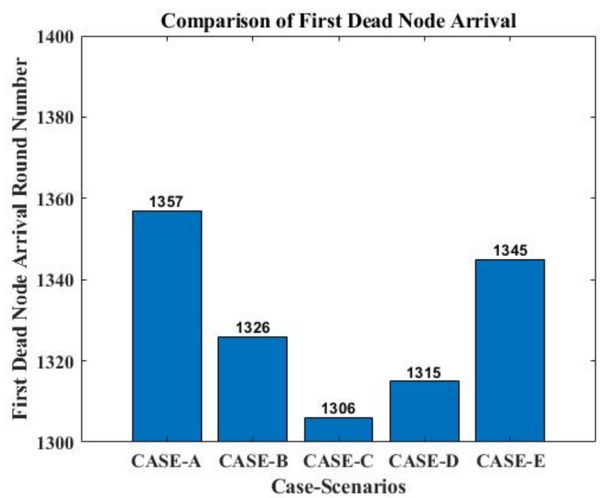

Fig 2. Analysis of Round Numberfor Arrival of First Dead Node

tabulated in Table VI to VI. Furthermore, the network performance parameters result for this comparison are also presented in Figure 10 to Figure 14. Table III proves the robust network performance of the designed sensor network in a heterogeneous environment. Furthermore, Table VI to VI proves the outperformance of OEERS in comparison to DL-LEACH scheme for all the corresponding network performance parameters.

Table 4. Network Parameters Comparative Analysis for 100 x 100 m^2

Parameter Name	OEERS	DL-LEACH
Round # of First Dead Node	1377	1004
Round # of Tenth Dead Node	1845	1063
Round # of All Dead Nodes (No Alive Nodes)	9848	1592
Number of Packets transmitted to BS	410406	109404

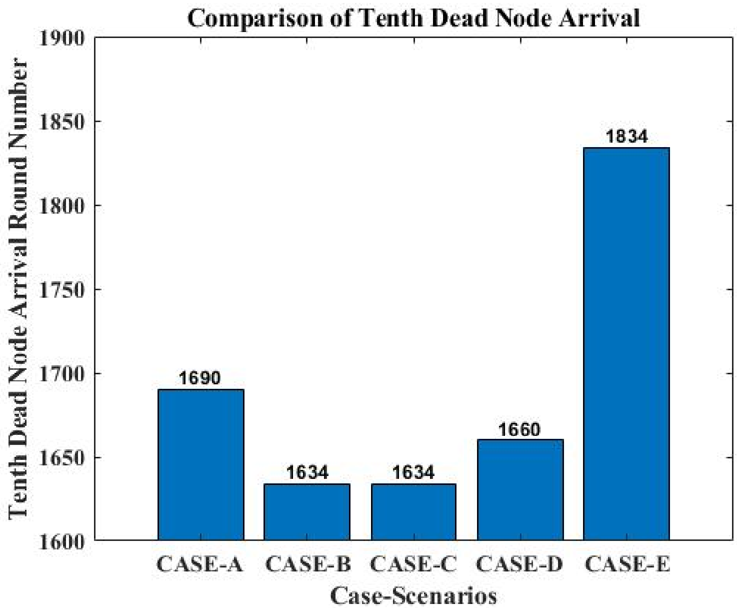

Fig 3. Analysis of Round Numberfor Arrival of Tenth Dead Node

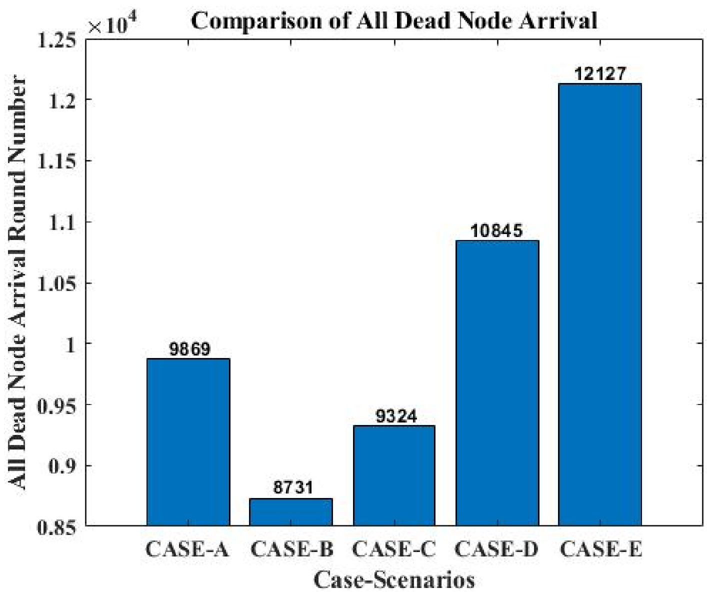

Fig 4. Analysis of Round Numberfor Arrival of All Dead Nodes (No Alive Nodes)

Table 5. Network Parameters Comparative Analysis for 150 x 150 m^2

Parameter Name	OEERS	DL-LEACH
Round # of First Dead Node	935	864
Round # of Tenth Dead Node	1083	1023
Round # of All Dead Nodes (No Alive Nodes)	9577	1380
Number of Packets transmitted to BS	318704	106417

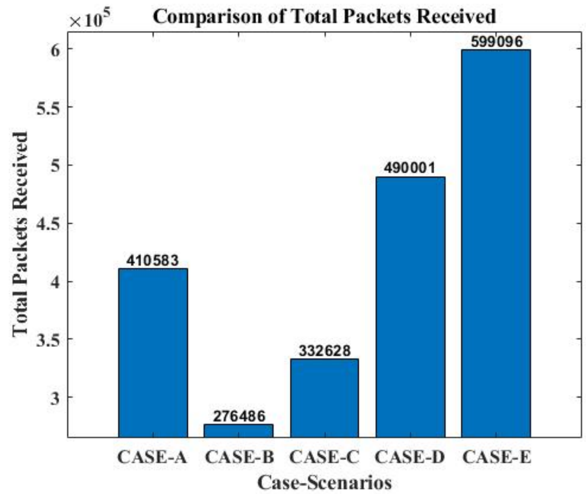

Fig 5. Analysis of Number of Packets Transmitted to Base Station (BS)

Table 6. Network Parameters Comparative Analysis for 200 x 200 m^2

Parameter Name	OEERS	DL-LEACH
Round # of First Dead Node	504	423
Round # of Tenth Dead Node	827	678
Round # of All Dead Nodes (No Alive Nodes)	8183	1329
Number of Packets transmitted to BS	233152	101882

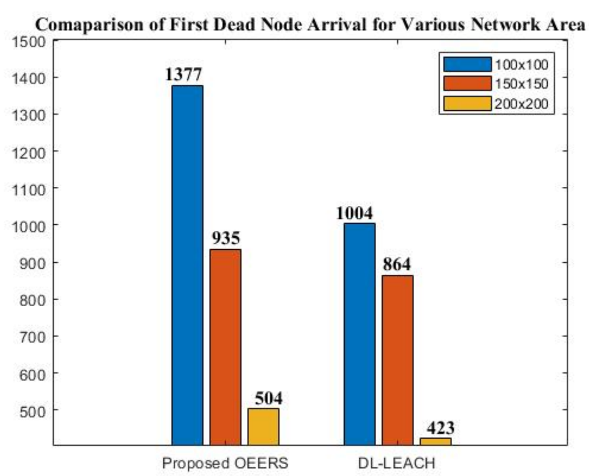

Fig 6. Comparative Analysis of Round Number for Arrival of First Dead Node

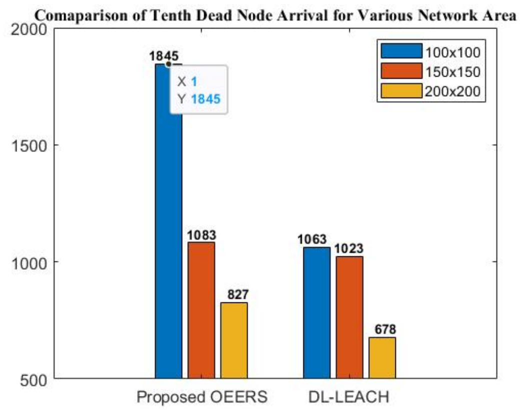

Fig 7. Comparative Analysis of Round Number for Arrival of Tenth Dead Node

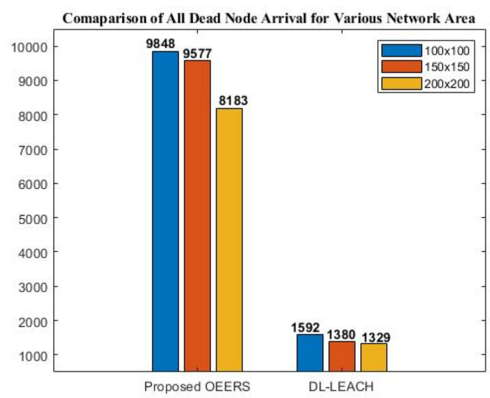

Fig 8. Comparative Analysis of RoundNumber for Arrival of All Dead Nodes (No Alive Nodes)

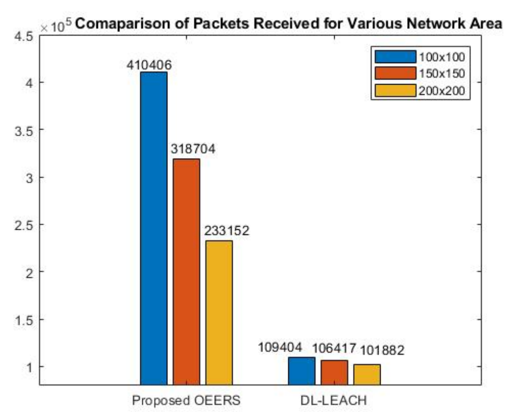

Fig 9. Comparative Analysis of Number of Packets Transmitted to Base Station (BS)

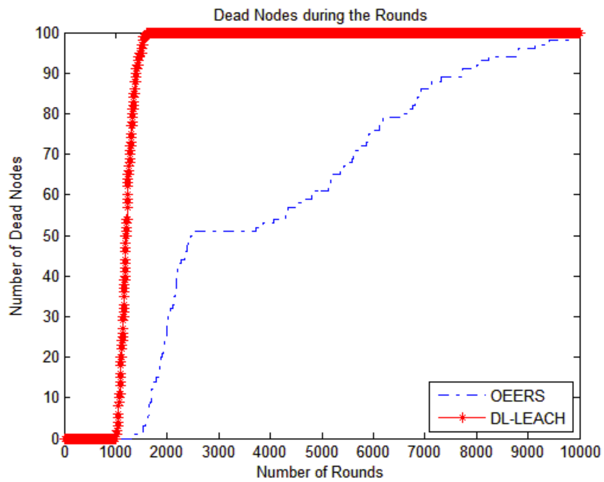

Fig 10. Comparison of Number of Dead Nodes during Each Round for 100 x 100 m^2

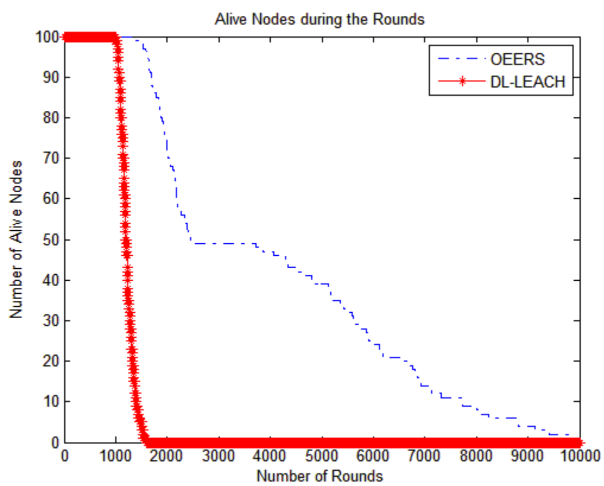

Fig 11. Comparison of Number of Alive Nodes during Each Round for 100 x 100 m^2

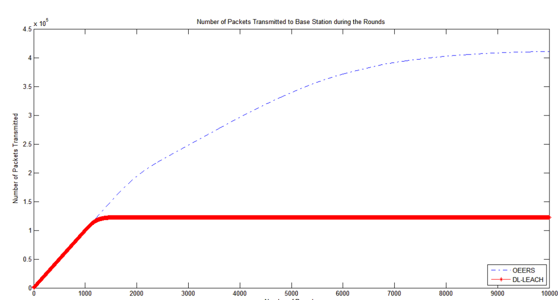

Fig 12. Comparison of Number of Packets Transmitted to Base Station (BS) during Each Round for 100 x 100 m^2

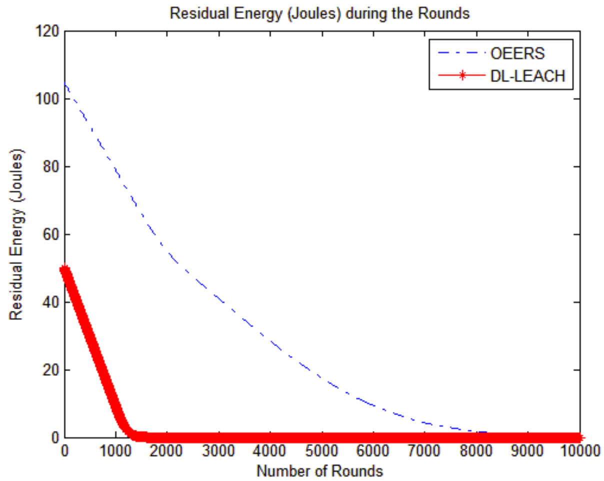

Fig 13. Comparison of Residual Energy during Each Round for 100 x 100 m^2

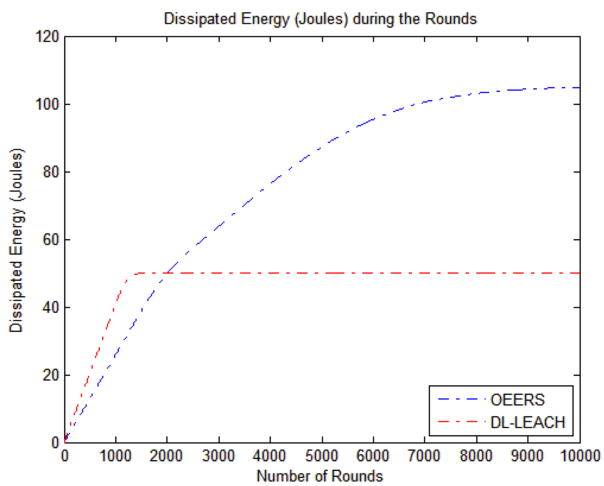

Fig 14. Comparison of Dissipated Energy during Each Round for 100 x 100 m^2

5 Conclusion and Future Work

In this study, we have carried out the robustness analysis and comparative analysis based on various network parameters for the Optimized and Energy Efficient Routing Scheme (OEERS) algorithm proposed in[7] designed for heterogeneous wireless sensor networks. The OEERS technique is a probability-based cluster head selection technique, where the probability values depend upon the residual nodal energy, number of clusters available inside the designed network, residual network energy, and the subsequent nodal distance concerning the corresponding base station. Analysis carried out here proves the robust network performance of the designed sensor network in the multi-level heterogeneous environment for various network parameters. In addition, from comparative analysis outperformance of the OEERS technique has been proven as compared to DL-LEACH scheme for all the corresponding network performance parameters.

In future this routing technique can be extended for multi level heterogeneous networks with good network security.

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