International Journal of Advance Research in Science and Engineering
Volume No. 12, Issue No. 06, June 2023
www.ijarse.com
IJARSE
ISSN 2319 - 8354

An Approach for Maximizing Network Coverage and Energy Utilization in Wireless Sensor Network

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Abstract

The development of various technologies, notably smart city and Internet of Things (IoT) applications, required the use of wireless sensor networks (WSNs). WSN has been employed in numerous crucial fields, including healthcare, defence, and transportation. However, the effectiveness of the deployed sensors nodes is primarily what these applications rely on, consequently, the deployment procedure must be performed effectively. In this paper, an effective and efficient WSN approach is developed where major work has been done on uniform node deployment. The main objective of the suggested technique is to reduce the energy consumption of nodes and enhance network lifespan. For this, three optimization models i.e. Particle Swarm Optimization (PSO), Whale Optimization Algorithm (WOA) and Teaching Learning based Optimization (TLBO) have been used in the proposed work for distributing nodes uniformly in the network for maximum coverage. This is due to the fact that these optimization algorithms have high convergence rate and doesn't get trapped in local minima. By distributing nodes uniformly, the communication holes are reduced which automatically reduces the energy consumption and hence enhances network lifespan. Through extensive experimentation the performance of proposed approach was validated in MATLAB software.

***Keywords**: Efficient energy, CH selection phase, Round Rotation method, WSN, overhead energy.*

Introduction

WSN research dates back to the Distributed Sensor Networks (DSN) initiative, which began circa 1980 at Defence Advanced Research Projects Agency (DARPA). The ARPANET (Advanced Research Projects Agency Network) had been up and running for a few years by this point, with roughly a couple of hundred hosts at research institutes and universities. DSNs were supposed to feature a large number of geographically spread economically efficient sensing nodes that worked with one another yet operated independently, with data being directed to the node that could best use it. This was a rather challenging programme at the time. There were no personal computers or workstations and processing was done primarily on minicomputers, and Ethernet was only beginning to gain popularity[1]. The latest advancements of economically efficient micro-sensor devices with wireless communication capabilities have drawn the attention of numerous academics and developers to WSN technologies. By constructing a network of battery-powered sensor nodes in a local or remote region, it is possible to receive information on the behaviour, condition, and position of elements.

However, the initial physical placement of the nodes has a significant impact on the efficacy of WSN in terms of coverage, connection, lifetime, and robustness, and there have been plans and surveys for sensor node deployment [2]. The deployment of nodes is a crucial but sometimes overlooked part of a WSN's performance. The deployment of nodes should take into account a number of important factors, including connectivity, coverage, and energy usage. Nodes are programmed to detect events within their sensing ranges and send the data to the base station(s). A WSN is made up of a smattering of self-configuring nodes with sensing, computing, and communication capabilities. The separate potential of WSN nodes may not be considerable though their network blend possess numerous implementation prospects. Usually, deployment of random node in hostile conditions or tough environment is preferable. The range upto which nodes can communicate with each other is defined as Communication range [3]

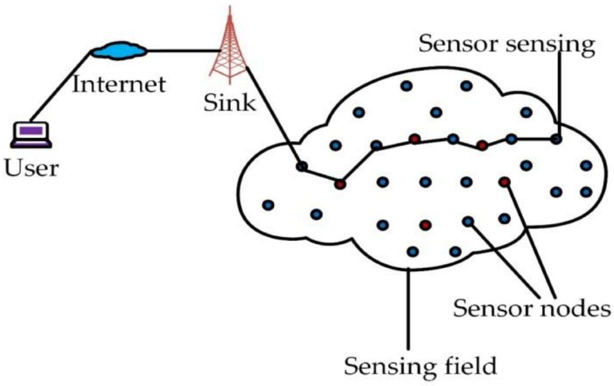


Figure 1. Architecture of WSNs

WSNs face a lot of challenges in its operation, among which WSN deployment is a major issue. It is due to the fact that consumption of energy and potential of the designed system is affected by WSN deployment. Hence, the critical issue which is required to be resolved in WSNs is deployment of nodes. Numerous problem complexities like communication, data fusion, routing, etc. can be easily minimized by following correct node deployment method. Moreover, with the reduction in energy consumption, WSNs lifetime will be prolonged. The effective utilization of possessed energy is the need of these nodes. Therefore, it resulted into designing of various techniques in order to ensure optimum usage of energy resources in WSNs integrating different clustering techniques [4]. Clustering is the process in which sensor nodes are grouped to form clusters and cluster heads (CHs) is elected for each cluster. CH is accountable for receiving the data from each node of cluster and dispatch the collected data to sink or base station. In order to fulfil the coverage requirement, sensors are generally deployed in a dense fashion enabling the sleep mode of particular nodes and hence ensures a good amount of energy savings. The lifetime of WSN is hugely affected by CHs selection. For CHs selection, a single or more criteria can be considered or it may be selected arbitrarily. An ideal cluster head is referred to that cluster head which possesses optimal residual energy, is located nearest to base station and comprised of neighbour nodes upto maximum limit. During selection of CH, it is tiresome to consider all the available criteria simultaneously and to sort it out, multiple attribute decision-making techniques can be applied [5].

Among the various challenges of WSNs, energy consumption is considered as the serious one. Taken into consideration the WSNs deployment in distant areas like forests, military zones or deserts, AA batteries are embedded in WSN nodes which possesses a lifetime which is limited. Also, it is not feasible to recharge these batteries. Moreover, many of these nodes are either mobile or stationary. As per the mentioned statement regarding constraints, the lifetime of node is reliable upon the source of energy. Hence, at the time of selection of node to move, usage of node's stored energy is significantly required by any deployment algorithm.

Failure of these nodes may give rise to the lacking sensor coverage in the FoI areas. The areas which lack sensor coverage are referred to as coverage holes. Performance of network can be degraded or the entire network is disrupted on the basis of severity of these coverage holes. By taking into consideration the goal of network coverage, there should be at least one node to cover the areas or zones with highest priority. While moving a node to high priority area in WSN network containing mobile nodes, more energy is consumed at the time of movement in case of large distance from that area. Therefore, if a target zone is nearer to a node, optimum performance is obtained in regard to energy efficiency. Hence, while designing the deployment algorithm, special attention should be paid to movement distance [4]. Since last years, the topic of research is maximization of coverage area covered by the WSN. WSN is dependent upon network coverage area which is fundamentally based on sensor nodes deployment. Depending upon the field taken under observance, various kinds of coverage areas are there i.e. point coverage, full coverage and barrier coverage. Among these, point coverage specifies coverage of a group of points whereas full coverage refers to coverage at each point in the AoI using at least one sensor and barrier coverage consists of covering an area from intruder attack. The evaluation of each coverage type is done following the process of deployment to assess the quality of each point [6].

According to available studies in which clustering is used for WSNs, the node are referred to as CHs at the time of selection. And hence, difficulties may emerge on observing a difference between actual node location and optimal CH locations, as clustering generally finds cluster head at cluster center. Foremost, at the time of determination of nearest nodes following the definition of CHs, the calculation burden gets hiked leading to reduction in the lifetime of network and more energy consumption. Next in order, due to large deviation between actual CH node location and optimal CH location, a selected node of another cluster might be by mistake employed as CH. At last, for more than one clusters, a single node may be selected provided it is nearer to the optimal location in several clusters. Therefore, CH nodes count may be lesser than the clusters count, resulting into suboptimal operation. Consequently, in order to consider the WSN characteristics involving the actual node location, clustering should be adapted [7].

Literature Review

In the past few years, a number of methodologies have been proposed for enhancing the lifespan of the WS Network. In this paper, we have studied papers from some renowned publications like "Scopus", "IEEE", "Hindwai", "Elsevier" and so on. A modified cluster-head selection algorithm was suggested by **Zhao, L. et al.** in [8] which was LEACH (LEACH-M) based, to meet the challenge of unreasonable cluster-head selection and extreme consumption of energy in WSNs. Both nodes network address and residual energy was used to optimize cluster-head threshold equation, on the basis of ZigBee's distributed address assignment mechanism (DAAM). Therefore, balancing of network energy burden and significant improvement in energy efficiency was carried out by LEACH-M using a cluster-head competitive mechanism. The algorithm when simulated on NS-2.35, results showcased minimization in energy consumption, a longer network lifetime and more data obtained at sink in both $300 \times 300m^2$ and $100 \times 100m^2$ regions. A new deployment method for sensor nodes was proposed by **Taniguchi, Yoshiaki &Kitani, et al.** in [9] to meet the challenge of accessing a monitoring region from the ground containing huge number of nodes which are distributed from the air. The proposed method consisted of a sensor in which each sensor node had a parachute and a device for switching between two falling behaviours i.e. gliding and falling in the air. Also, while being airborne, messages were exchanged between sensor nodes which alternated the falling behaviour in respect to neighbouring nodes density for reduction of non-uniform areas. The evaluated outcomes presented that the model attained a high uniformity in the node placement in comparison to conventional airdrop techniques. The main challenge faced in WSNs was selection of optimal cluster heads. Another technique modelled by **Puneet Azad, Vidushi Sharma et al.** in [10] was a fuzzy multiple attribute decision-making approach (MADM) for the purpose of CHs selection. The approach used three major criteria namely, the distance from the base station of the nodes, number of neighbors and residual energy for selection. The demonstrated results showed the efficiency of proposed approach in extension of network lifetime when compared to the distributed hierarchical agglomerative clustering (DHAC) protocol used in homogeneous environments. **X.-X. Ding, M. Ling et al.** in [11] proposed a method called as Dynamic K value LEACH (DK-LEACH) with the purpose of minimization of energy consumed which comes under distributed WSNs possessing uneven energy. DK-LEACH, an optimized cluster structure routing method, took into account the energy factor of CHs during clusters formation phase. Moreover, on the basis of distribution of nodes, proportion of calculated distance between CHs and non-CHs nodes and excess CHs energy was managed in a robust manner. Through simulated results, better performance of the proposal in comparison to LEACH was confirmed respective to network life time and energy consumption. Also, at least 8.75% of improvement was noticed in node survival rate comparative to LEACH. For the purpose of reduction of communication overhead, **Barati, H., Movaghar, A., et al.** in [12] presented an innovative cluster-based communication protocol for WSNs which was named as Energy Aware Clustering Hierarchy Protocol. The protocol generated a multi-level hierarchical structure in order to sufficiently route the data and collected later in WSNs. The proposed efficient model was able to choose the optimal cluster head (CH) in regard to several criteria such as lower communication costs, residual energy, cluster density and least distance base station, cluster members and cluster head for contribution in prolonging of network lifetime. The evaluated simulations showed the least energy consumption by the proposed model during clustering. Also, the suggested protocol selected correct count of CHs and ensured rapid completion of clustering comparative to available WSN clustering mechanisms. One of the major problems with respect to energy consumption was loss of packets occurred because of mobility of the sensor nodes. To meet the challenges, another routing protocol based on clustering was presented for mobile sensor nodes (CBR-Mobile) by **Awwad, S.A.B. et al.** in [13]. The technique involved cross layer design between network layers and medium access control (MAC). CBR-Mobile was traffic and mobility adaptive protocol which used two simple databases. The assigned timeslots of mobile sensor nodes which did not send data or moved out of the cluster would be reassigned to ingoing sensor nodes which lies within the cluster region. CBR-Mobile showcased better performance when scrutinized under MATLAB. It showed improvement in delay and fairness, energy consumption and packet delivery ratio in comparison to LEACH-Mobile and

AODV protocols. **Y. Jaradat, M. Masoud et al.** in [14] studied the impact of various node distributions in respect to consumption of energy in WSNs. Exponential, Normal and Uniform were the three node placement strategies which were used. To scrutinize the potential of the three node placement distributions with respect to network lifetime, network throughput and energy expenditure, LEACH clustering algorithm was applied. The evaluated outcomes showcased outperformance of normal distribution particularly when the distance from base station was larger. **X. Yu, W. Huang et. al** in [15] proposed a modified virtual force-based node self-deployment algorithm in which all nodes were computed as points controlled by attractive and repulsive force applied on them and movement of nodes were subjected to the calculated force. Delaunay triangulation was created with the use of these nodes resulting into adjacent relationship if connection was established between two nodes in the Delaunay diagram. The exertion of force can only be done from adjacent nodes falling within the communication range. Through extensive simulations, the proposed technique presented quicker convergence time and increased coverage rate comparative to conventional virtual force approaches. The non-uniformity in placement and dimensions of clusters effect the performance of WSN. **Enam, Rabia & Qureshi et. al** in [16], proposed an algorithm called as a Distributed Uniform Clustering Algorithm (DUCA) for WSN which were cluster-based. In the proposed algorithm, the basis of cluster formation was virtual-grid system and node sensing ranges providing homogenized cluster sizes, decrease in energy consumption and even clusters distribution. The simulation outcomes showcased reduction in consumption of energy upto 15% to 50% range and more than 2 times improvement in cluster heads distribution when compared to state-of-the-art algorithms. The consumption of energy in selection phase of cluster head (CH) of a wireless sensor network (WSN) which based on random clustering was presumed as an irrelevant factor in the earlier study works. In [17], After analysing the above given literatures, it is observed that researchers have already proposed a number of approaches for enhancing the lifespan of WS networks. A number of factors contribute to the efficient working of WSN, out of all factor’s node deployment is one of the major factors to be considered in WSNs. Majority of authors have worked on effective CH selection and communication techniques and not much work has been done on uniform deploying nodes. Moreover, the existing WSN models tend to deploy nodes randomly which results in huge communication lag areas in the sensing region. Due to this uneven distribution CH have to travel farther distances for collecting data from nodes which results in high energy consumption and ultimately low network lifespan. Keeping these findings in mind, a new and effective WSN approach will be designed in this work that can overcome above mentioned shortcomings and enhance lifespan of entire wireless network.

Overview of Proposed Work

As discussed earlier that traditional Wireless networks models undergo through some limitations due to the uneven nodes distribution in the sensing region, resulting in huge energy consumption of nodes and less network lifespan. Therefore, in order to overcome these limitations, a novel and improved wireless network model is proposed in this paper, wherein nodes are distributed uniformly in the network. The key goal of the proposed wireless network is to deploy nodes in the sensing region in such a fashion that communication holes are reduced so that overall energy consumption reduces which ultimately enhances the lifespan of network. Unlike, any other wireless model, the basic functioning of proposed wireless network remains same except for the fact that, we have focused on uniform node deployment. After analyzing the literature, we analyzed that due to random deployment of nodes, some areas in the sensing region are heavily clustered with sensor nodes whereas, there are some areas where not a single node in present, thereby creating communication holes. These communication holes disrupt the effective functioning of the wireless network as CH needs to travel longer distances for collecting information from sensors which depleted their energy more frequently and ultimately reduced network lifespan. To combat this problem, the nodes in the proposed wireless network are distributed uniformly in the network so that all areas are covered. The issue of network coverage in WSN can be addressed effectively by using optimization algorithms. In the proposed work, we have utilized three optimization algorithms i.e. Particle Swarm Optimization (PSO), Whale Optimization Algorithm (WOA) and Teaching Learning based Optimization (TLBO) for solving the network coverage issue in WSNs. In our wireless network, we have tried to deploy nodes uniformly in the network by using PSO, WOA and TLBO individually. The main motive of using three algorithms individually is to analyze which algorithm is able to effectively reduce the communication holes in the network and enhance the network lifespan. In order to find the communication holes in the network, we have used triangularization method by employing Delaunay algorithm in the MATLAB software. In our approach, we have tried to reduce these communication holes by deploying nodes via PSO, WOA and TLBO algorithms. The main motive for using these three optimization algorithms in proposed work is that they possess high convergence rate and doesn't get trapped in local minima while searching for best solution. Once the nodes are deployed in the sensing region, again communication lag difference is calculated which serves as the fitness function. Finally, we have analyzed the efficacy of three optimization models in order to demonstrate how uniform distribution of nodes can reduce energy consumption whilst increasing the network lifespan.

The proposed approach then works in similar fashion of making clusters, selecting CH in the networks and finally starts communication. the clusters are formed in the network by using LEACH technique and for selecting the CHs in the network, equation 1 is used.

$$T(n) = \begin{cases} \frac{P}{1 - P(r \bmod \frac{1}{P})} \times \frac{E_{residual}}{E_{initial}} k_{opt}; for\ all\ n\ ÚG \\ 0; otherwise \end{cases} ------(1)$$

Where, $E_{residual}$ and $E_{initial}$ represent the remaining energy present and initial energy of nodes, whereas, k_{opt} represents the optimal number of clusters formed in the network and can be calculated by using the equation 2.

$$k_{opt} = \sqrt{n/2\pi} \sqrt{\frac{E_{fs}}{E_{amp} d^4 (2m-1) E_0 - m E_{DA}}} ----(2)$$

Where, M represents the diameter of network and E_0 demonstrates the initial energy of the nodes. The CH nodes then collects information from sensor nodes and passes it over the base station or sink node via single hop or multi-hop communications. The step by step working of the proposed model is given in coming up sub section of this paper.

Implementing Proposed Work

In order to get the desired results, the proposed model undergoes through number of steps of network initialization, node deployment, cluster formation, CH selection and finally communication and each step is discussed in this section in brief. As mentioned earlier, that proposed work utilizes three optimization algorithms like PSO, WOA and TLBO for distributing nodes uniformly in the network. These optimization algorithms tend to reduce the communication holes so that energy consumption is reduced and network lifespan is increased.

Network Initialization: In the very first step, network is initialized wherein different parameters like diameter of network, total nodes to be deployed and their energy is defined. Other than this, there are number of other parameters whose specific values are recorded in tabular form and are shown in table 1.

Table 1: Network initialization Parameters

Parameters	Values
Network Diameter	100m^2
Total nodes to be deployed	100 nodes
Total network energy	0.25 j
Energy dissipation: receiving (E_{amp})	0.0013pJ/bit/m^4
Energy dissipation in Free space model (E_{fs})	10 pJ/bit/m^2
Energy dissipation in power amplifier (E_{amp})	100 pJ/bit/m^2
Energy dissipation in aggregation (E_{DA})	5nJ/bit

Random Node distribution: After the network has been initialized, nodes are deployed randomly in the given sensing region of network. A total of 100 nodes are deployed in the 100*100-meter sensing region with initial residual energy of 0.25j. The nodes deployed in the region are shown in figure 1.

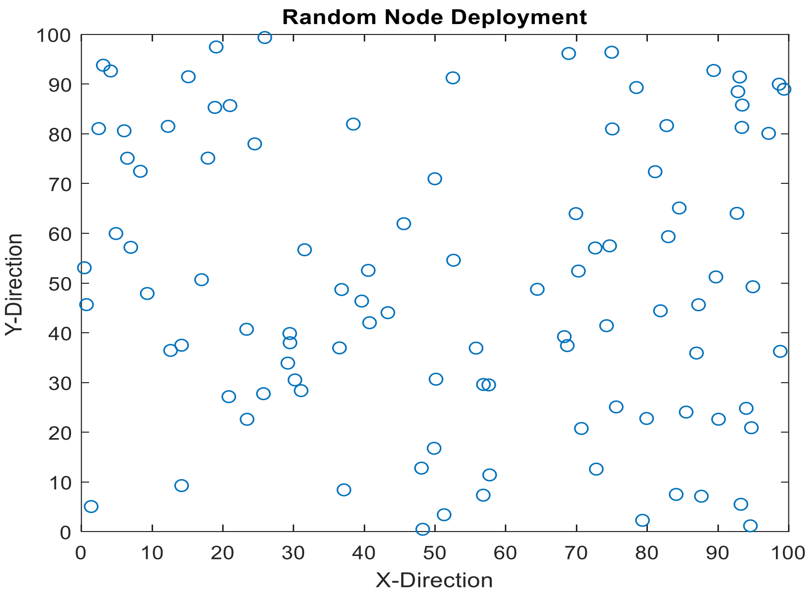


Figure 1. Random node deployment

As seen in figure 1, that due to random deployment there are some region in the sensing area that are clustered with huge number of nodes whereas, there are some regions where nodes are not present, thereby creating communication holes.

International Journal of Advance Research in Science and Engineering
Volume No. 12, Issue No. 06, June 2023
www.ijarse.com
IJARSE
ISSN 2319 - 8354

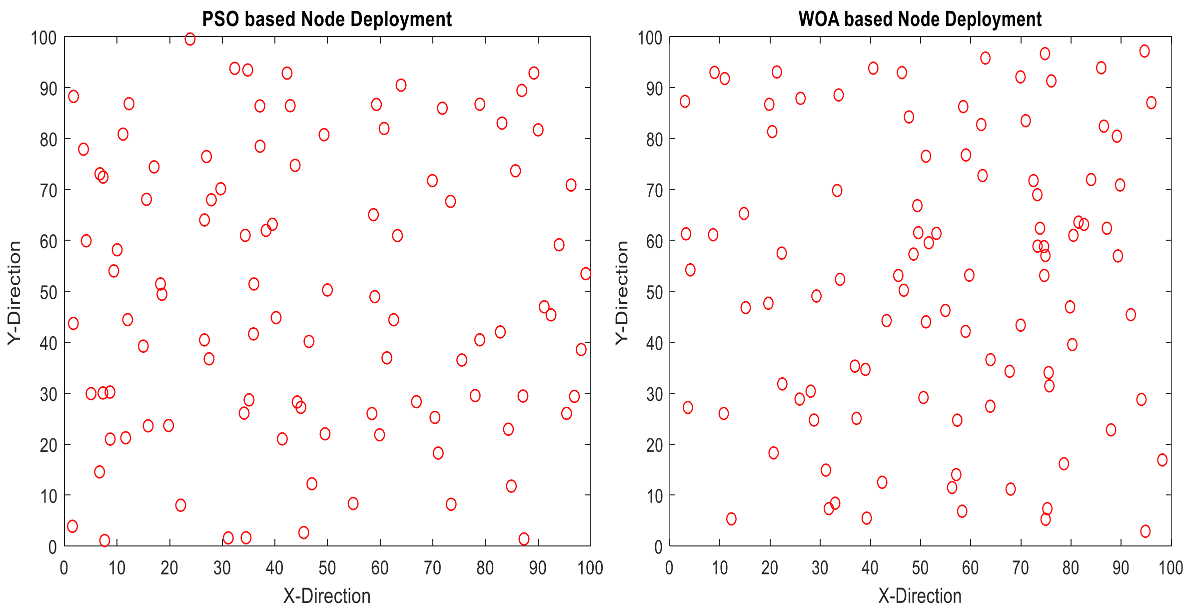
Implement Triangularization Technique: In the next phase of proposed model, triangularization technique is implemented by using Delaunay algorithm for calculating the total area covered by nodes and communication holes in the network. The communication holes present in the network are responsible for the increased energy consumption and reduced network lifespan. The main motive of our technique is to reduce these communication holes by deploying nodes uniformly in the network.

Initialize PSO, WOA and TLBO: After this, three optimization algorithms i.e. PSO, WOA and TLBO are initialized wherein population size of 5, total iteration 100 are defined along with some other specific parameters. Table 2 represents the tables wherein different optimization parameters are defined.

Table 2: Initialization of PSO, WOA and TLBO

Parameter	PSO	WOA	TLBO
Population	5	5	5
Iteration	100	100	100
C1	2	-	-
C2	2	-	-
w	[0.4 0.9]	-	-
b	-	1	-
p	-	[0 1]	-
a	-	[2 0]	-
l	-	[-1 1]	-

Once these algorithms have been initialized, nodes are deployed uniformly by using PSO, WOA and TLBO optimization algorithms. The three optimization models try to distribute nodes in such a way that entire sensing region is covered and communication holes are reduced. The nodes deployed by PSO, WOA and TLBO are shown in figure 2 (a), (b) and (c) respectively.



(a) (b)

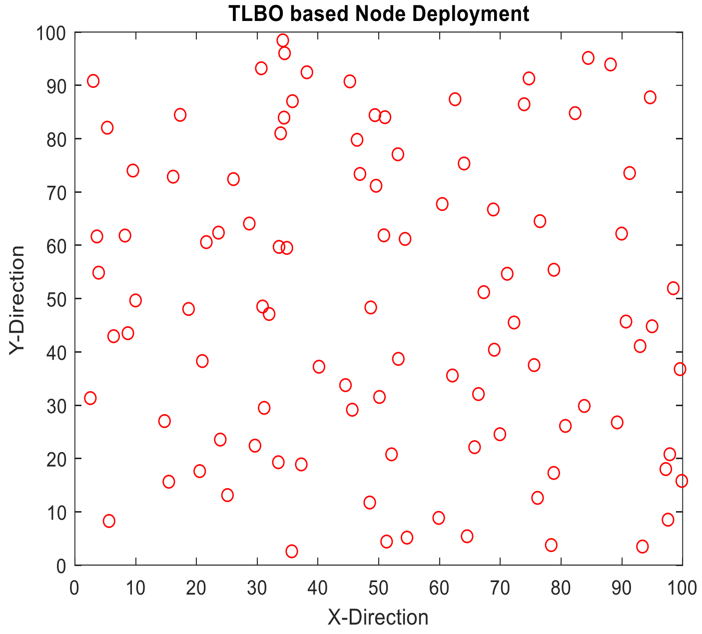


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Figure 2. Uniform node deployment by PSO, WOA and TLBO algorithms

Calculate communication lag: After deploying nodes uniformly in the network, again the communication lag is calculated in the network in order to see is there any difference marked through node distribution. The efficacy of the model is inversely proportional to the communication lag, which means if the communication lag is more in the network, less efficient is the network and vice versa.Figure 3 represents the communication lag when nodes are deployed randomly and uniformly by PSO, WOA and TLBO algorithms.

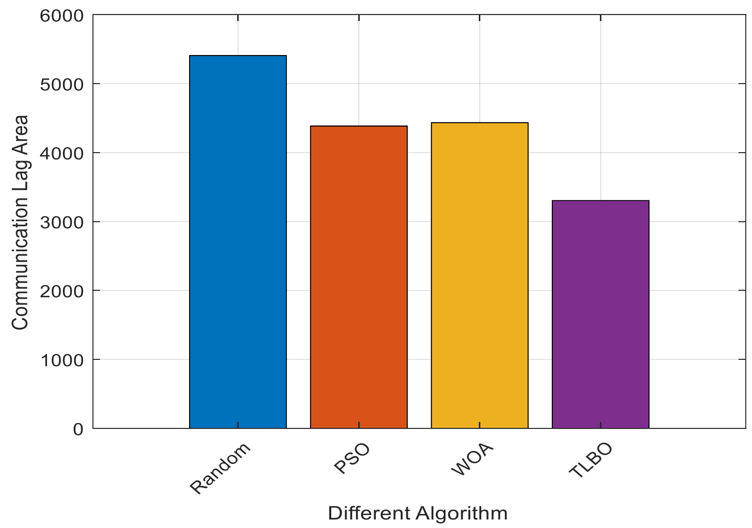

Figure 3. Communication lag in random and uniform nodes distribution

Above figure shows the comparison graph for communication lag obtained in random and uniform node deployment. As per the graph, it is clear that during random deployment, the communication lag is highest, while as communication lag reduces considerably with uniform node deployment. The specific value of communication lag are given in table 3.

Table 3: Comparison for communication lag

Parameter	Value
Random	5407.9
PSO	4386
WOA	4433.9
TLBO	3305.5

The table values specific that least communication lag is obtained by TLBO optimization algorithm, followed up by PSO and then WOA with 4386 and 4433.9 respectively.

Calculate fitness value: Finally, the fitness value obtained in the PSO, WOA and TLBO models is determined for 100 iterations. At each iteration, the communication lag is calculated and if the value attained is better than previous one, then it is replaced otherwise next iteration is performed. This process keeps on repeating for a specific number of iterations until the best fitness value is attained. Figure 4. Shows the fitness value graph attained for 100 iterations.

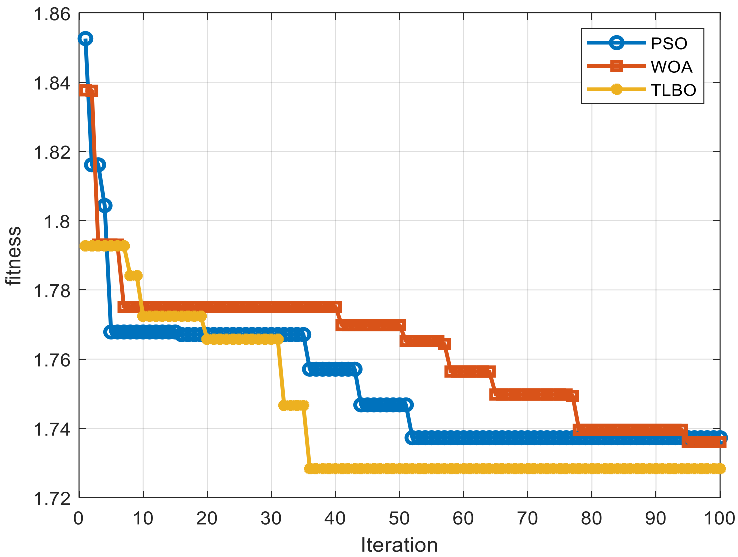

Figure 4. Fitness value obtained in PSO, WOA and TLBO

Cluster formation: The next phase is to form clusters in the network by randomly selecting CH nodes in the network. These CH nodes are responsible for forming clusters in the network where all the nodes that lie in the close proximity are grouped together. The clusters are formed by using equation 2.

CH selection: once clusters are formed in the network, it is time to select the CH in each cluster so that less energy is consumed while collecting information. In the proposed work, CH are created by using the equation given in 1.

Communication: After selecting CHs in the network, communication phase is started wherein, CH node collects information from sensor nodes and then passes it over to the base station or sink node via single hop or multi-hop.

Performance Analysis: Finally, the efficacy and effectiveness of the suggested uniform distribution technique is examined and validated by comparing it with few state of art methods in MATLAB Software. The results obtained for each model are discussed briefly in next section.

Simulation Results

In order to prove the efficacy of our approach, we analyzed its performance with few standard WSN models in terms of factors like, dead node, throughput, average and Residual energy. The results obtained for each parameter were validated by comparing it with standard models to prove the efficiency of proposed WSN technique.

Performance Evaluation

In the very beginning, we analyzed and contrasted the performance of five routing protocols i.e. LEACH, R-LEACH, PSO, WOA and TLBO models in terms of dead nodes. The comparison graph obtained for the same is given in figure 5, where x-axis and y-axis calibrates to total number of rounds to be performed and dead nodes value. After analyzing the given graph, it is revealed that nodes are trying more quickly at 800 and 1100 simulation round in previous approaches like LEACH, R-LEACH. On the other, by deploying nodes uniformly PSO and WOA techniques were showing better results as nodes were depleted at 1200 and 1300 simulating rounds respectively. While as, we also observed that optimization model TLBO model is yielding more promising results as nodes start dying at 1400 simulating round because of the uniformly distribution of nodes throughout the sensing region.

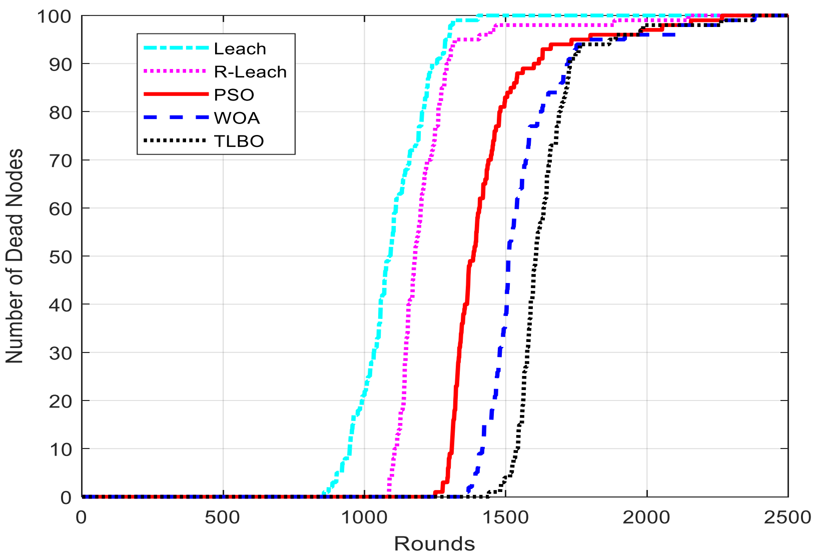

Figure 5. Comparison for dead nodes

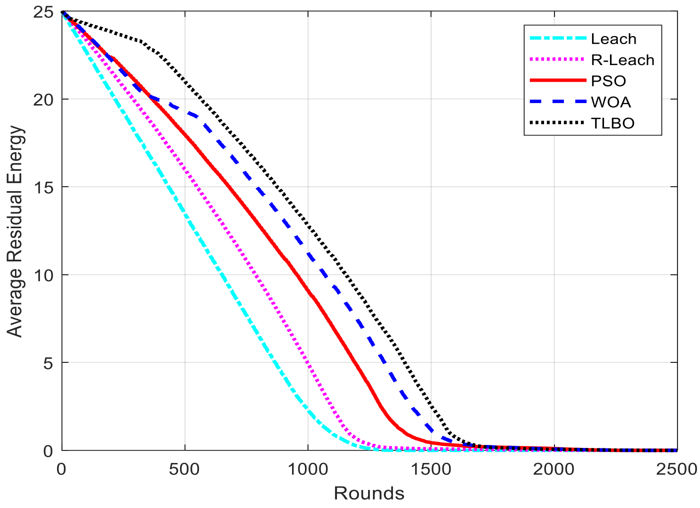

Figure 6. Average Residual Energy comparison graph

Figure 6 illustrates the comparison graph between traditional LEACH and R-LEACH models and optimization models PSO, WOA and TLBO models in terms of their Residual energy. The x-axis of the above graph corresponds to the simulating rounds and y-axis corresponds to average residual energy of different models. After carefully analyzing the graph, it is observed that standard LEACH model shows worst performance as its entire energy is depleted just after completing 1300 rounds, whereas, average residual energy is retained up to 1400 rounds by the R-ELACH model. However, the energy is further optimized by PSO, WOA and TLBO optimization algorithms in which node energy lasts up to 1500, 1600 and 1650 simulation rounds. Moreover, it is also analyzed that TLBO is outperforming other two optimization models in terms of residual energy because of the less communication lag generated by model.

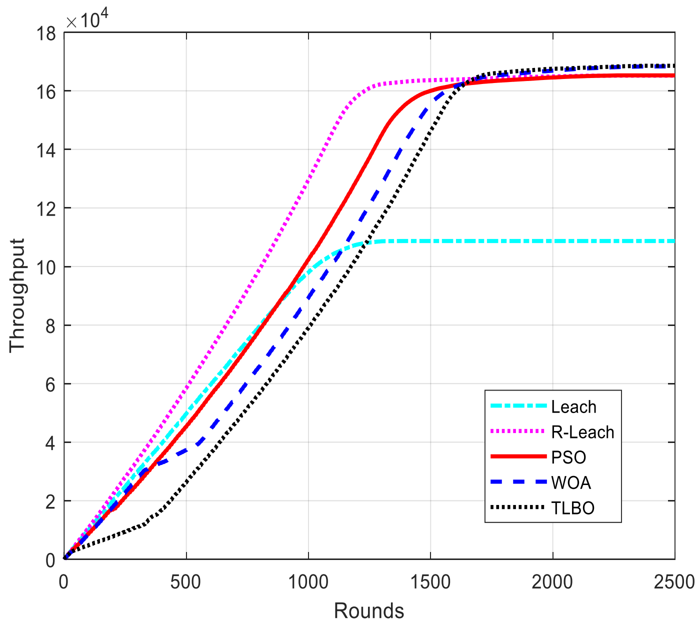

Figure 7. Comparison for Throughput

Moreover, the performance of the proposed approach is also analyzed and compared with standard models under Throughput. After analyzing figure 7, throughput comparison among LEACH, R_LEACH, PSO, WOA and TLBO shows lowest throughput is produced by LEACH models, followed up by WOA, PSO, R-LEACH models. While as, TLBO model is able to generate highest throughput. These stats prove that efficiency of the WSN is enhanced greatly when nodes are distributed uniformly in the sensing region.

From the above given graphs and tables, it can be concluded that the lifespan of wireless network is enhanced significantly with uniform node distribution. Among the three uniform distribution systems i.e. PSO, WOA and TLBO, WOA has highest network lifespan up to 2381 rounds, followed up by TLBO up to 2381 rounds and lastly PSO up to 2266 rounds. These figures prove the efficiency and effectiveness of the proposed approach.

Conclusion

This paper presents an effective and efficient WSN approach wherein, nodes have been distributed uniformly in the network. The effectiveness and usefulness of the suggested approach is analyzed and examined in MATLAB software. The simulating results were observed in terms of their dead nodes, throughput, residual energy and lifetime evaluation. The results revealed that when nodes were distributed uniformly nodes communication holes decrease significantly when compared with random node distribution models. The communication lag attained during random distribution is 5407.9, whereas, it was obtained 4386, 4433.9 and only 3305.5 in PSO, WOA and TLBO uniform node distribution models. These values stimulated that TLBO optimization model has lowest communication lag which means communication happens more effectively with enhance network lifespan. In addition to this, it was also analyzed that network lifespan came out to be least in LEACH model followed up by R-Leach Model that also have random node distribution. On the other hand, it was observed that when nodes were distributed uniformly in PSO, WOA and TLBO models the lifespan of network was increased considerably. These figures show that network lifespan is enhanced considerably when nodes are distributed uniformly to validate proposed work.

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