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ORIGINAL RESEARCH

Fault Tolerance and Energy Efficient Multi-Hop Clustering with Dual Base Stations in Large Scale Wireless Sensor Network

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Abstract
Wireless sensor network (WSN) with the recent advancement in wireless technologies and numerous applications gaining its impact and market value. WSNs are the collection and connection of low-cost sensor nodes deployed over some monitoring areas, where human monitoring is quite difficult. At the same time, the limitation of these low-cost sensor nodes has identified numerous issues and implementation challenges. In this paper a brief introduction to WSN and its market statistic and impact. Some of the major issues and challenges are identified and addressed in this paper. The main contribution of this research work is to design a fault tolerance in the network with multiple base stations. The multiple base station will work with the multi-hop cluster head based on the shortest distance in the WSNs. The proposed method is focused on major metrics of the WSN application like—throughput and network lifetime. With the usage of multiple base stations this paper aims to contribute to major challenges in WSN.

Keywords FECH · LEACH · Multiple base station · Fault tolerance · Mobile agent

Introduction

Wireless Communication has seen vast advancement in recent years with many latest technologies, and protocols. This impact has made wireless sensor networks (WSNs) the most influential for many real-time applications. WSNs are also influencing other domains like—artificial intelligence, machine learning [1], internet of things [2]. These domains are data-driven and need real-time data for analysis and prediction. This application requirement is fulfilled by WSNs by providing real-time data collection from the environment. This data collection is automated without the actual need for human intervention in many of the remote locations. This feature of WSNs makes it an integral component of the majority of automated applications [3] like—home automation, industrial applications, military and surveillance applications, intelligence traffic management, the health sector, IoT, and many others.

These features of WSNs create a huge response in the business sectors and making a huge demand in the market. As per the report, the overall market size of WSNs was $85.7 billion in 2021 and it is to be expected to increase to $108.6 billion by 2028 [4, 5]. This impact and numerous applications of WSNs are the main motives for this research work to contribute to the WSNs research sector by addressing some of its challenges and issues.

Issues and Challenges in WSN

WSNs have gained an impact because of their architecture and remote accessing ability in hostile environments. The reason for this WSNs is low-cost sensor devices come with minute components. This makes WSNs compromise some functionality like—limited energy sources because of low battery capacity, limited memory and storage, and

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physical damage to the sensor nodes [6–8]. These properties of WSNs may affect their performance in terms of the reduced lifetime of the sensor nodes, fault in data transmission to the destination, and loss of critical information in between operations. Some of the other issues and challenges depending on these properties are presented in Tables 1, and 2.

Considering these issues and challenges in WSNs, this paper focuses on addressing some aspects of WSNs to enhance their performance. From the initial survey, it is identified that there exist numerous approaches to address various challenges, as listed in Table 3.

Related Work

This section focuses on identifying some of the specific approaches in WSNs that are mainly concerned with energy efficiency, fault tolerance, data availability, and multiple base station.

Fault-Tolerance Review

Researchers in [13] have identified and classified faults in the WSNs into various types, as shown in Fig. 1. Each stage in WSNs has some types of faults which affect the performance of the WSNs. A component fault like—sensor nodes and base station, or network fault–intermediate nodes failure, affects overall network performance.

A Robust Mutual Authentication Protocol for WSN with Multiple Base-Stations [14]

A robust and effective multiple base station protocol is proposed in the existing work. This protocol also addresses the various security issues in WSNs and analysis has been carried out with respect to the security aspect. Authentication is one of the major security parameters that need to be considered for most applications. Figure 2 shows the network topology with multiple base stations. These multiple base stations will optimize the energy consumption of the sensor nodes by reducing the transmission distance.

Table 1 Issues in WSN

Limitation	Issues
Low battery capacity	The sensor node's lifetime may be reduced and may fail to perform the operations as required for applications
Low memory	Sensor nodes may fail to execute the protocols or algorithms for data sensing and transmission
Low storage	Sensor nodes will be unable to store the data collected for a long duration
Physical damage	An entire node may fail to operate accurately and may cause failure to enter the application

Table 2 Challenges in WSN

Issues	Challenges
The lifetime of the network	Increasing the lifetime of the sensor nodes to increase the operational lifetime of WSNs is one of the major challenges. One needs to ensure the overall energy consumption of the nodes
Node failure	The energy dissipated from the sensor nodes for various operations must be optimized to ensure the failure of nodes
Operational complexity	Designing a protocol or algorithm with low complexity is a major challenge. Since the protocol or algorithm is one of the ways to enhance the performance of the sensor networks
Data availability	The data collected from the sensor nodes must be available for further processing by sink or base station. Failure of nodes may result in loss of data. Ensuring fault tolerance and making data available may be challenging

Table 3 Performance enhancing approaches

Approaches	Features
Clustering, routing	Energy-efficient data transfer, optimizing the energy dissipated by the sensor nodes for data transmission
Multi-path, multi-hop	Ensuring data availability in the network with fault tolerance
Multiple base station	Network area provided with multiple base stations ensuring load balancing

Based on the above approaches, many numerous descendant approaches exist centralized, decentralized clustering, hierarchical clustering [9], protocols based on processing, data aggregation with clustering [10], location aware clustering [11] gossiping, flooding [12]

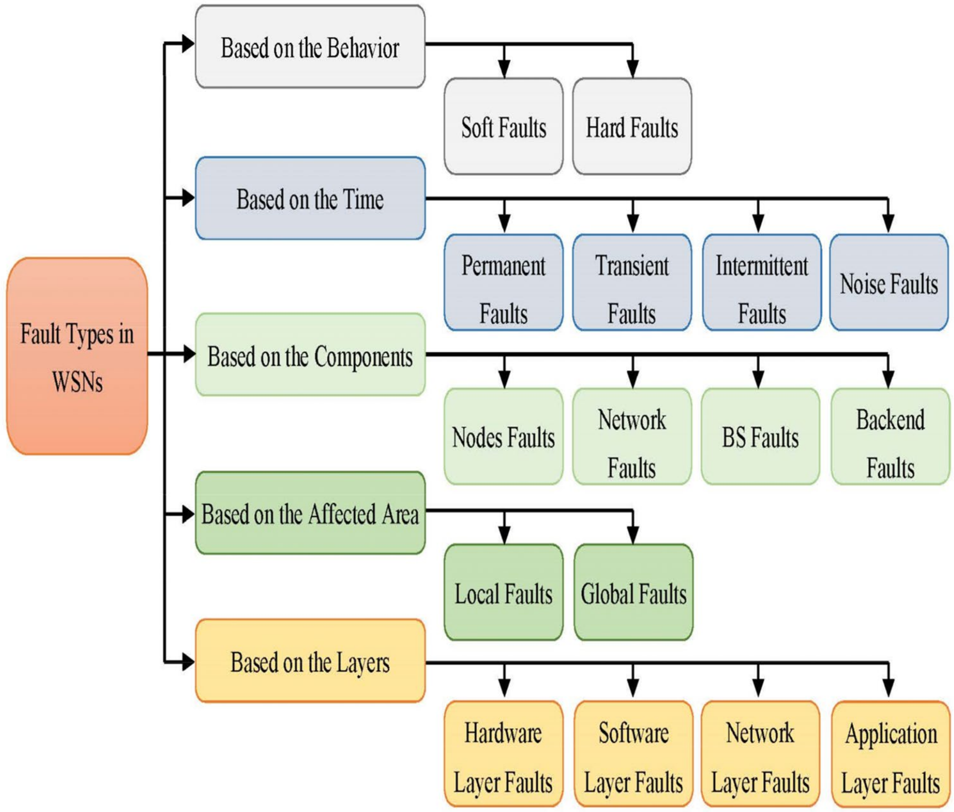

Fig. 1 Types of faults in WSNs [13]

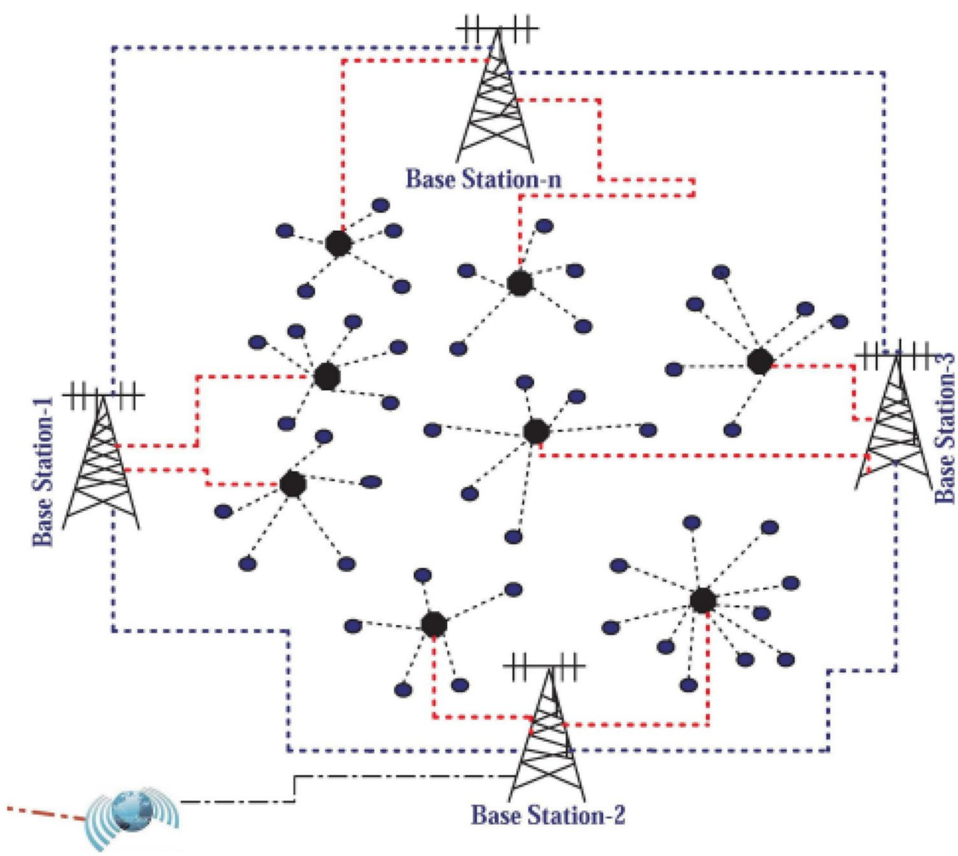

Fig. 2 Multiple base station architecture in WSN [14]

Fault-Tolerant Optimized Multipath Routing in WSN [15]

This reference addresses one of the major limitations of the sensor nodes, which is battery limitation. Here, power optimization is focused on the implementation of clustering techniques with multipath routing. This is based on the LEACH Clustering with multi-path routing. This is implemented considering various parameters like—link quality, delay, and distance within the cluster and outside the cluster.

Energy-Efficient and Fault-Tolerant Drone Base Station [16]

A heterogeneous fault-tolerant algorithm is proposed considering high-end sensor nodes with more battery capacity. In which the high energy or advanced sensor nodes act as a gateway for collecting the information from normal nodes. Data transmission is carried out in a multipath routing way to ensure fault tolerance within the network. Apart from the heterogenous nodes, this reference focused on addressing the issues with the static base station. To ensure the energy efficiency of the network and reduce the energy consumed for data transfer by sensor nodes a drone is used as base station. This drone base station effectively tries to aggregate the information from sensors thereby making the network energy efficient.

An Optimal Base Stations Positioning for the Internet-of-Things Devices [17]

This paper focused on addressing the challenges in multi-hop data transmission. The main problem identified here is nodes that are near to base station dissipate more energy to transfer the data with unnecessary data transmission using multi-hop.

To overcome this issue and make the network more energy efficient usage of multiple base stations and the positioning of each base station in an appropriate location is proposed in this existing work.

FEHCA: A Fault-Tolerant Energy-Efficient Hierarchical Clustering [18]

In this various issue in hierarchical clustering is identified and addressed with a new solution. Instead of electing the cluster head randomly, a uniform and density-based cluster head are elected. This ensures the uniform distribution of energy over the network and thereby enhances the overall network performance.

Clustering of WSN Based on PSO with Fault Tolerance and Efficient Multidirectional Routing [19]

To optimize the energy dissipation in the network particle swarm optimization approach is used in this paper. This clustering approach comes with a master cluster head and a surrogate cluster head. The clustering with this approach works in multidirectional routing. The role of the surrogate cluster head is to act as a temporary cluster head when there is any fault with the actual cluster head.

Towards Clustering Technique for a Fault Tolerance Mobile Agent [20]

To overcome the energy-related performance issues in WSNs a mobile agent-based clustering is proposed in this method. Using the mobile agent nodes can communicate to the base station with optimized energy dissipation. This mobile agent is assumed to be very effective to ensure the optimal energy utilization of the sensor nodes in the network.

Fault Tolerance in WSN Through Uniform Load Distribution Function [21]

A uniform cluster formation approach is used here to overcome the various energy dissipation issues in the WSNs routing algorithm. The uniform way of selecting clusters and members will be effective and distribute the load effectively within the cluster and network. This uniform load distribution ensures equal energy dissipation from all the nodes and also avoids fault tolerance in the network.

Intelligent Fault-Tolerance Data Routing Scheme for IoT-Enabled WSNs [22]

An IoT-based application requirement of WSNs is discussed in this paper highlighting the application features and issues of WSNs in IoT. IoT works with real-time data collection and application information any fault or link failure in the network will fail applications. A reinforcement learning-based algorithm is used here to identify the faulty nodes in the network. Finally, this is evaluated for detecting false alarms, accuracy, throughput, and lifetime of the network.

Proposed Fault-Tolerance Approach

Section "Related Work" focused on identifying and analyzing the various existing approaches of WSNs to enhance the performance avoiding faults in the network. Table 4 summarizes the analysis of the existing approaches.

Referring Table 4, the majority of the algorithm have focused on working on the heterogeneous nodes considering drones, mobile agents, and multiple base stations and positioning the base stations for fault tolerance and energy efficiency. In this paper, the proposed approach works on integrating some of the existing concepts along with some

Table 4 Analysis of existing

Existing approaches	Working
Robust mutual authentication with MBS	Usage of multiple base stations
Fault-tolerant optimized multipath routing	Multipath routing
Fault-tolerant drone base station	Drone base station
An optimal base stations positioning for the internet-of-things devices	Positioning base station
Fault-tolerance data routing scheme for IoT-enabled WSN	Fault-tolerance routing
Fault-tolerant energy-efficient hierarchical clustering	Fault-tolerance routing with hierarchical clustering
Clustering of WSN based on PSO with fault tolerance and efficient multidirectional routing	Swarm optimization with multi-directional routing
Fault-tolerance mobile agent	Mobile agent for energy optimization

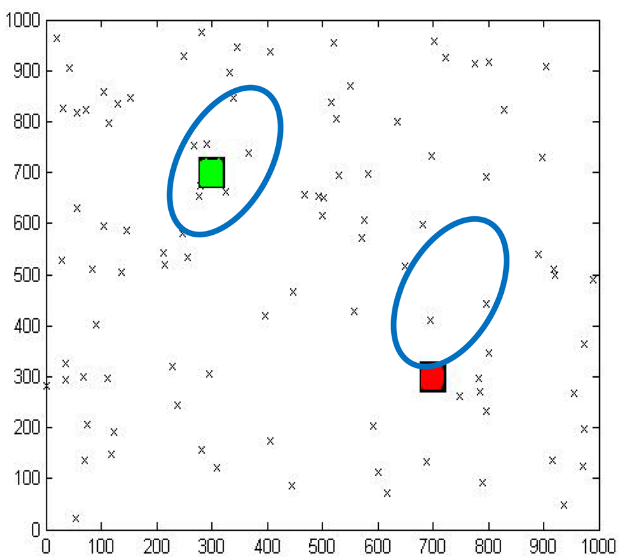

Fig. 3 Proposed topology

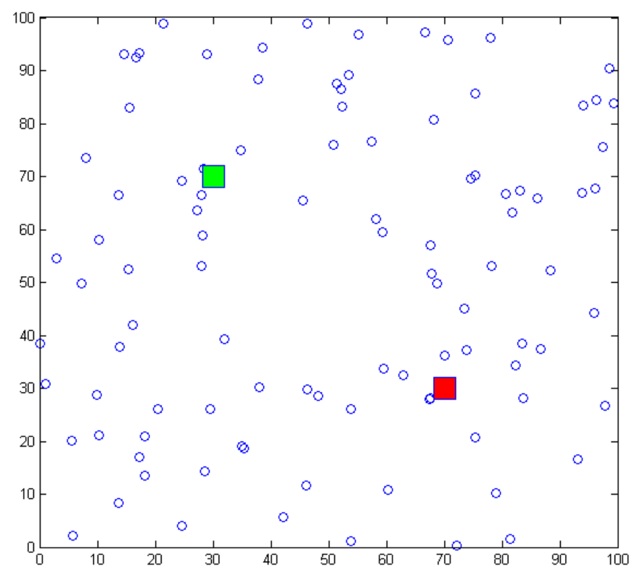

Fig. 4 Initial network state

unique features to enhance efficiency and reduce the fault in the network.

Metrics and Approaches of Proposed Fault-Tolerance Clustering

Large Scale topology creation: in the proposed network topology 100 sensor nodes are used over the network area of 1000 × 1000 this will give the exposure of WSNs on large scale with numerous nodes and analyze the situation for optimizing the base station as in Fig. 3.

Dual base station: the proposed technique aims to focus on the usage of the dual base station. The novelty involved here is positioning the Base Stations based on the sensor node's density or population of the sensor nodes. Since the network lifetime is dependent on the sensor nodes, the main focus must be given to optimizing the energy of these nodes to communicate to the Base Stations. Figure 4 shows the topology of the proposed technique.

- Positioning of base stations: the 2-base station is placed in the area, where the sensor density or population is very high. This process makes the sensor nodes spend less amount of energy transferring data to the base station
- Changing the base station position: another novelty of the proposed techniques changing the position of these dual base stations during the half round of simulation time to balance the load between the dual base stations.

Other Parameters Considered for the Proposed Algorithm

- Number of sensors considered by implementation
- The energy of the sensor nodes
- Cluster density
- Energy dissipate model: E = (ETX ∗ EDA) ∗ K + EFS ∗ K(EBS ∗EBS), EDA,EFS, EBS are the node's circuit energy required for data aggregation, antenna energy dissipation and energy required for transmission

Proposed Algorithm—Muti-Hop Fault-Tolerance Clustering with Dual Base Station

Step-1: Initially sensor nodes are deployed on the large scale WSNs

Step-2: Two mobile base stations will be deployed in the given network area. A base station will be relocated within 2 defined locations over some time.

Step-3: Initiate the clustering process by selecting random nodes on CH nearby nodes as member nodes.

Step-4: Once the cluster formation is done data transfer will be done within the cluster.

Step-5: Once the cluster is formed each cluster head will identify the nearest other cluster head or base station.

- If the base station is the nearest node, then the data will be transmitted directly to the base station.
- If the other cluster head is the nearest node, then multi-hop data transmission will be initiated.
- Either way ensures fault tolerance in the network, since data will reach the base station directly or through multi-hop without them getting affected by any node failure.

Step-6: At the half round of simulation the dual base station will be swapped with the next high-density nodes region and the same clustering with the multi-hop process will be carried out.

Step-7: If some of the normal nodes are nearest to the base station compared to cluster heads then data transmission will be done directly to the base station.

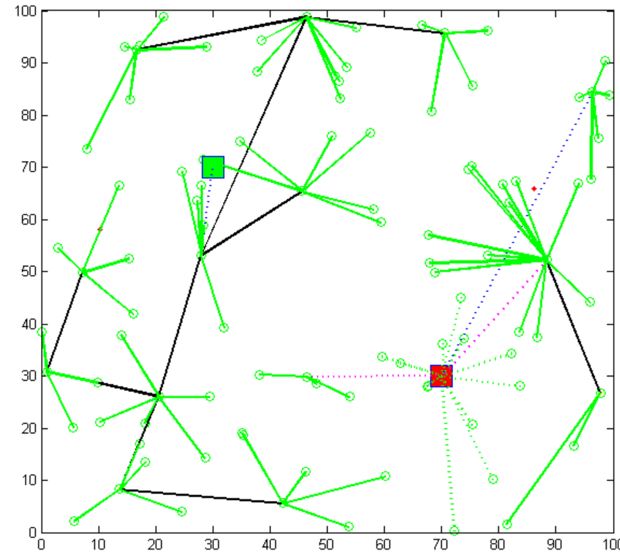

Fig. 5 Clustering process state

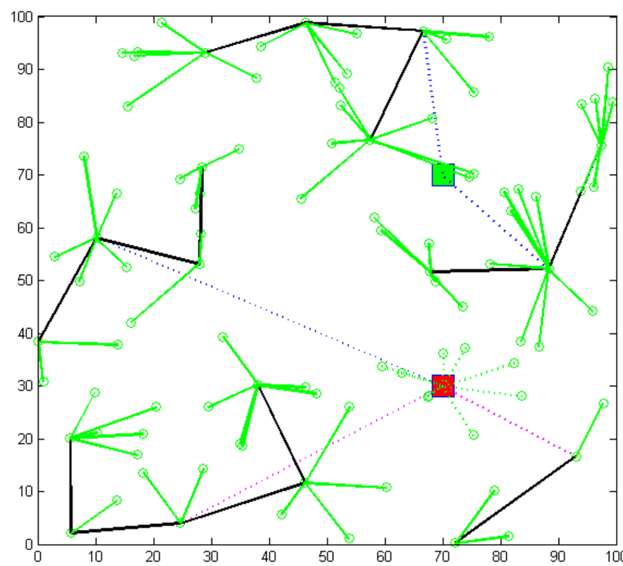

Fig. 6 Intermediate clustering process state

Results and Discussion

In this section, a detailed discussion of the result achieved through the proposed algorithm is carried out. Figure 4 shows the initial network state of the proposed approach with 2 base stations at different positions. Figures 5 and 6 represent the intermediate cluster process with a multi-hop cluster head, where the data from one cluster head will transfer to another cluster head based on the nearest distance. Finally, the data will be transferred to the nearest base station.

Figures 5, 6, 7, 8 show the clustering process from the initial state to the final state. Each cluster is represented by green color lines, where the center nodes are cluster heads. Each black lines represent the data transfer between the cluster head to the cluster head. Blue and Pink dotted lines represent the data transfer from the cluster head to the nearest base station.

The main highlight and the novelty of this proposed approach are changing of base station position after half rounds of simulation to ensure equal energy balancing. Second, nodes near to base station will not participate in any clustering process. This way ensures the nodes will not spend energy with multi-hop clustering communication.

Figure 7 represents the clustering process at the final state of the simulation, where most of the nodes failed but with multi-hop and dual base station node fault has been reduced.

Network Performance

The proposed approach resulted in better performance of the WSNs. The performance is measured in terms of through packets and the network lifetime. Figures 9 and

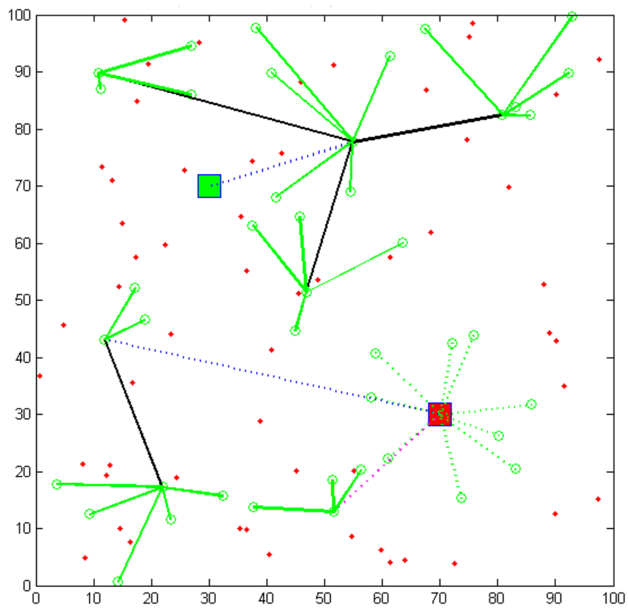

Fig. 7 Final clustering process state

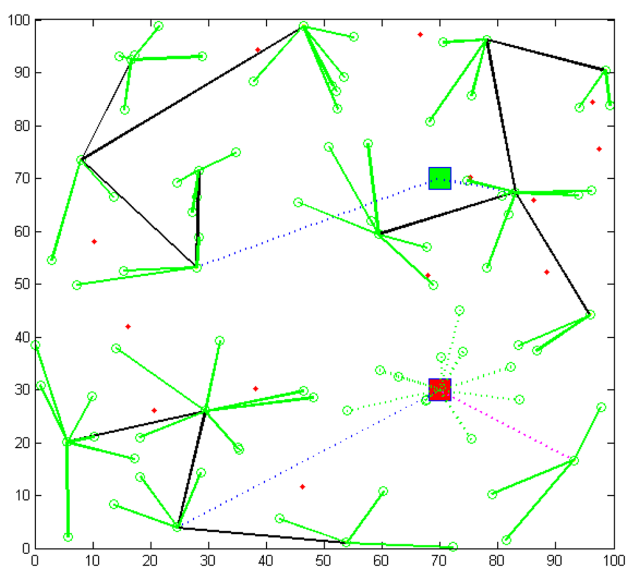

Fig. 8 Clustering process state

10 show the packets transferred to cluster heads through multi-hop and two base stations, respectively. Where the *x*-axis represents the number of rounds and the *y*-axis represents the average packets transferred.

Table 5 presents the percentage of alive nodes in the network for 1000 rounds of simulation with 100 nodes deployed. From the table, one can observe the proposed approach is efficient compared to LEACH and FEHCA algorithms. The reason for this performance enhancement

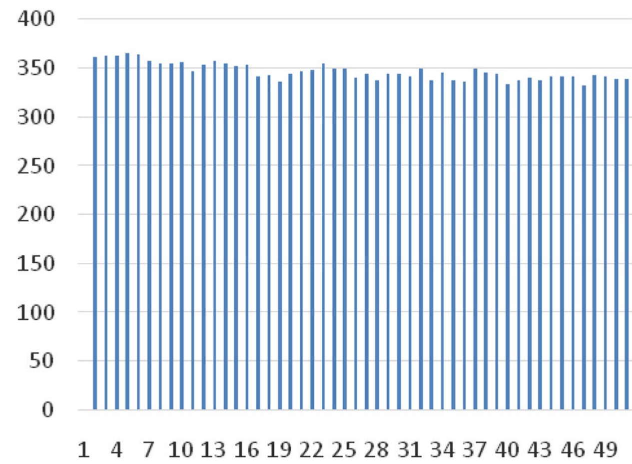

Fig. 9 Packets transferred to various cluster head

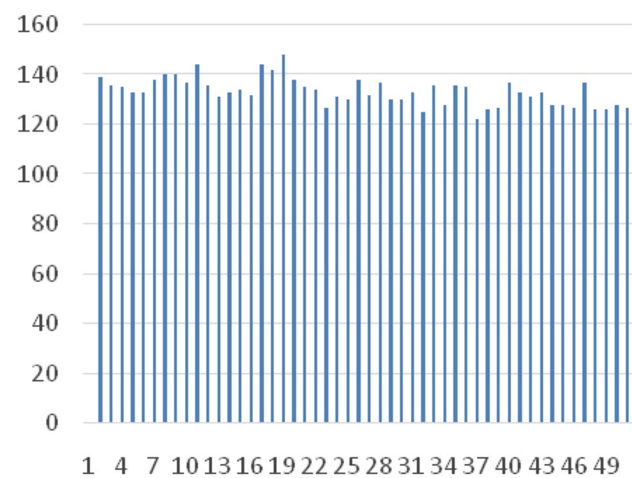

Fig. 10 Packets transferred to both base station

is because of avoiding the fault in the network and the usage of multi-hop and multiple base stations.

Conclusion

WSNs has a variety of applications with the integration of many other technologies like—machine learning, artificial intelligence, internet of things. To enhance the performance of the networks in this paper a detailed study is carried out in identifying the various issues and challenges in the WSNs. The fault tolerance, energy efficiency, and base station positioning are addressed with a different approach to enhancing the performance of the network. The multi-hop clustering approach proposed with the dual base station works effectively. The results justify the performance enhancement in terms of throughput and network lifetime.

Table 5 Lifetime comparison of proposed approach with existing approaches

No. of rounds	Alive nodes in LEACH [18]	Alive nodes in FEHCA [18]	Alive nodes in proposed
50	100	–	100
100	100	100	100
200	100	99	100
300	100	99	98
400	100	99	98
500	100	99	98
600	100	97	97
700	100	96	97
800	39	95	97
900	0	94	96
1000	0	93	96

Author Contributions The authors confirm their contribution to the paper as follows: KSR, has technically contributed to the paper by designing the proposed algorithm and implementation of the same. SDKA, has supervised and contributed by carrying out the analysis of the existing work and identifying the unique problem statements. Both authors have contributed significantly in preparing this manuscript.

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Declarations

Conflict of Interest The authors declare that there is no conflict of interest.

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