An Energy Efficient Cross-Layer Cluster based Multipath Routing Protocol for WSN

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Abstract: - Wireless sensor networks are the most widely used technologies with a wide range of applications and data collection processes. WSN is the major component for real-time data collection at various places where human intervention is difficult. With so many features, advantages, and impact WSN have some major challenges and hurdles, and these challenges the performance of the WSN is reducing and affecting the application part. This paper discusses the impact of WSN, and why WSN is gaining so much impact in recent days from a business perspective. A detailed survey and analysis made on the major challenges of WSN are carried out to identify the major performance factor of WSN. This paper aims to solve the major performance factor of WSN - power optimization, using novel cluster-based multipath routing. The proposed routing ensures the energy efficiency of the WSN for the data transfer process. Finally, the proposed method will be compared over some standard algorithms to analyze the performance in terms of the lifetime of the network and packet transmission by the sensor.

Key-Words: - Cross-Layer Protocol, MAC Protocol, TDMA, WSN, Routing, Multipath routing, Clustering, LEACH, EECACL, CL-Model, OSI Layers.

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1 Introduction

Wireless Sensor Networks (WSN) is one of the most prominent technologies in the recent digital and technology world. WSN contributes to the major development and implementation of other technologies like- IoT, Cloud computing, Data Analytics, AI & ML, and others. In all these technologies WSN is the major component as it is used for main data collection automatically where manual intervention is difficult or not feasible. The data collected from WSN is the main data source to store in the cloud and the same data is used for data analytics, and visualization using AI and ML. According to the report published by fortune business insight the global WSN market value was \$38.99 billion in 2018 and is expected to increase by \$148.67 billion by 2026, [1]. Another forecast on WSN predicted the market value of WSN will reach \$215 billion by 2028, which was \$56 billion in 2020, [2]. All this impact is due to the great demand for automated systems where human intervention is quite difficult. Some of the automated applications, [3-5] of WSN are – Health Sector, Automatic Traffic Control, Military Applications, Surveillance Application, Industrial IoT, wearable devices, and many others, [6], [7], [8]. Apart from the application, WSN is gaining impact because of its usage – Hardware, Software and Services, Area of usage, types of sensors used for different applications, and major contributors as shown in Fig. 2.

Fig. 1: WSN Market Forecast [2]

Fig. 2: WSN Primary Demand, [2]

With this market forecast and demand, WSN is gaining a huge impact in recent days. This impact of WSN is making a new path for the researchers to focus on increasing the performance of the WSN. In this paper, a novel cross-layer-based clustered approach is proposed to optimize the energy consumption for data transmission in WSN.

This is paper is organized as follows:
This section 1 Introduction presents the impact and need of WSN from a market perspective and scope for the researchers to fill the research gaps. Section-2 Problem Formulation focuses on the survey of various works carried out by the researchers in the field of power optimization of WSN, cross-layer approach, OSI layer features of WSN, and many others. Section 3 presented the proposed work as a novel cluster-based cross-layer approach to maximize the lifetime of the network. Section 4 gives the results and discussion of the proposed work over some standard benchmark algorithms and comparison over identified metrics. Section -5 finally concludes the paper by highlighting the features of the proposed cross-layer-based approach.

2 Problem Formulation
In this section, a detailed survey is carried out for identifying the various challenges in the WSN for routing and energy optimization. The survey carried out is explained in detail as follows:

2.1 OSI Layer
The first part of the survey starts with the study of the OSI layer model since the proposed method is based on the cross-layer approach. The proposed approach aims to contribute the Data Link Layer, Network Layer, and Transport Layer of WSN for effective energy optimization, [9] as shown in Fig. 3.

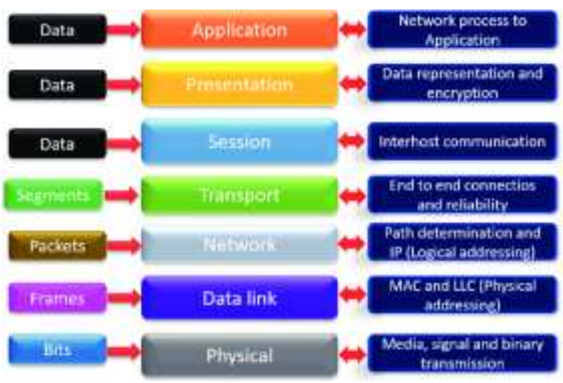

Fig. 3: OSI Layer

2.2 EECACL
An Energy Efficient Clustering Algorithm using Cross Layer for WSN has been proposed in EECACL, [9]. This method focused on optimizing the energy consumption of the WSN using a LEACH, [10] based cross-layer approach. A cluster model has been proposed considering the various parameters for the implementation of the algorithm.

2.2 EELP
An Enhanced Efficient LEACH-based Protocol proposed over the cross-layer network. In this paper, a novel cross-layer approach is used based on the probability of cluster head selection. This method focused on the packet ratio, network lifetime, and analyzing the delay in the network, [11].

2.3 Energy-efficient Fuzzy Logic-Based Cross-Layer Hierarchical Routing Protocol
A fuzzy logic-based cross-layer approach was implemented for efficient routing in WSN. Using fuzzy logic, a novel hierarchical approach was implemented to improve the network lifetime of the WSN based on the LEACH protocol, [12].

2.4 Cross-Layer Framework
An OSI layer-based cross-layer framework has been designed in this reference paper. This paper has considered and contributed to the Physical, Data Link, and Network Layer of the OSI model. This paper is also based on the LEACH clustering mechanism with a primary focus on – reducing energy consumption, reducing latency, increasing the throughput and scalability, and enhancing the overall network lifetime, [13]. The framework used is shown in Fig. 4.

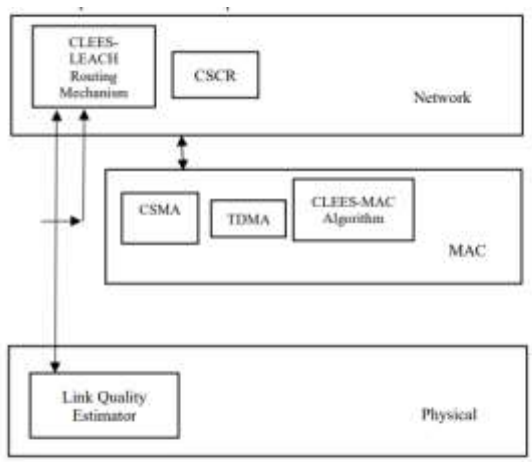

Fig. 4: Cross-Layer Framework of WSN [13]

2.5 Cross-layer Design with Weighted Sum Approach
A weighted sum approach based on the minimal hop-count cross layer was proposed in this reference to enhance the lifetime of the WSN in smart city applications. Various routing metrics like the number of nods, battery capacity, minimal total power metric, and conditional maximum and minimum battery capacity were considered to enhance the performance of WSN, [14].

2.6 Multipath Cros Layer
A multipath routing based on the Node-Disjoint Route Establishment algorithm over the cross-layer to enhance the performance is developed. This paper concluded the benefits of having Multipath routing to improve the performance of the network. This also impacts the duty cycle process at the MAC level in WSN, [15].

Table 1 presents the analysis of the existing work in the field on WSNs and also the feasible future enhancement to enhance the performance of the WSNs.

Table 1. Analysis of Various WSNs Approaches

Ref.	OSI Layer	Issues Addressed	Further Enhancement
[9]	Data Link	Energy Optimization	Can be further enhanced to improve the quality of data
[10]	Network Layer	Energy Optimization using Clustering	Multi-path routing can be adopted for more efficiency
[11]	Data Link and Network	Cluster-based energy optimization	Optimization of Cluster selection can be done
[12]	Data Link and Network	Efficient routing using Fuzzy Logic	Computation power for integrating fuzzy logic can be optimized
[13]	Physical, Data Link, and Network	Reducing Energy Consumption and increasing the throughput	Physical Layer standards can be adopted for efficiency
[14]	Data Link and Network	Energy Optimization	Selecting best hop
[15]	Data Link and Network	Multipath route optimization	Optimal Multipath can be included

Based on the existing work and analysis carried out section 3 explains the need for a cross-layer-based approach for the WSNs.

3 Research Requirements
In Section 2 a detailed survey has been carried out concerning the cross-layer approaches, performance factors of WSN, and others. Based on the survey following research requirements were identified.

3.1 WSN Application Requirements
For any kind of WSN application, the algorithm must be capable of ensuring – Lifetime of WSNs, [16], [17], Data Availability, and Data Freshness, [18], [19]. A lifetime of WSN can be achieved by increasing the lifetime of the sensors in the network, if the sensor node's energy consumption is reduced then the overall network lifetime can be increased. Coming to Data Availability and Data Freshness depends on the routing path of the data transferred from sensors to the base station. If the multi-path or multi-hop routing is enabled in the network means there will be no data loss and also one can ensure the freshness of data without getting the data delayed.

3.2 Benefits of Multi-path
With the integration of multi-path routing in the WSNs, all sensor nodes in the network have multiple options to transfer the data collected to the base station. Without a multi-path, each sensor node will have only one path to transfer data collected to the base station. This process ensures data freshness in the WSNs if there is no multi-path the data may be transferred to the base station with a delay by searching for an alternate path.

3.3 Need for Research in WSN
Sections 3.1 and 3.2 address the issues and solutions required for applications in the WSNs. To enhance the performance of the WSNs there is a need to address various challenges and issues, [20]. This paper aims to contribute to the WSNs domain by increasing the lifetime of the network using the cross-layer multi-hop approach as discussed in section -4.

4 Proposed Work

4.1 Outcomes of Survey

Based on the survey the proposed algorithm focuses on improving the Lifetime of the WSNs and also multi-hop routing based on the cluster to ensure data availability and freshness. The proposed algorithm is implemented by considering the following parameters identified from the survey carried out.

Parameters identified:

- Total number of Nodes Deployed
- Network Area where nodes are deployed
- Node Energy: All sensors node's Initial energy
- Cluster Head Probability: Number of nodes becoming cluster head
- Routing: Multi-hop Clustering

Apart from the above parameters, the proposed algorithm for optimizing the energy consumption in the WSN.

Additional Parameters:

- **Minimum Transmission energy (MTE):** This is the energy that every cluster node must possess to become the cluster head. This method will overcome reliability issues and increase the throughput. This is calculated using the threshold Base Station Distance.

  - **Threshold Base Station distance (TBS)** - A constant distance chosen by the nodes to transfer the data to BS from Cluster Head. This is to ensure that every CH will be able to transfer the data to BS without any failure. The nodes which do not have sufficient energy to transfer the data to this minimum distance will not be considered to become the CH. These nodes will be considered normal members and utilized up to their efficiency rather than making it CH and dissipating more energy for the unsuccessful transmission.

MTE = (ETX ∗ EDA) ∗ K + EFS ∗K(TBS ∗ TBS)

Where, TBS = 30m / 100 Sqm network area, EDA, EFS, and ETX are the Node's circuit energy required for Data Aggregation, Antenna Energy Dissipation, and Energy Required for Transmission

4.2 Proposed Algorithm

Step-1: All the nodes will be deployed in the given Network Area

Step- 2: All nodes will be Normal Nodes and Initially, BS will be selecting some probability of nodes to become the CH

Step- 3: The CH will advertise its presence to other member nodes using a TDMA Time slot

Step-4: Normal member nodes will acknowledge the CH message and Transfer the Data to the nearest CH or BS using the Euclidean distance when its TDMA slot duration.Distance (node1 to node2) = Sqrt((node2.x − node1.x)2 + (node2.y – node1.y)2)

Step-5: After receiving the data from members CH will find the nearest CH or Base Station and transfer the Data to it thereby causing Multiple path routing

Step-6: -During the next round new sets of CH will be elected CH satisfying the condition in Step-7

Step-7: The nodes which are having MTE will be added to the CH group, this will ensure the nodes won't fail to transfer the data collected from many members

Step-8: The newly selected CH will take over and repeats Step 3

4.3 Network Topology

Fig. 5 and Fig. 6 show the Network topology implemented for the proposed work. The nodes are indicated in Circles where the circle area decreases as the round progresses.

- Square Node – Base Station
- Green Nodes – Normal
- Yellow Nodes – CH nodes
- Red Nodes – Dead nodes

Data Transmission is represented using a Straight Line:

- Green Line – Data Transfer from Normal Node to CH

- Blue Dotted Line – Data Transfer from CH to Base Station
- Black Line _ Data Transfer from CH to CH to form a multi-hop transmission

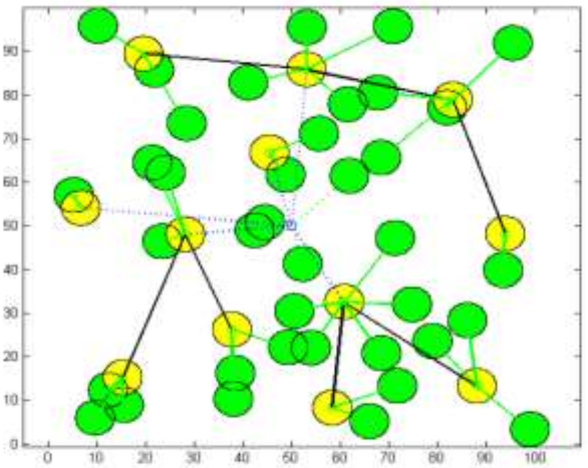

Fig. 5: Network Topology (Initial Stage)

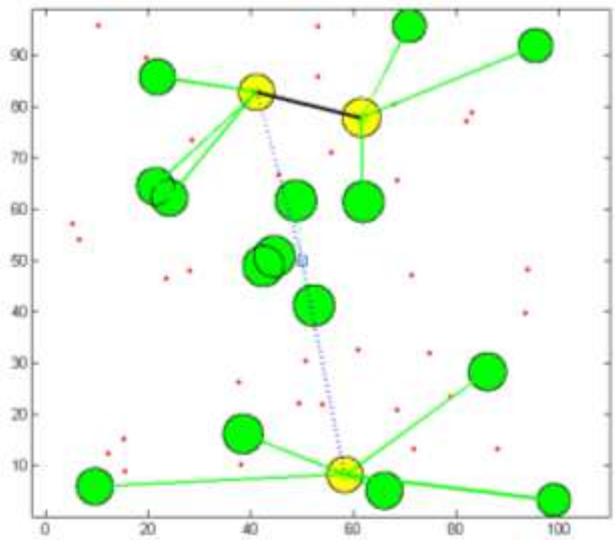

Fig. 6: Network Topology (Final Stage)

The proposed algorithm comes with a novel method of clustering and multi-path routing using various parameters. Section 4.4 further explains the advantage of the proposed algorithm.

4.4 Advantage of Proposed Cross Layer

Following are the features of the proposed algorithm concerning the OSI model:

- **Physical Layer:** The node is considered for becoming CH only after the analysis of the Physical Layer i.e. after identifying the battery capacity or energy available.
- **Data Link Layer:** In the Clustering Process, TDMA protocol is adopted as the Data can be transferred only during the allotted time slot thereby avoiding Collision and Traffic Congestion at the CH and BS. Thereby dealing with the Data Link Layer and Part of the Network Layer

- **Network Layer**: Using Multi-Hop / Multiple Path Routing protocol routing is done efficiently in the optimized way to solve the power consumption issues in unnecessary routing thereby Network layer issues are also considered and addressed.

- **Transport Layer**: Since the CH is identified based on MTE it is ensured that the CH is RELIABLE in the data transmission Phase there by Transport layer is also considered in implementing the proposed protocol.

4.5 Result and Discussion

This section presents the results of the proposed algorithm which is simulated using MATLAB considering the various parameters identified from the survey as standard benchmarks. Apart from these parameters some additional parameters are identified concerning the proposed work and used for the simulation. By considering these additional parameters and the algorithm proposed has shown a significant improvement in the performance of the WSNs

Fig. 7 presents the Lifetime of the various existing WSN algorithms which are discussed in section 2 [3]. Considering these results of the existing algorithms, a comparison is made with the proposed algorithm as shown in Figure-8.

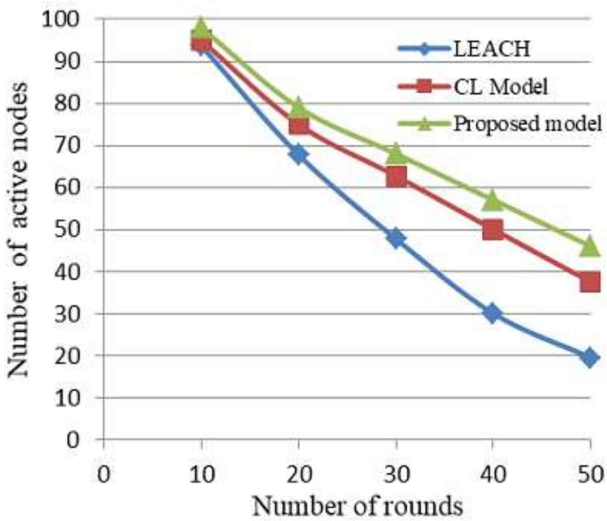

Fig. 7: Lifetime of the Existing Algorithms, [3]

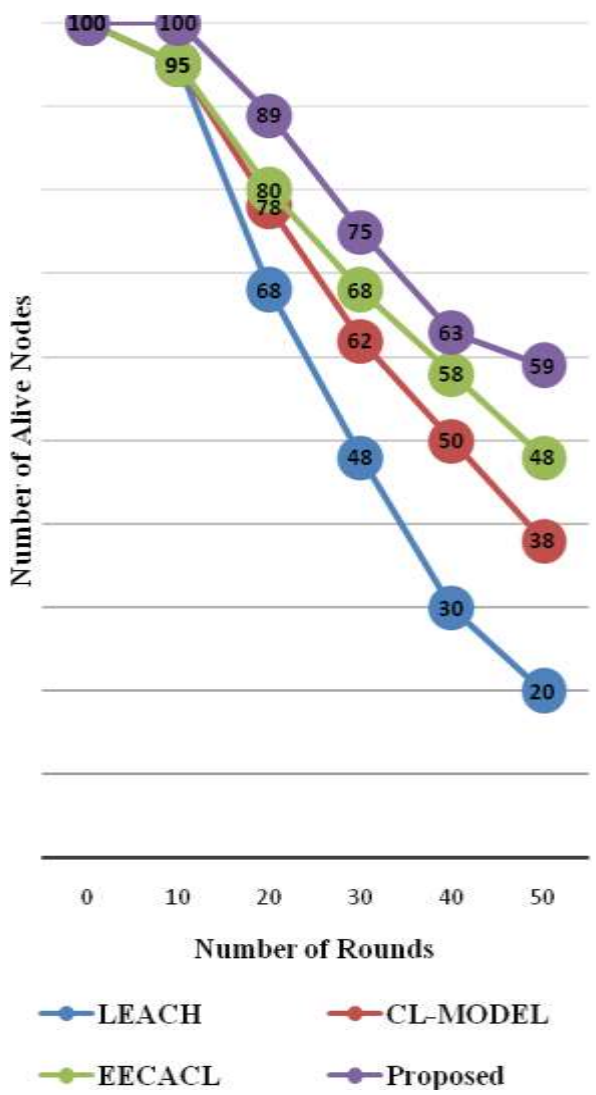

Fig. 8: Lifetime of the Proposed Algorithm, [3]

Fig. 8 shows the comparison of various Cross-layer WSN routing algorithms. In this LEACH, CL MODEL and EECACL (Mentioned as Proposed in Above Graph). This simulation is carried out for 100 Nodes for 50 rounds. The Network lifetime graph represents the number of alive nodes for the given simulation rounds.

At the end of the simulation, one can observe the number of alive nodes from LEACH is around 20, CL Model is around 38, and EECACL is around 48. The simulation setup is carried out by our Proposed algorithm (CLCBMR) where the number of alive nodes is 59 which is more than all the other three protocols used for comparison.

The lifetime of the proposed CLCBMR is 59%, EECACL is 48%, and CL and LEACH are 38% and 20% respectively. So, thereby we can conclude that the proposed CLCBMR is 11% more efficient than EECACL, 21% more efficient than CL Model, and 39% more efficient than LEACH.

Table 1 gives information on the failure nodes at various rounds compared with the LEACH, CL-Model, and EECACL existing algorithms. One can observe the algorithm's efficiency by looking into the number of failure nodes at the end of various rounds. At the 0^{th} round number of nodes is alive for all algorithms at 100% as the round progresses the nodes will dissipate more energy and become a failure. At the end of the 50^{th} round, the number of live nodes for the proposed algorithm is more than the existing algorithms. Thereby the proposed algorithm is more efficient than the existing algorithms.

Table 2. Failure Nodes Comparison

Algorithms	Rounds					
	0	10	20	30	40	50
LEACH	100	95	68	48	30	20
CL-MODEL	100	95	78	62	50	38
EECACL	100	95	80	68	58	48
Proposed	100	100	89	75	63	59

Fig. 9 presents the total number of live nodes of various existing algorithms referred against our proposed algorithm where the x-axis represents the number of rounds and the y-axis represents the number of live nodes.
During each 10^{th} round of over-simulation rounds, the number of rounds for the proposed algorithms is more than other existing algorithms. In the 10^{th} round, the proposed algorithm’s live node is 100% whereas other algorithms have around 95%. Similarly, at the 50^{th} round, the proposed algorithm has around 59% alive nodes whereas LEACH has 20%, CL-Model has 39% and EECACL has 48% alive nodes. This justifies the efficiency of the proposed algorithm.

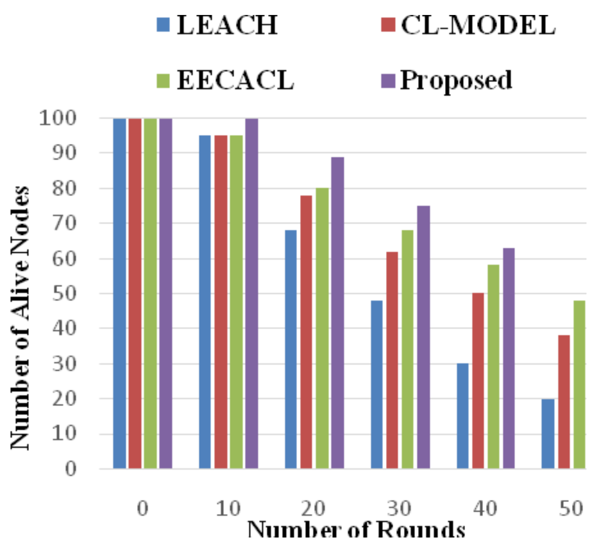

Fig. 9: Number of Alive Nodes

Fig. 10 represents the number of nodes becoming the cluster head during each round based on the probability. Where the X-axis represents the number of rounds and the y-axis represents the number of nodes that become CH. Fig. 11 represents the number of packets transmitted to the Cluster Head to Base Station and Normal Member to Cluster Head during various rounds. In this graph, the x-axis represents the number of rounds and the y-axis represents the number of packets transmitted

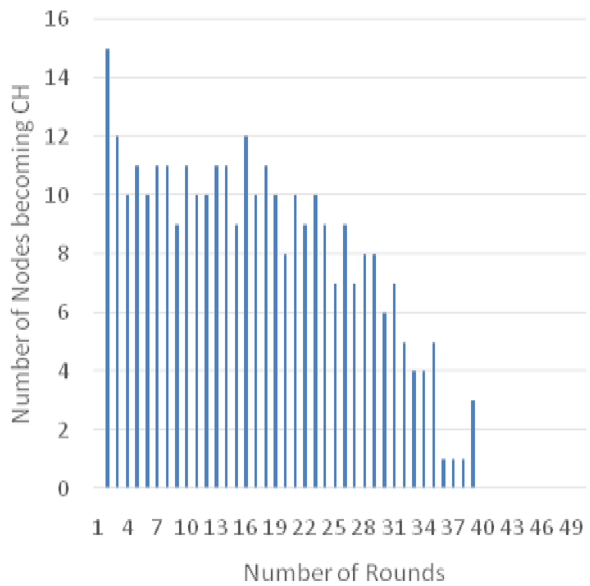

Fig. 10: Number of Nodes of Becoming CH

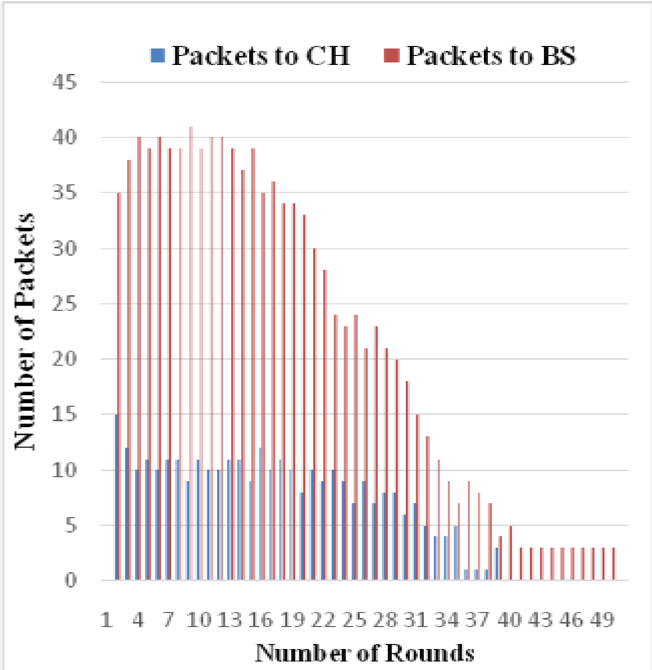

Fig. 11: Packet Transmission

5 Conclusion

Wireless Sensor Networks are one of the most prominent technologies with a wide range of applications in many domains. Along with this impact, the application requirements and challenges make it compromise the performance of the WSNs application. The proposed work has developed an algorithm that focuses on the performance factor of WSNs. The proposed algorithm has resulted in an efficient result compared to some of the benchmark algorithms. The proposed algorithm has increased the lifetime of the network by reducing the energy dissipated at the sensor nodes. The result achieved shows a significant number of packets transmitted to the cluster head and base station. This result is achieved because of the cross-layer implementation in the WSNs and this also contributed to different OSI layers. Thus, the proposed cross-layer approach shows an optimized approach for making a significant contribution to the WSNs domain.

The main motive of this contribution is to enhance the performance of WSN using the Cross-Layer approach. Hence, the proposed work doesn't highlight the WSNs limitation for mobile nodes, heterogeneous nodes, and large-scale WSNs applications. Further, the proposed algorithm can be enhanced for various WSNs applications, and heterogeneous sensor nodes and also mobile sensor nodes can be considered. The proposed algorithm can also be used for various WSNs applications where the nodes are deployed with high intensity and the need for fresh data collected from sensors are where much expected as in Surveillance and Military applications.

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