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FTDA: Performance Enhancement of WSN using Fuzzy based Traffic Data Analysis

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Abstract: In the present time in Wireless Sensor Network plays an essential role in the monitoring of different physical phenomena. Monitoring of city traffic data analysis is very important in different metro cities due to rapid increase in population. This research work proposes a model for traffic data analysis using wireless sensor network incorporated with fuzzy technique. The proposed model is tested for performance parameters such as node dead rate , data packed received. The proposed model improved the efficiency compared to existing techniques of the WSN network for traffic data collection and analysis.

Keywords: WSN, traffic data, sensor node, residual energy, average node dead.

1. Introduction

A Wireless Sensor Network (WSN) can be described as a network where nodes are distributed and deployed over a physical environment which sends control and actuates to communicate the state of the given environment. A node is a hardware device in a network equipped with actuators and sensors. It must be capable of performing some processing, gathering sensory information and communicating wirelessly with other nodes. Since every node needs to live longer in a remote field, the goal is to use low processing power and resources to last the batteries longer. Nodes are categorized as the Source node, sink node, and intermediate node. Every sensor can act as any node type depending upon the behaviour performed by them. So the sink node is interested in receiving the data from the network and is the one that initiates the request to get interested data [1]. It may be a part of the wireless sensors network itself or an external entity which is located outside of the network. All the data collected by the sensor node are forwarded to the local sink node. An intermediate node highlighted in yellow is the one that routes the data to and from the sink node or sometimes intermediate nodes. We can also have multiple source nodes in a network in such cases where the sink node is interested in aggregating data from multiple source nodes. For example, a green node is interested in knowing the moisture level of the area where the red node is installed. It initiates the request which goes and comes back all the way to and from the source node, passing from the yellow nodes to the intermediate nodes. The very basic architecture of wireless sensors network could look like this. The task managers are also known as remote users. Controls and manages the entire network by communicating with a single node in a network. So this network as a whole is known as Microscope architecture which allows us for the first time to observe the world environment, building people or any other kind of network at a very high specular resolution [2]. Make this observation continuously in real-time and collect the observation in digital form.

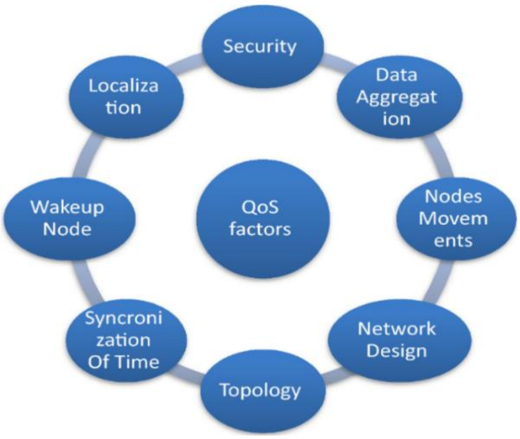

Fig.1:Different challenges for QoS factors in WSN

The processing can be done either on individual nodes independently or it can be done at aggregation points. On the intermediate nodes as well? Or all the processing can also be handled and managed at the task manager nodes.

1.1. Role of WSN in city traffic management

WSN nodes can be deployed in a random manner, like throwing the notes from the aeroplane in the forest, or either they can be planned. For example, installing them in smart cities for city traffic monitoring [3]. Gateways are necessary to the Internet for more access to and from the wireless sensors network. This allows the local wireless sensor network to get itself connected with the Internet of Things world. The gateway node needs support for dual protocol to communicate with field nodes as well as with the Internet. As the network gets more exposed to the outside world, security risks are more severe. The communication channels to and from every task manager node to the gateway nodes need an extra layer of security like DLS or SSL certificates etc. One of the key ideas is to implement a tunnel between two remote sites. Allow the Internet to tunnel through the packets between them. Having explaining about the basics of the wireless sensors network, it is also good to know how the wireless connectivity on the fields was done before. It's called a network without infrastructure, a network that is constructed for a special purpose known as ad hoc network, where the communication is done using the network abilities of each participant. All in all, routing was the best connectivity scenario, consisting of no centralized protocol defined because no specific central entity is defined. So if one link fails, the network is not smart enough to send packets from alternative nodes if they exist. Some of the examples are. Car-to-car communication, small factory automation, disaster recovery, mobile ad hoc networks and soldiers connecting with each other through their walkie-talkies. Whereas in wireless sensors network, we have a centralized controller entity that can control and manage the entire network. Like routing, topology, control, etcetera. It can also broadcast and echo to and from the sync node to the multiple nodes. These are all the things that are missing in the ad-hoc network.

WSNs face several challenges that need to be addressed to ensure their effective operation and utilization in city traffic management. In this work we have focused on the following issue for traffic monitoring using WSN:

1.1.1. Limited Energy Resources: Sensor nodes in WSNs are typically powered by batteries with limited energy capacity. Since replacing or recharging batteries may not be feasible in many deployment scenarios, energy efficiency is a critical challenge. Maximizing the network's lifetime while ensuring sufficient energy for data collection, processing, and communication is a significant challenge .

1.1.2. Data Aggregation and Processing: WSNs generate a vast amount of data from multiple sensor nodes, which needs to be aggregated, processed, and efficiently transmitted to the base station or sink node. Handling the data aggregation process, minimizing redundant transmissions, and ensuring timely and accurate data processing pose significant challenges.

1.1.3. Routing challenges: Given the unique features that set Wireless Sensor Networks (WSN) apart from traditional wireless networks, designing routing protocols for WSNs is a challenging task. Developing a universal identity scheme for a large number of sensor nodes is one of these issues, which makes traditional IP-based protocols less useful. Unlike conventional communication networks, WSNs require the convergence of data from various sources to specific base stations. Since numerous nodes provide the same information, redundancy is typical in WSN data, which makes routing algorithms that can optimize bandwidth and energy economy vital. Moreover, WSN nodes are subject to strict restrictions on onboard power, storage, bandwidth, and transmission energy. As a result, new routing techniques have been created to deal with these unique problems in wireless sensor networks.Addressing these challenges requires the development of efficient algorithms, protocols, and techniques specific to WSNs for traffic management. Researchers and practitioners in the field of WSNs continue to work on innovative solutions to overcome these challenges and make WSNs more robust, energy-efficient, and reliable in diverse application domains [4].

2. Related Work

The population-oriented and single-point exploration category is one of the most discussed and categorised. Iterations are used to enhance a single-based solution, whereas sets of solutions are used to optimise a population-based solution. Classification based on natural and artificial inspiration is another crucial field. According to recent study, nature-inspired algorithms are popular and effective in resolving a wide range of issues. This category of methods is divided into four primary types [5]. They are based on physics, evolution, swarm intelligence (SI), and human intelligence [6].

Finding the optimum path is the aim of this work. Recent studies choose SI techniques over other approaches because they consistently outperform them in problem-solving, especially when it comes to path finding issues. SI techniques often draw their inspiration from nature and are established on a herd's or a group's social behaviour and community based thinking.

In [7], authors suggested a routing strategy for a distributed, multi-hop based system that uses the Ant Colony Optimization (ACO) algorithm for secure data transmission. Based on sensor nodes with high quantities of energy, the path's further hops are chosen. However, because it does not operate in a fair and balanced manner, it is not seen as being very effective in terms of energy efficiency. The fitness function utilised does not use enough parameters, which is the major cause of issue.

In [8], to increase the energy efficiency of WSNs, authors proposed at a novel pheromone based updating mechanism in the ACO based algorithm. The researchers went through two energy efficiency measures. Sensor nodes closest to the goal are more likely to be chosen when choosing the next node for routing. In the probabilistic decision function, four control parameters are also utilised. It struggles to demonstrate efficient performance in the general analysis since it does not utilise memory effectively.

In [9], a novel routing algorithm built on the ACO algorithm was suggested by the authors in order to ensure balanced energy consumption on each network sensor node as well as the selection of the cheapest path. They create route discovery in their work, known as Improved Energy and Mobility Ant Colony Optimization (IEMACO), based on a variety of variables, including the routing algorithm's speed of convergence, the likelihood that a transition would occur, and the nodes' remaining life. The remaining lifespan of the connection may be predicted using position and speed data. The use of the memory approach is the study's most glaring flaw.

In [10], the authors put forth the so-called ACOHCM, a dynamic energy threshold technique that differs from multipath approaches. It offers benefits including network topology, finding the best route, and load balancing over the network. The ACOHCM uses a hop counting system at first. The sink (BS) has a hop count of 0. Depending on their neighbours, other nodes' hop counts are increased by one. The network's topology changes, and the hop counting technique is then re-used. Therefore, various time periods should be used to update the hop counts. Finally, each node is subjected to an energy threshold method.

In [11], authors presented a dynamic decision-making system for connected automobiles in IoT networks based on the ACO algorithm. To regulate the dynamics of linked cars in traffic flow and do autonomous computations, they deployed artificial ants.

In [12], the research presents an ant colony optimization-based routing protocol for multi-agents that efficiently copes network enabled resources in real-time .The suggested approach is utilised to control pheromone updates and evaporation rates in addition to ant movement management and determining their future location. Energy left, buffer size, traffic rate, and distance are some of the important factors that are considered while choosing the next location under various circumstances. The performance of the suggested method's simulation results is outstanding in terms of network lifespan and energy usage.

To attain the best performance, it was suggested in [13] to merge simulated annealing(SA) with genetic algorithms(GA). A GA-based strategy has been compared to the reported outcomes in terms of average residual energy, network longevity, and packet transfer between the BS and sink.

In[14], the authors introduced Clustered-Based Routing (CBR) for Information-Centric WSNs (ICWSNs), enabling CBR for these networks named as CBR-ICWSN . In this, the selection of a Cluster Head (CH) and the decision of the best path are the two major phases of this protocol. Consequently, an ideal collection of CHs is chosen by using the Black Widow Optimisation (BWO) approach to choose CHs.

In present time, Artificial Intelligence(AI) based techniques are very helpful to solve many problem. In this work we have used Fuzzy based AI approach to solve the aforesaid problems and improve the efficiency of WSN for traffic data analysis in metro cities. The three parameters state of traffic, average distance to sink, and residual energy of CH are considered to create a hybrid algorithm that incorporates the ideas of Fuzzy based Traffic Data Analysis(FTDA) using AI technique. Using a range of measures, the performance of the selected technique is contrasted with that of other conventional methods. The proposed model has greater normalised energy when compared to other traditional approaches. The chaotic fuzzy membership is used in this research work to optimise routing on the WSN. The remaining energy, network life, and packet delivery ratio were the three parameters that were used to assess the effectiveness of the proposed strategy [15].

3. Proposed Model

The proposed FTDA technique uses AI based searching for the best suitable route for data transmission to the Base station form cluster head node. The CH is called the source that collected the traffic data from the nodes inside it’s cluster. The CH uses the proposed FTDA technique to identify the next hope for data transmission[3] [16][17].

3.1 FTDA based path selection Algorithm

We have identified the three key parameters in FTDA and their respective Fuzzy membership functions used for the next best hope selection are as follows:

a. State of Traffic in Cluster (α1)

The state of traffic at CH are computed for all sensor nodes, as the sensor node(SN) requires sufficient energy while communicate to their corresponding CH, the volume of monitored traffic data is essential for transmitting the data to next CH or Base station [18][19].

$$\alpha_1 = \sum_{s=1}^{v} \left(\frac{1}{h_s} \sum_{w=1}^{h_s} Traffic(SN_w, CH_s) \right) \qquad \text{……………………… (1)}$$

b. An average distance from the sink (α2)

This phenomena is computed between each CH and sink . The SN’s require certain amount of energy in order to communicate with their respective CH, the distance between CH and sink node should be minimum for energy efficiency in the network.

$$\alpha_2 = \sum_{s=1}^{v} \left(\frac{1}{h_s} \sum_{w=1}^{h_s} dis(CH_S, BS) \right) \qquad \text{………………………….. (2)}$$

c. Residual energy of node (α3)

Even though energy consumption affects how long a network lasts, it is critical to reduce energy consumption.

Energy is one of the major key factor in WSN, and energy utilization in the network is must. The residual energy represents the remaining energy of node after each transmission round. It is essential utilize all of the energy of SN efficiently [20][21].

$$\alpha_3 = \sum_{s=1}^{v} \left(\frac{1}{\sum_{S=1}^{V} RE_{CHs_S}} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3)$$

Fig.2 shows the model representing the proposed FTDA protocol comprising the aforesaid parameters.

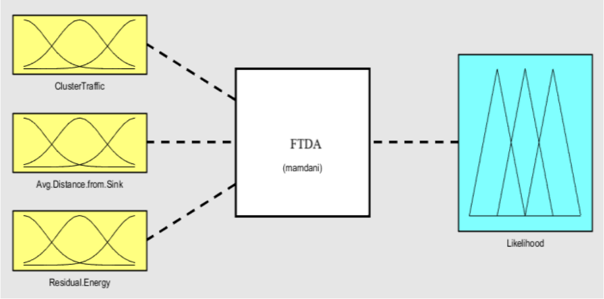

Fig.2. Proposed FTDA model

In the proposed FTDA model, the selection of Cluster Head depends upon three key IMFs: state of traffic , average distance to the sink, residual energy of CH. The input range values are represented using Fuzzy triangular function.

3.2 Formation of Fuzzy based Membership Function

The proposed FTDA model selects the optimal next hope for data transfer from CH to the sink node using the pre-defined Fuzzy Inference System(FIS) rule base.

The Membership [15] for the state of traffic in clusters is defined in the range between Low, Medium, and High using the fuzzy based function , shown in figure 3.

Equation 4 denotes the mathematical notation for state of traffic membership.

$$\left(\frac{Input}{Membership}\right) = \begin{cases} 1 & \text{if } Input \le \mathrm{TH}_1 \\ \mathrm{TH}_1 - Input \big/ \mathrm{TH}_1 - \mathrm{TH}_2 & \text{if } \mathrm{TH}_1 < Input < \mathrm{TH}_2 \\ 0 & \text{if } Input \ge \mathrm{TH}_2 \end{cases} \ldots\ldots\ldots\ldots\ldots \ (4)$$

Where, TH_1 and TH_2 are upper bound and lower bound threshold.

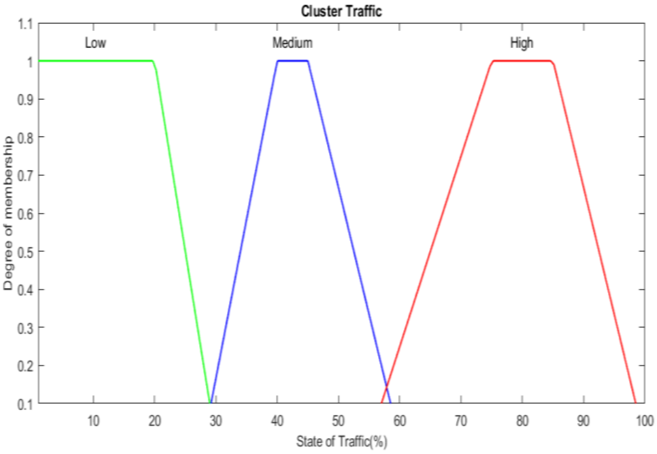

Fig.3. Membership state of traffic

The average distance from the sink is used for the formation of CH; high-traffic areas require more data aggregation; hence, a proper formation of CH is essential. The Triangular MF graph is used to show average distance from the sink node and, is depicted in figure 4 [16].

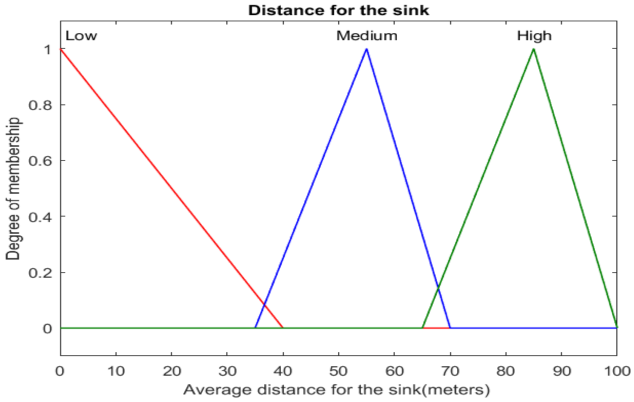

Fig.4. Average distance from sink node

If a CH reduces energy consumption while transmission of data, it will lead to increase in lifetime of network. The third MF in the proposed FTDA model is residual energy, that denotes the available energy in the node after each data transmission. Figure 5 shows the representation of residual energy in the proposed model.

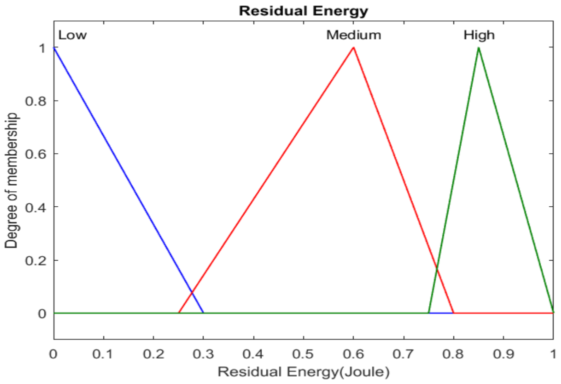

Fig.5. Residual Energy of node

A ranking function is used based on the Fuzzy rules embedded in the FIS of the proposed FTDA model. The three included key parameters are used to get the rank value of nodes for the path selection in data transmission for next hop. Figure 6 shows the output membership for ranking.

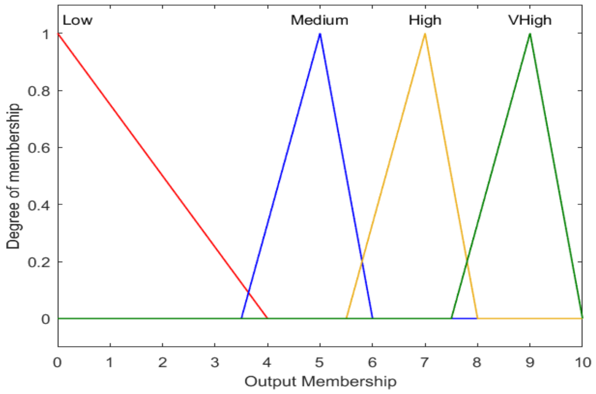

Fig.6. Output membership using Fuzzy Logic

The mapping of IF-then based output variable using the Fuzzy rules is shown in table 1. Table 1 shows the probability(likelihood) of CH selection for obtaining the optimal path for data transmission.

Table 1. Fuzzy IF-then else rule base

Rule Count.	**State of Traffic**	**Avg. distance from the sink**	**Residual Energy**	**Likelihood**
1.	High	Low	High	VHigh
2.	High	High	High	High
3.	Medium	Medium	Medium	Medium
4	.Low	High	Low	Low
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
27.	Low	Low	Low	Low

3.3. Development of a Fuzzy Inference System

In the proposed FTDA model , one of the most essential component is the FIS , where all the fuzzy rules are stored and based on the input values of the selected parameters the respective rule is triggered and the corresponding cluster node is elected as CH for data transfer operation in the network as optimal path. The proposed algorithm for the FDTA model for FIS is as follows:

```
Algorithm : FTDA algorithm
Ct: Cluster traffic , L=Low, M=Medium, H=High
Ds : Avg. distance to BS from the CH
Re: Residual energy of SN
Step 1: Translate Input values to corresponding Fuzzy MF's
    - For each value of Ct :
        { Transform MF value in {L, M, H}}
    - For each value of Ds :
        { Transform MF value in {L M, H}}
    - For each value of Re :
        { Transform MF value in {L, M, H}}
Step 2: Calculate Fuzzy Likelihood
    - For each combination of Ct, Ds and Re:
        - Trigger If-Then-Else from rule base of the Fuzzy Inference System to determine likelihood.
Step 3: Perform De-Fuzzification
    - Calculate the fuzzy value for likelihood based on the rules applied in Step 2.
    - Perform de-fuzzification to obtain a crisp likelihood value.
Output: Crisp likelihood value representing the decision or result.
```

After forming the cluster and electing a Cluster Head (CH) using FTDA, cluster nodes begin sensing and transmitting data to their CHs. CHs then aggregate the data to reduce redundancy before deciding the optimal path for transmitting it to the BS. This process begins with each CH selecting the best next hop.

4. Simulation

This section compares several routing techniques by simulating the FTDA approach using MATLAB. A network with 100 sensor nodes deployed inside a monitoring area measuring 100 × 100 m² is shown in Figure 7. Sustaining uniform simulation parameters is essential to guarantee an equitable comparison with alternative approaches. We have included a list of additional simulation settings that we used in our assessment or experiment in Table 1. These criteria were carefully chosen to ensure a relevant and equitable comparison with those used in similar studies.

Table 2. Simulation parameters

Network area (m^2)	100 × 100
Total deployed nodes	100
Starting Energy node(J)	0.5
Size of Packet (bits)	5000
Packet Header Size (bytes)	25
Control Message Size (bytes)	50
E_{mp} (pJ/bit/m^4)	0.0015
E_{Elec} (nJ/bit)	50
E_{DA} (nJ/bit)	5
E_{fs} (pJ/bit/m^2)	10

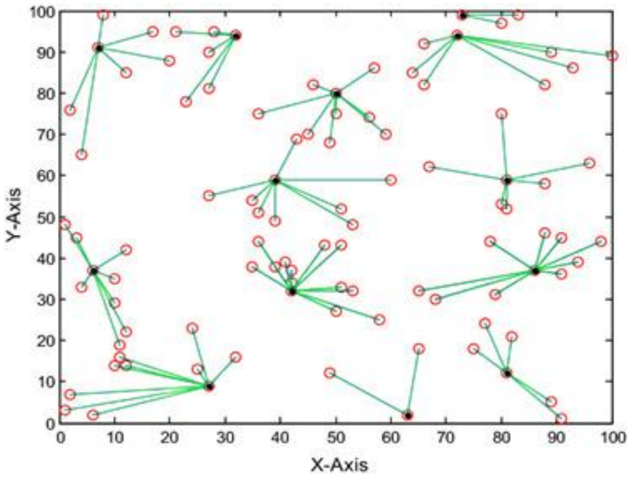

Fig.7. Deployment of 100 nodes in (100 x 100)m^2 region

The LEACH protocol, in its initial implementation, experienced a First Node Dead (FND) event at 700 rounds. This indicates that the first node in the monitoring area depleted its energy resources. Though, researchers have introduced various enhancements to prolong the FND and improve the network's overall performance. By integrating protocols such as MHACO, IEMACO, ACOHCM, and CBR-ICWSN, the FND index was notably extended. Table 2 provides a comparative analysis of various existing protocols, including the proposed FTDA protocol, to illustrate their performance characteristics.

Table3. Comparative analysis of various protocols

	LEACH	**MHACO**	**IEMACO**	**ACOHCM**	**CBR-ICWSN**	**FDTA**
First Node Dead	700	950	1200	1400	1800	2100
Half Node Dead	900	1350	1700	1800	2350	2650
Last Node Dead	2900	3500	3600	3950	4400	4850

The FND index was enhanced to 950 by the MHACO approach, to 1200 by IEMACO, and to 1400 by ACOHCM. These improvements were made possible by streamlining the cluster creation and data transfer procedures, which increased energy efficiency and extended the network's lifespan.

The FND value was further raised to 1800 in the instance of the clustering-based CBR-ICWSN protocol. This enhancement was made possible by skilfully grouping the sensor nodes into clusters and using cluster heads to manage data transmission and aggregation. This decreased energy consumption and increased the network's operational lifetime.

Moreover, WSN node clustering is optimized by the proposed FTDA. Using fuzzy logic and rule-based fuzzy approaches, this protocol sought to create a more equal distribution of energy throughout the whole WSN and limit energy dissipation within the cluster.

Thus, as shown in Figure 7, the FTDA protocol was able to achieve an impressive enhancement of the FND rounds to 2100 rounds. This proves the efficacy, greatly extending the network's lifespan and enhancing its general functionality.

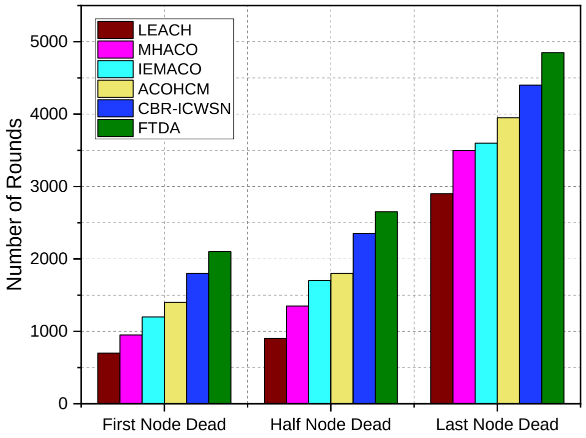

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Fig.7. Energy consumption at various time intervals

The simulation result also showed the improvement in the data packets received in the network. The data packets received in the network is shown in Figure 8, at different phases of the simulation process. It provides a comparative analysis of the data packets received between FTDA protocol and various existing protocols.

As illustrated in Figure 8, the FTDA protocol consistently outperforms the state-of-the-art techniques in maintaining the greatest number of data packets received across different simulation rounds. by using the fuzzy logic-based FTDA, which enhances the processes for data transmission, routing, and CH selection. The network will get more data packets as a result of this optimization strategy, which guarantees that energy consumption is kept to a minimum and network resources are used efficiently.

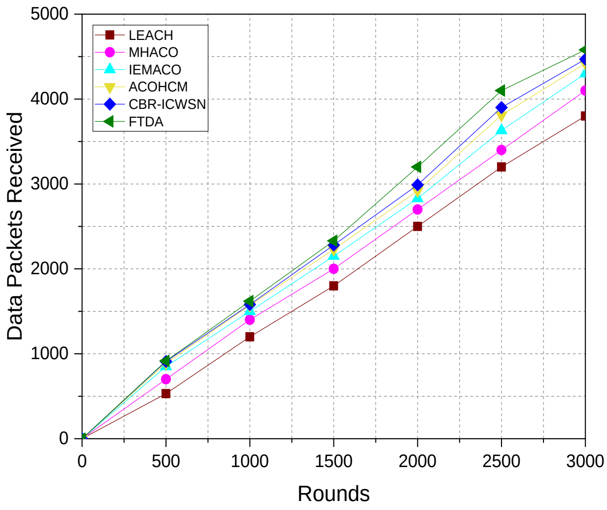

Fig.8. Data packets received in the network

In the comparative assessment of the FTDA protocol's simulation, various protocols were assessed in terms of energy consumption in the sensor network. Among them, the LEACH protocol drained out 100% at 3000 rounds, MH-ACO, and IEMACO consumed 90% and 88% energy at 3000 rounds. ACOHCM and the CBR-ICWSN protocol managed to continue for 82% and 77% at 3000 rounds, respectively. The proposed FTDA protocol demonstrated impressive endurance by operating successfully for a longer duration, lasting up to 3000 rounds with 70% energy consumption.

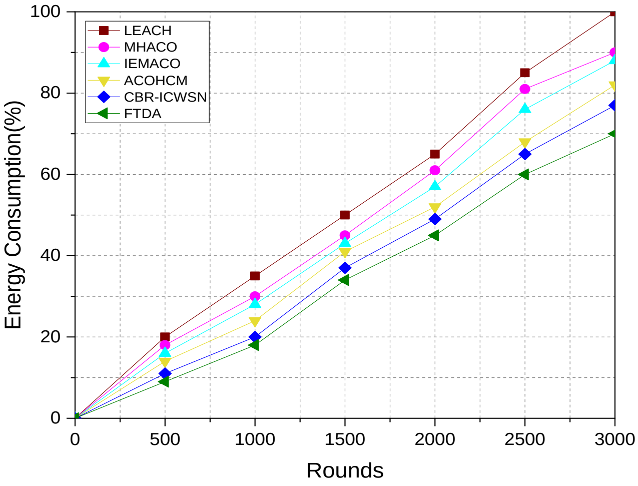

Fig.9.Total energy consumption in the network

5. Conclusion

The FTDA (Fuzzy-based Traffic Data Analysis) protocol, which integrates fuzzy logic, was proposed for Wireless Sensor Networks (WSNs). Extensive simulations were conducted with the help of various parameters to evaluate the performance. The simulation demonstrated substantial reductions in energy dissipation across the network. FTDA effectively minimized energy wastage during data transmission and clustering processes, including FND, HND, and LNDA more even distribution of energy and a longer network lifetime were the outcomes of this reduction in energy dissipation. Furthermore, FTDA consistently maintained a higher number data packets received compared to existing protocols, indicating its success in improving performance, ensuring robust network connectivity and efficient data transmission. The performance evaluation unambiguously confirms that FTDA excels in network resilience, energy efficiency, and overall network performance, underscoring its suitability for practical implementation for city traffic data management in resource-constrained environments.

Reference

[1] Kundaliya, B. L., & Hadia, S. K. (2020). Routing algorithms for wireless sensor networks: Analysed and compared. Wireless Personal Communications, 110(1), 85–107.

[2] Mall, P. K., Narayan, V., Pramanik, S., Srivastava, S., Faiz, M., Sriramulu, S., & Kumar, M. N. (2023). FuzzyNet-Based Modelling Smart Traffic System in Smart Cities Using Deep Learning Models. In *Handbook of Research on Data-Driven Mathematical Modeling in Smart Cities* (pp. 76-95). IGI Global.

[3] Wang, H., Ouyang, M., Meng, Q., & Kong, Q. (2020). A traffic data collection and analysis method based on wireless sensor network. EURASIP Journal on Wireless Communications and Networking, 2020(1), 1-8..

[4] Liang, H., Yang, S., Li, L., & Gao, J. (2019). Research on routing optimization of WSNs based on improved LEACH protocol. EURASIP Journal on Wireless Communications and Networking, 2019(1), 1–12.

[5] Behera, T. M., Mohapatra, S. K., Samal, U. C., Khan, M. S., Daneshmand, M., & Gandomi, A. H. (2019). I-SEP: An improved routing protocol for heterogeneous WSN for IoT-based environmental monitoring. IEEE Internet of Things Journal, 7(1), 710–717.

[6] Zhou, Y., Wang, N., & Xiang, W. (2017). Clustering hierarchy protocol in wireless sensor networks using an improved PSO algorithm. IEEE Access, 5, 2241–2253.

[7] Kim J-Y, Sharma T, Kumar B, Tomar GS, Berry K, Lee W-H. Intercluster Ant Colony Optimization Algorithm for Wireless Sensor Network in Dense Environment. International Journal of Distributed Sensor Networks. 2014;10(4). doi:10.1155/2014/457402

[8] Mittal, N., Singh, U., Salgotra, R., & Bansal, M. (2020). An energy-efficient stable clustering approach using fuzzy-enhanced flower pollination algorithm for WSNs. Neural Computing and Applications, 32(11), 7399–7419.

[9] Abidoye, A. P., Ochola, E. O., Obagbuwa, I. C., & Govender, D. W. (2020). An improved ant colony optimization algorithm: a technique for extending wireless sensor networks lifetime utilization. International Journal of Advanced Computer Science and Applications, 11(8).

[10] Jiang, A., & Zheng, L. (2018). An effective hybrid routing algorithm in WSN: Ant colony optimization in combination with hop count minimization. Sensors, 18(4), 1020.

[11] Maheshwari, P., Sharma, A. K., & Verma, K. (2021). Energy efficient cluster based routing protocol for WSN using butterfly optimization algorithm and ant colony optimization. Ad Hoc Networks, 110, 102317.

[12] Acciarini, G., Izzo, D., & Mooij, E. (2020, July). MHACO: a multi-objective hypervolume-based ant colony optimizer for space trajectory optimization. In 2020 IEEE Congress on Evolutionary Computation (CEC) (pp. 1-8). IEEE.

[13] Yang, D., Xia, H., Xu, E., Jing, D., & Zhang, H. (2018). Energy-balanced routing algorithm based on ant colony optimization for mobile ad hoc networks. Sensors, 18(11), 3657.

[14] Vaiyapuri, T., Parvathy, V. S., Manikandan, V., Krishnaraj, N., Gupta, D., & Shankar, K. (2021). A novel hybrid optimization for cluster-based routing protocol in information-centric wireless sensor networks for IoT based mobile edge computing. Wireless Personal Communications, 1-24.

[15] Faiz, M., & Daniel, A. K. (2022). A Multi-Criteria Dual Membership Cloud Selection Model based on Fuzzy Logic for QoS. International Journal of Computing and Digital Systems, 12(1), 453-467.

[16] Choudhary, S., Narayan, V., Faiz, M., & Pramanik, S. (2022). Fuzzy approach-based stable energy-efficient AODV routing protocol in mobile ad hoc networks. In Software Defined Networking for Ad Hoc Networks (pp. 125-139). Cham: Springer International Publishing.

[17] Faiz, M., & Daniel, A. K. (2021, December). Multi-criteria based cloud service selection model using fuzzy logic for QoS. In International Conference on Advanced Network Technologies and Intelligent Computing (pp. 153-167). Cham: Springer International Publishing.

[18] Narayan, Vipul, A. K. Daniel, and Pooja Chaturvedi. "E-FEERP: Enhanced Fuzzy based Energy Efficient Routing Protocol for Wireless Sensor Network." Wireless Personal Communications (2023): 1-28.

[19] Narayan, Vipul, and A. K. Daniel. "CHHP: coverage optimization and hole healing protocol using sleep and wake-up concept for wireless sensor network." International Journal of System Assurance Engineering and Management 13.Suppl 1 (2022): 546-556.

[20] Narayan, Vipul, and A. K. Daniel. "Energy Efficient Protocol for Lifetime Prediction of Wireless Sensor Network using Multivariate Polynomial Regression Model." (2022).

[21] Narayan, Vipul, and A. K. Daniel. "IOT based sensor monitoring system for smart complex and shopping malls." International conference on mobile networks and management. Cham: Springer International Publishing, 2021.