



A HYBRID APPROACH FOR ENERGY-EFFICIENT ROUTING AND SECURE DATA TRANSMISSION IN WSN-IOT WITH AN ANALYTICAL FRAMEWORK FOR ENHANCED DATA AGGREGATION

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ABSTRACT

Energy-efficient routing and safe data transfer are two major issues that Wireless Sensor Networks (WSNs) and the Internet of Things (IoT) must address. The primary challenges stem from the limited communication range, unreliable wireless links, and the fact that the data transit is multi-hop. One shortcoming of this approach is the inability to develop a solution that simultaneously achieve optimal energy consumption, routing efficiency, and secure data delivery. This limitation adversely affects each node's energy levels and energy depletion factors, ultimately reducing the overall life time of a the network. By solving these issues when implementing secure delivery of data inhibit the amount of usable energy in the network system as a whole. This study suggests a hybrid energy-aware routing method to address these problems by combining Tabu Flower Pollination Algorithm (TFPA) and Fuzzy Clustering (FC), which systematically calculates the optimal clustering using sensor node cluster parameters, focusing on energy levels and spatial relationships. It provides a mechanism for transferring information between nodes, optimizing the cluster nodes, and ensure that the entire network operates under low levels of energy and congestion. A hierarchical routing model is employed based on a fitness function energy efficiency and distance travelled, and must be able to assure that nodes operate correctly and optimally. The load is evenly distributed across the network, minimizing loss of energy as nodes are utilizing their energy and capabilities properly. Simulation result using the NS-3 network simulator show improvements in network throughput of 4.6 Kbits/sec, a packet delivery ratio (PDR) of 8.2 bytes, and a network lifetime of 350 units of time. These results provide evidence that the TFPA-FC algorithm improves network and operational efficiency compared to traditional methods while also improving ecological resilience by providing viable, energy-efficient, and secure, and transmission in IoT network.



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I. INTRODUCTION

Internet of things (IoT) has involved the alteration of several sectors by creating a wide network of related devices that could share information and control each other. These electronic devices have sensors to monitor their surroundings, health status, or other values. Wireless Sensor Networks (WSNs) are also an essential part of IoT structures and imply a set of spatially dispersed sensors that collect and transfer data. The WSNs offer many opportunities in real-world applications that can drive improvement. However, WSNs are facing several issues that negatively influence their effectiveness and practical implementation [1].The problem on IoT networks is the limited amount of energy available in sensor nodes. Such devices are normally portable, are operated by batteries, and a finite working duration.

Whereas with increasing data collection and transmission, energy consumption culminating in premature node failure. The energy consumption problem is compounded by the fact that vital communication requires multiple stages during the data is relayed through other nodes to the target recipient. Such networks require effective routing protocols that could enable efficient utilization of energy resources with a view of effecting reliable transmission [2]. Recognizing the limitations imposed by communication methods on IoT networks is equally important. Though the wireless links are at low cost and convenient, suffering from inter-link interference and a decrease in signal strength when used in large populated networks, as shown in Figure 1. Transmission from one node to another through several hops involves delay and additional challenges to the routing process. As throughput with low latency is required in current networks, the routing algorithm must consider the energy, scalability, dynamics, and heterogeneity of a network [3].

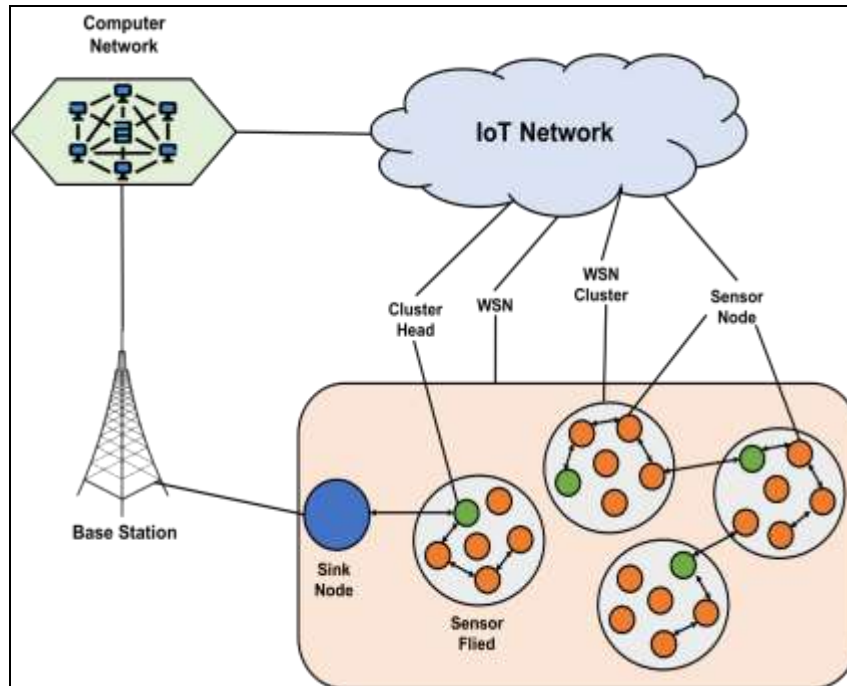


Figure 1: Transmission of Data in IoT.

Source: Authors, (2026).

Energy-efficient routing is a bigger challenge in such scenarios, as it determines the overall performance and lifespan of IoT networks. For a long time, conventional routing paradigms like direct diffusion and simple multi-hop techniques with direct communications have led to inefficient utilization of energy. The admission control protocols, also called clustering protocols, tend to achieve energy efficiency in the nodes, where nodes are grouped into clusters helping the cluster heads to consolidate data. Although these methods have been depicted to improve the challenges faced, the main issues persist, including energy consumption of nodes and data transmission [4]. General work has been done in developing routing protocols. These protocols focus on selecting cluster heads and node group construction to reduce energy consumption during data transmission. Some of the advantages associated with flow and overload control include network lifetime enhancement and optimized data transmission load. However, these advantages come within a rigid control structure and therefore cannot adapt to the variation in the network status, such as energy depletion or congestion [5]. The combined approaches that incorporate different kinds of optimization methods are increasingly adopted because the approach allows IoT networks to accommodate the versatile problems that encounters.

In implementing different strategies of a single method, for instance, swarm intelligence algorithms or the machine learning (ML) technique within the same model of computation, hybrid models can overcome the flaws of each particular method while exploiting its strengths. In the conventional method by integrating optimization with fuzzy clustering (FC), both algorithms are capable of solving large-scale optimization problems under dynamic characteristics, which is manifest in WSNs [6]. The FC forms an effective tool that empowers variations depending on energy, location, and communications. Compared to standard clustering, where the nodes belong to the definite cluster, the fuzzy memory allows the given node to belong several clusters of various extents. These properties make the network scalable; it leads to a possibility of accommodating changes in node energy and geographical distribution at lesser effect on overall load and energy balance [7]. The bio-inspired optimization technique, specifically the standard approach based on the flower pollination has been proven to solve routing and network optimization problems.

It is suitable for searching the solution space and controlling the ratio between exploitation and exploration to escape from being trapped in local optima. In IoT routing, conventional methods can determine the cluster heads, and paths require less energy to be employed to maximize information transfer, and used for FC in the proposed hybrid scheme [8]. The combination of the optimization algorithm with the FC technique makes it possible to develop an adaptive and energy-conscious routing protocol for IoT systems. The proposed hybrid approach uses FC for grouping the sensor nodes and a trust-based fused power architecture for selecting a more efficient cluster head with load balancing. This model works in response to network changes and enhances the generalized connectivity while prolonging the network lifespan [9]. To compare the performance of this approach with the conventional coordination, its efficacy is tested in networks simulator (NS-3), a useful tool for realistic emulation of WSNs. In the performance evaluation of the performance measures. These metrics are significant for evaluating the efficiency and the possibility of using the routing protocol in power-saving networks [10].

I.1 RESEARCH OBJECTIVE AND KEY CONTRIBUTION

The objective of the research is to design a combined energy-efficient routing scheme that enhances IoT network reliability by incorporating the benefits of TFPA and FC, focusing on low energy consumption and adaptability to network conditions.

- ✱ To integrate the Tabu Flower Pollination Algorithm (TFPA) and FC for efficient IoT network routing.
- ✱ To design a dynamic hierarchical structure that considers the overall network conditions and selects the best set of cluster heads (CHs) with the available energy and transmission ranges.
- ✱ To assess through the simulation of a network developed with NS-3 to analyse various parameters like throughputs, packet delivery ratios, energy expenditure, and the object's life cycle.
- ✱ To compare the performance of the resulting protocol with the preceding protocols, showing that the proposed approach is for greater energy efficiency and a stronger network.

II. RELATED WORKS

Energy-constrained devices pose challenges for WSNs, affecting their dependability and efficiency [11]. Techniques for clustering have been created and developed to improve the sustainability in energy utilization. Transmitters with multiple inputs and outputs (MIMO) were utilized in IoT applications for 5th generation (5G) transmissions. Rapidly changing IoT networks required an effective clustered strategy. To maximize the Quality of Experiences (QoE) for connected devices, it suggested 5G an optimized energy-efficient method based on smart MIMO that uses 30% less energy than current protocols. In [12], an energy effective data connection system (EEDC) to deal with energy-related issues with scaled WSN-IoT frameworks. It used a multi-tier clustering framework and an organization methodology to ensure successful long-distance communication. Simulation outcomes have shown that EEDC reduces energy used in the sensor networks by 31% while improving the packet loss ratio by 38%. Durability was impacted by data deviations and electrical power issues in the hybrid IoT (H-IoT) [13]. To enhance anomaly detection in WSN-IoT, a novel approach called the Energy-effective Memetic Clustered Method (EEMCM) combined the design of (AlexNet) along with the Parallel Memetic Algorithms (PMA). The model detects anomalies and possible assaults by classifying anomalies using high-level features and sending information to the framework of AlexNet.

The energy-efficient grid topology (EEGT) was discussed in [14] to increase the life of WSN-based network of things technologies. To provide data, divide the entire framework into constructed grid segments, and manage sensor nodes, EEGT employed Kruskal and ant colony approaches. According to simulation data, EEGT performed better than current methods. Hardware components were connected by the IoT to exchange information and cooperation was investigated in [15]. The routing protocols were difficult to use because each system node had immediate web access. To improve energy economy and strengthen cluster-based routing algorithms for secure data transfer, it offered and enhanced cluster forming protocols with neural fuzzy rules. The significant progress in WSNs that utilized IoT [16]. The framework proposed a routing structure based on deep belief networks (DBNs) that maximized the speed of data and the rate of packet delivery while requiring less power. The method used mantaray hunting efficiency, machine learning (ML), and additional learning to improve network endurance. The High-Level Clustering Technique for Wireless Heterogeneity Sensor Networks utilizing the Modification Zonal-Stable Voting Protocol (MZ-SEP) Route Protocol was presented in [17]. It suggested a hybrid approach that combined symmetric and symmetrical encryption systems providing connections and safe managing keys.

The method was tested and contrasted with previous research for the enhancement of bandwidth utilization and execution time. Demand for the IoT has increased in industries, such as military surveillance, smart homes, medical treatment, and factory automation was examined in [18]. The energy was required to maximize WSNs, which has prompted research on dynamic self-configuration routing that used less energy. An optimal energy-driven smart routing (OEDSR) technique for IoT applications was proposed to improve the data secure transmission. In [19], safe routing and bilateral authentication in WSNs for promoting connection in the IoT. It provided an encrypted cluster head selecting and routing channel approach depending on the hybridized optimizing algorithms (HOA), with a significant packet delivery ratio of 99.848% for a network of 100 nodes. With an emphasized on managing privacy issues [20], the risks related to IoT devices and wireless data networks (WSNs). It offered methods for stopping, identifying, and lessening these risks to create secure IoT growth and general awareness. By integrating data within the cluster heads and reducing data transfers to the base stations throughput [21], a hierarchy-based fuzzy logic cluster (HFLC) minimal power utilization routing (MPCR) strategy for IoT systems that reduced the power usage. The technique provided fast packet delivery and a large bandwidth.

The secure encrypted random permutations phenomenon (SERPPA) for the IoT-related WSNs to address security issues and the use of energy was examined in [22]. Inefficiency, power consumption, and data transmission rate, the cluster head-based method exceeds existing methods. To maximize data transmission efficiency and authenticity, [23] proposed a trust-based network behavioral assessment method on IoT-WSN. Additionally, it offered a routing method that maximizes packet delivery ratio and minimizes delays. Data analytics, new innovations, and distributing resources techniques could be explored in future studies. To address the quality constraints in WSNs brought by the exponential expansion of IoT products, [24] suggested a modified particle swarm optimization technique Route Protocol (MPSORP). Low latency, and rapid packet delivery ratio, which was high in throughput, low normalizing load, and energy efficiency provided by the protocol. To lessen energy consumption caused by short battery existences, [25] suggested a giving feasible routing system for the IoT-based WSN. Reducing end-to-end (E2E) delay, increasing throughput, limiting energy consumption, minimizing packet loss, optimizing packet detection, and extending the lifespan of networks were all achieved by the suggested QoS-based optimum energy clustered routing (QOECR) protocol.

II.1 RESEARCH GAP

The challenges related to a high level of energy consumption in MIMO-based approaches, the complexity of anomaly detection, and the lack of security in routing protocols in IoT and WSNs even if there is an improvement in energy efficient clustering techniques.

Other models lack consideration of dynamic scalability needed in rapidly growing IoT networks or aspects of heterogeneous devices to solve real problems. Further, currently known techniques lack proper optimization of energy consumption with the concern of data privacy and secure data transfer and transmission. The research develops a novel approach that involves a multi-tier clustering technique integrated with an improved energy-efficient routing protocol for energy utilization while harnessing data transmission efficiency. It embeds the feature for intelligent detection of anomalies and security measures that improve its defences against network risks. Additionally, the approach also handles the dynamics of the IoT networks, making it versatile in the best sense of the word, which consumes 30% less power than traditional approaches.

III. METHODOLOGICAL FRAMEWORK

The methodological framework targets the improvement of energy performance in IoT and WSNs using research directions such as TFPA for dynamic cluster head selection, energy-aware routing, and secure data transfer from one cluster to another.

III.1 NETWORK ENVIRONMENT

In a network environment, there are a hundred sensor nodes distributed over a certain geographical area and are interconnected with other nodes and a fixed node known as a base station through a wireless medium. These sensor nodes are the primary data attainment and can be segments that provide environmental parameters (e.g., temperature, humidity) or application data. The base station takes the information from the sensor nodes, stores it, and sends it to other systems external to the network for processing. The routing mechanism should consume less energy than feasible, as the sensor nodes require energy to function for feasible transmission. The network topology is created when multiple nodes with intermediate nodes enable the data to reach the base station and can improve the probability of data transmission in the network, as shown in Figure 2.

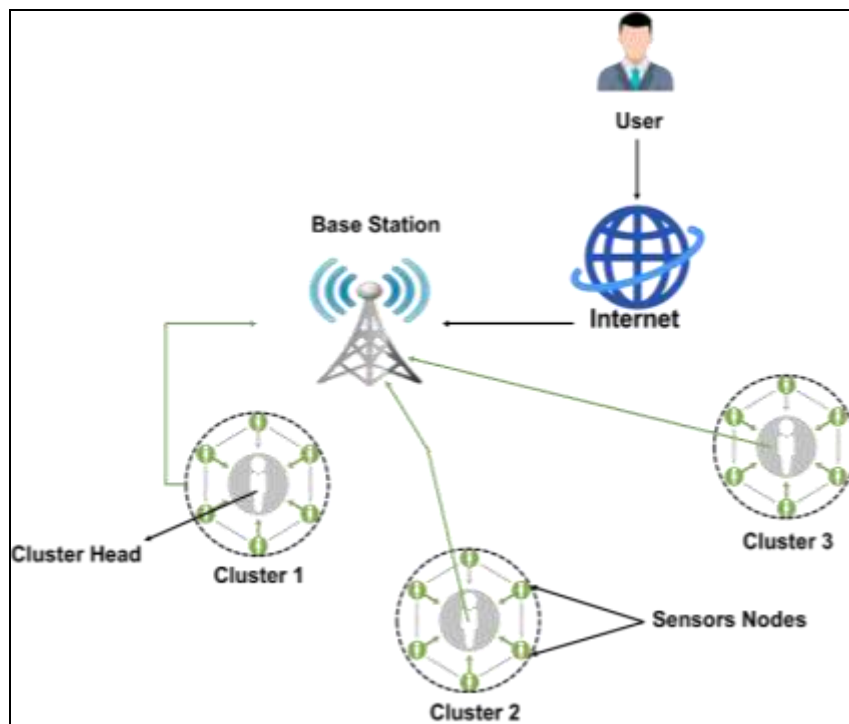


Figure 2: Network Environment of Multiple Nodes and Base Station.

Source: Authors, (2026).

III.2 CLUSTERING

It is a process of grouping the nodes based on certain properties like geographical position, residual energy, or the abilities of communication. The main objective is to group all the nodes into several clusters, with a collective head node in each one heading up data coordination within the cluster and the entire network with several sensor nodes. This method is generally employed in the WSN or IoT network.

III.2.1 Fuzzy Clustering (FC)

Hard clustering is a complex type of clustering to perform in which nodes can be split across multiple clusters, based on the degree to which assignable. In WSN or IoT helps organize nodes by energy level and location. The advantage of using fuzzy technique that it can generate partial memberships which involve a membership value ranging from (0 to 1). The most common FC technique is also known as Fuzzy C-Means (FCM). This approach is specifically used in the network environment for the collection of data from various clusters around the base station. Additionally, it results in a decrease in energy efficiency in the messaging node and extends the total network durability through identifying groups of nodes with similar capabilities. Due to its capacity to operate under conditions of uncertainty and noise, FC is ideal for network optimization in lightweight IoT and sensor networks. The technique can be more effective than a clustering approach because of its adaptability or nodes' state changes, including the energy level or mobility.

III.3 CLUSTER HEAD SELECTION

It is one of the essential procedures in WSNs and IoT systems. It selects particular nodes to operate as the communication hub within the sets of keys. To reduce network oscillations and insecurity, specified nodes have sufficient energy to remain awake. Adequate geographic connections to adjacent nodes, and space for data aggregation as well as transmission. The cluster heads was selected using TFPA.

III.3.1 Utilization of Tabu Flower Pollination Algorithm (TFPA) for cluster head selection

For identifying cluster heads in IoT networks, TFPA integrates the FPA for exploratory qualifications and Tabu Search for memory-dependent optimization. It selects dynamic cluster head assignment depending on its energy utilization, communication range, and load distribution allowing a more energy-efficient network and longer network life through the use of incremental iteration and memory-based search strategies.

III.3.2 Tabu Search Algorithm

By storing information about nearby nodes in short-term memory termed Tabu lists, Tabu search is a meta-heuristic searching technique that eliminates looping back to previously used routes. Tabu lists contain details about the energy levels and status of nearby nodes. To eliminate looping, Tabu search utilizes memory depending on recurrence to avoid certain re-instancing in a given time (this is done using a tabu list). The relevant routes that are reachable at each frequency level are stored in the Tabu list. This type of information is provided in the form of static data packets dubbed fuzzy-rule based routing protocol (FRRP), which are employed during data transfer to identify the optimum way from the source toward the sink between the many alternative routes, as in Figure 3.

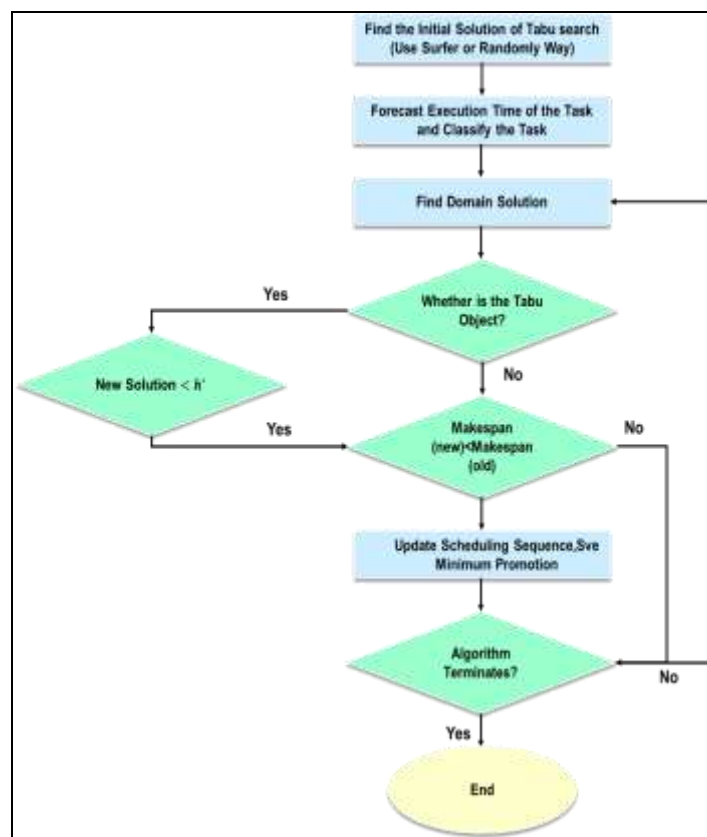


Figure 3: Flow of Tabu Search Algorithm.
Source: Authors, (2026).

III.3.3 Flower Pollination Algorithm (FPA)

The basic idea of FPA reflects natural pollination where insects, birds, or wind take pollen from one plant and place it on the stigma of another plant for plant breeding. The algorithm is designed to optimize complex problems by using two main pollination processes: long-distance and short-distance pollination.

Key Mechanisms of FPA

(i) Pollination Process

The pollination process includes three stages for the distribution function at efficient time management.

✱ **Global Pollination:** It is long-distance pollination, where the pollinators travel long distances. To supplement this new search, a broad exploration of the solution space is required, modelled by Lévy flights.

- * **Local Pollination:** It describes short-range movement where pollinators transfer pollen from one flower to the other close to each other, as the data transfers from one node to another node. It is realized by random walk patterns, which can be inhibited in the close area.
- * **Flower Constancy:** It defines the bias that pollinators have developed moving around specific plant species to ensure enhanced pollination. It can be given mathematically by the reproduction probability from flower to flower.

The pollination process can be expressed mathematically in such expressions given below.

- **Global Pollination:** This equation (1) could be utilized to establish the globally pollinating method, the pollen of the flower j . The y_j component is modified and refined according to the best solution found in C found in equation (1).

$$y_j(s+1) = y_j(s) + \gamma K(\lambda) (y_j(s) - C) \quad (1)$$

Here, γ is a scaling factor, and $K(\lambda)$ on the other hand is the Lévy flight step length. The parameter Leg controls the step size distribution of the Lévy flight.

- **Levy flight Distribution:** equation (2) specifics that it is applied in global pollination for long-distance transmission of data in the solution space.

$$K(\lambda) \sim \Gamma(\lambda) \cdot \sin\left(\frac{(\lambda)}{\prod(1+\lambda)}\right) \quad (2)$$

- **Local Pollination:** In local pollination, the given update rule goes for a random walk in nearby node, as shown in equation (3).

$$y_j(s+1) = y_j(s) + V(y_j(s) - y_l(s)) \quad (3)$$

Where y_j and y_l are pollen solutions from other flowers in similar flowers or populations V is a random uniformly distributed variable from (similar flowers and V is a random uniform distribution. Figure 4 depicts the flow of FPA that has the global pollination and local pollination process. Levy flights for long-distance search and random walks for short-range data transmission in optimization.

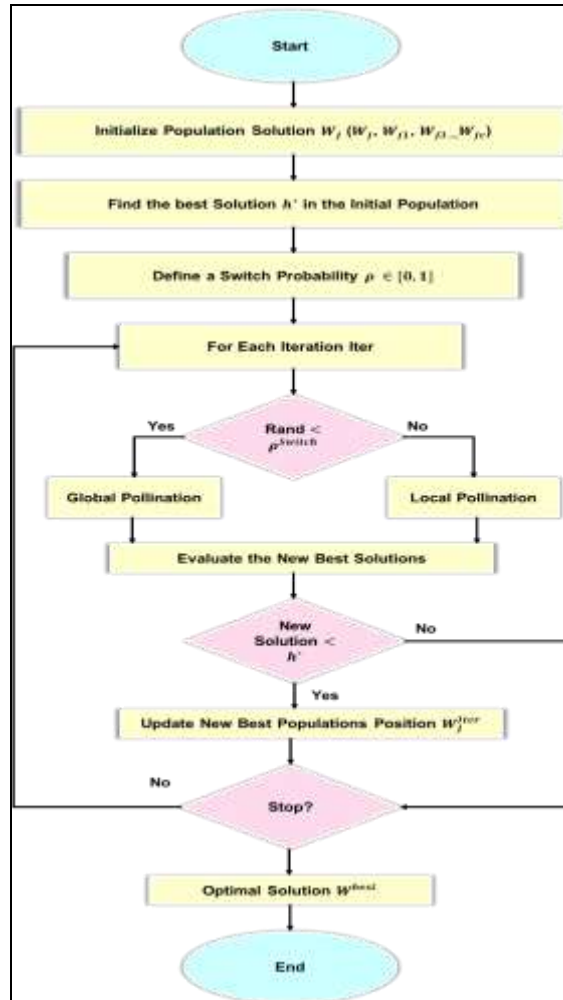


Figure 4: Flow of FPA.
Source: Authors, (2026).

The TFPA is based on the merging of FPA and Tabu search can effectively select the cluster heads for IoT networks. The FPA provides a way to search possible solutions in a network environment, and Tabu search avoids looping through previous solutions by using a Tabu list. This hybrid approach improves energy efficiency, communication range, and network lifetime for better selection of the cluster heads in Algorithm 1.

Algorithm 1: The Hybrid approach of TFPA.

```

Initialize the population of sensor nodes with energy levels and positions
Define Tabu List (TL) to store previously explored solutions
Define parameters:  $\gamma$  (scaling factor), Lévy flight step length  $K(\lambda)$ , and memory length
for each iteration:
  For each node i:
    Select random node j from the population
    Calculate fitness (energy, communication range)
    Apply Global Pollination Update:
       $y_{j(s+1)} = y_{j(s)} + \gamma * K(\lambda) * (y_{j(s)} - C)$ 
    If the new solution is better, update the best solution C
    for each node i:
      Select random neighbors ( $y_j, y_l$ ) from population
      Apply Local Pollination Update:
         $y_{j(s+1)} = y_{j(s)} + V * (y_{j(s)} - y_{l(s)})$ 
      If local pollination improves the solution, accept it
    for each node i:
      Store energy level, position, and status in the Tabu List
      If the solution is in the Tabu List, avoid revisiting or accept based on aspiration criteria
      Based on energy, communication range, and load distribution
      Select the best node as Cluster Head
  Return the best Cluster Head after iterations

```

Source: Authors, (2026).

III.4 FC WITH TFPA

The combination of the TFPA and FC aims to improve In WSN-IoT systems, secure transfer of data and sustainable route in algorithm 2. In FC the classification assigns nodes to clusters according to parameters like energy levels and location where nodes can belong to several clusters, which reduces the amount of data that needs to be collected, thereby extending the network life significantly. The TFPA-based algorithm also selects a dynamic cluster head energy consumption, communication range, and load balancing.

Algorithm 2: A hybrid approach of FC and TFPA.

```

initialize nodes with energy, position, and communication range
Initialize Tabu List (TL)
Initialize centroids for clusters
for each node i:
  Calculate the membership degree for node i for each cluster based on the distance to centroids
  Assign the node to the cluster with the highest membership degree
for each iteration:
  for each node i in the population:
    Select random node j from the population
    Calculate fitness (energy, communication range)
    Update solution using global pollination:
       $y_{j(s+1)} = y_{j(s)} + \gamma * K(\lambda) * (y_{j(s)} - C)$ 
    If fitness of  $y_{j(s+1)}$  is better, update best solution
  for each node i in the population:
    Select random neighbors ( $y_j, y_l$ ) from population
    Update solution using local pollination:
       $y_{j(s+1)} = y_{j(s)} + V * (y_{j(s)} - y_{l(s)})$ 
    If fitness improves after local pollination, accept new solution
  for each node i:
    Store energy, position, and status in the Tabu List
    If the solution is in the Tabu List, skip or accept based on aspiration criteria
  Select the node with the best fitness (energy and communication range) as the Cluster Head
Return best Cluster Head

```

Source: Authors, (2026).

III.5 DATA TRANSMISSION

The process of transferring and receiving data through systems is known as data transmission. It involves encoding, transferring, and decoding information over a communication medium, such as WSN. The cluster transmission is based on two transmissions: inter and intra-cluster transmission.

✿ Intra-cluster transmission

Communication within a cluster is known as intra-cluster communication, where a sensor node sends its observed data towards the CH. It captures information from the nodes and might conduct basic processing, such as a simple average, to reduce duplication in the received information before saving it, thereby making it more energy-efficient. Transmissions are only made between the node and CH, which saves the network resources. For intra-cluster communication, direct or multi-hop routing is used depending on the clustering size and distribution of the nodes. The use of energy-efficient protocols ensures that the network operates for an extended period, minimizing energy consumption.

✿ Inter-cluster transmission

Inter-cluster communication is the process of exchanging data between clusters and from a CH to a base station. After data aggregation, CHs use multi-hop routing to communicate with other clusters or base stations directly. Standard protocols are typically used for energy-efficient data transmission in this communication. Inter-cluster communication also depends on security using encrypted communication with authentication. Inter-cluster communication allows the reduction of redundant transmissions and the optimization of routing paths. Ensuring routing paths and inter-cluster communication ensures that the network can scale efficiently, providing long-term reliability while reducing energy consumption and maintaining data integrity across the network.

IV. RESULTS AND DISCUSSIONS

The section includes the outcomes of the sensor nodes' performance by performance metrics for effective transmission of data and durability of the network lifetime in WSN with IoT applications.

IV.1 EXPERIMENTAL SETUP

The NS-3 experimental setup is described in this one, in which WSN and IoT devices are simulated. NS3 positions the nodes in a context topology defined by the attributes of energy levels, communications range, and routing protocols. In this setup, FC methods are used to generate the clusters, and the TFPA is used to choose the cluster's header. The transfer of data communication scenarios are created both within and between clusters, and their network lifespan and efficacy characteristics are observed. Simulation outcomes are examined to evaluate network efficacy and security.

IV.2 EVALUATION CRITERIA

Figure 5 (a and b) shows the use of energy consumption and ratio of packet delivery on the suggested TFPA technique of networks. Figure 5 (a) represents the energy consumption dynamics on various network configurations and the effectiveness of the energy-saving mechanisms utilized is illustrated. Figure 5 (b) shows the packet delivery ratio performance, which illustrates that the proposed TFPA routing and clustering schemes increase the reliability of data delivery. Each figure demonstrates the efficient techniques of preserving the network performance while using less energy.

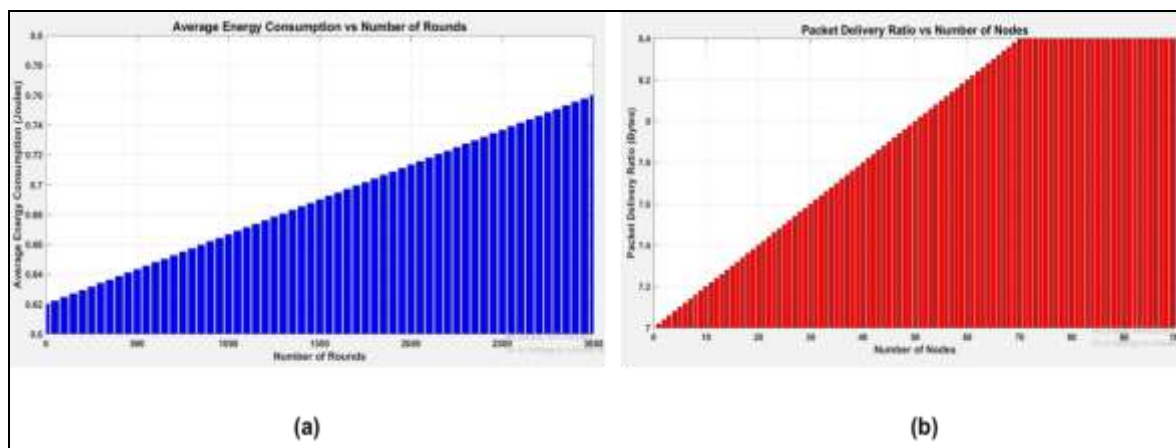


Figure 5: Implementation of (a) Energy consumption and (b) Packet delivery ratio.
Source: Authors, (2026).

The throughput and network lifetime have been incorporated into the proposed model successively, as shown in Figures 6 (a and b). Figure 6 (a) displays the throughput performance, the rate at which data is transmitted given certain conditions and configurations. The routing and clustering strategies achieve high throughput, as the plans are optimized. Figure 6 (b) illustrates the network lifetime, endured after energy-efficient clustering and routing protocols have been used. However, both of them confirm the reliability of the analysing method to improve network performance.

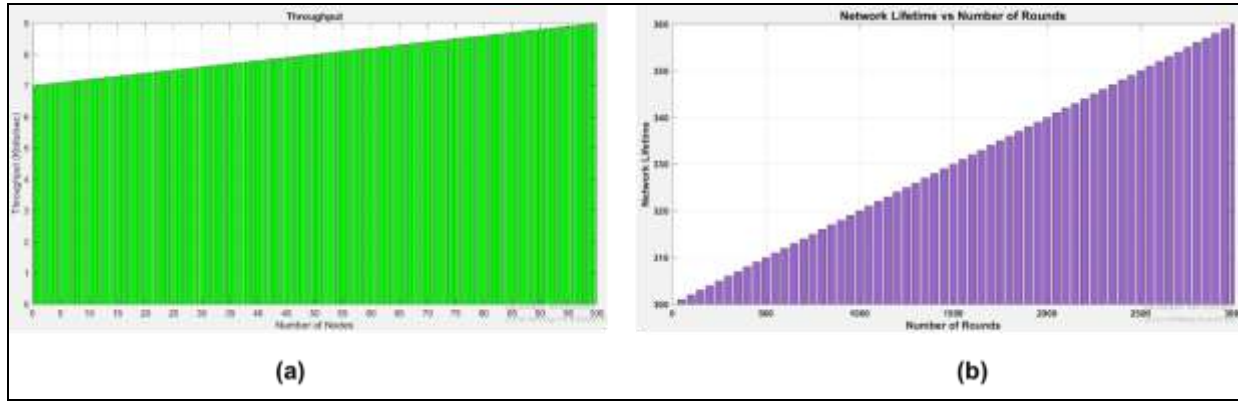


Figure 6: Implementation of (a) Throughput and (b) Network Lifetime.

Source: Authors, (2026).

IV.3 COMPARISON ANALYSIS

The methods of Energy-efficient Clustering and Particle Swarm Optimization-based Fuzzy routing (ECPF) [26] were compared with the TFPA proposed model and analysed through the performance indicators including throughput, packet delivery ratio, consumption of energy, and networks longevity.

* **Throughput:** It measures the data transfer rate and is calculated using equation (4).

$$\text{Throughput} = \frac{\text{Total data transfer}}{\text{time}} \quad (4)$$

* **Packet delivery ratio:** It is the rate of successfully delivered packets, as shown in equation (5).

$$\text{Packet delivery ratio} = \frac{\text{Number of delivered packets}}{\text{Total Packets sent}} \quad (5)$$

* **Energy Consumption:** It represents the energy used by the network, which was calculated as equation (6).

$$\text{Energy Consumption} = \sum \text{Energy used by each node} \quad (6)$$

* **Network Lifetime:** The duration until reduces its energy, expressed as in equation (7).

$$\text{Network Life Time} = \frac{\text{Total number of alive nodes}}{\text{Time}} \quad (7)$$

Figure 7 and Table 1 depict that the ECPF technique's throughput of 2.1 Kbits/sec provides a moderate amount of data transfer appropriate for small or non-complex networks and the TFPA algorithm enables a significant increase above ECPF with a performance of 4.6 Kbits/sec. The higher capacity in TFPA indicates better utilization of network resources, which leads to faster data transfer, improved flexibility, and enhanced reliability for large or more complicated WSN and IoT applications.

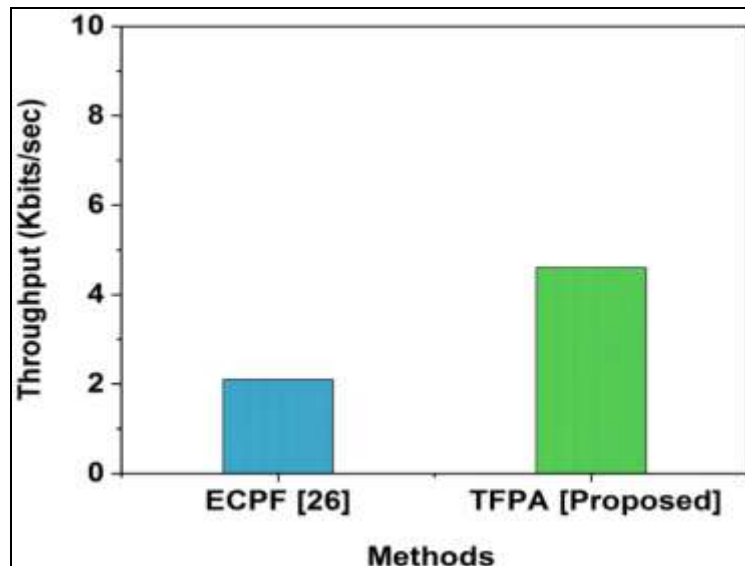


Figure 7: Throughput of Methods.

Source: Authors, (2026).

Figure 8 and Table 1 show that the ECPF method suggests an insufficient packet delivery ratio of 6.1 bytes and an average level of data transmission dependability. The packet delivery at 8.2 bytes, the TFPA technique is significantly better than this, indicating a high degree of success in successfully delivering packets. Thus, it shows that the TFPA is a more operative option for an effective transfer of data in WSN and IoT systems it performs more effectively in retaining data integrity and minimizing packet loss.

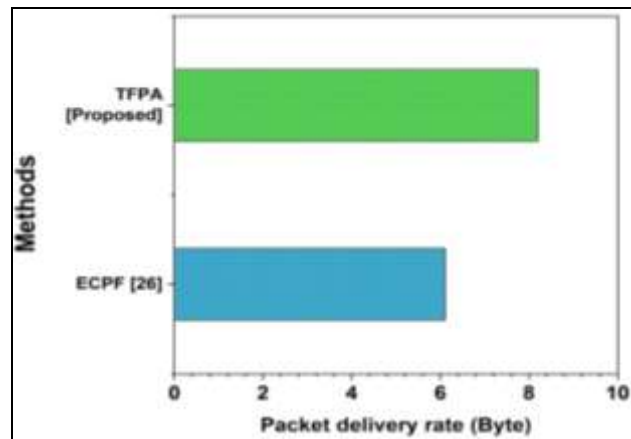


Figure 8: Packet delivery ratio of Methods.

Source: Authors, (2026).

Figure 9 and Table 1 show a total energy usage of 0.5 for Joules the process ECPF [26] is an efficient design that is especially suited for networks requiring minimal use of energy. The algorithm TFPA uses 0.74 Joules of energy, which is higher but still manageable. Due to its higher throughput and transmission ratio, TFPA uses a lot of energy, but this trade-off results in better efficiency.

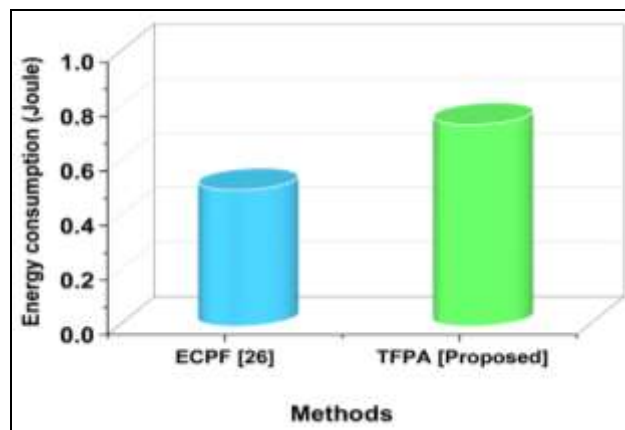


Figure 9: Energy Usage of Models.

Source: Authors, (2026).

The ECPF [26] method is claimed to have a comparatively short lifetime when used for bigger or more complex deployments, having estimated around 300 living nodes. In contrast, the TFPA algorithm has 350 live nodes, which extends the network's life. Additionally, this suggests the TFPA, better controls energy usage, which helps the system's nodes maintain for a longer duration of time, increasing the network's general reliability and efficiency. This is especially helpful for deployments that are shown in Table 1 and Figure 10.

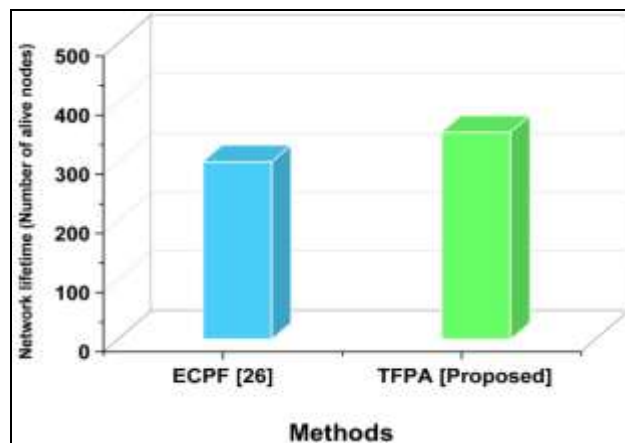


Figure 10: Network Lifetime Comparison of Methods.

Source: Authors, (2026).

Table 1: Numerical Values of Performance Metrics.

Methods	Throughput (Kbits/sec)	Packet delivery ratio (Byte)	Energy consumption (Joule)	Network lifetime (Number of alive nodes)
ECPF [26]	2.1	6.1	0.5	300
TFPA [Proposed]	4.6	8.2	0.74	350

Source: Authors, (2026).

IV.4 DISCUSSION

The outcomes of ECPF are not easily scalable and have limitations in handling large networks. It can be challenged in achieving high energy efficiency while maintaining high performance and network longevity. The proposed TFPA algorithm achieves superior performance to the ECPF method in throughputs, delivery ratio of packets, and network lifetime with reasonable energy consumption. The observed higher throughput of TFPA suggests better idle resource management and faster and more dependable data transmission in complicated WSN and IoT networks. The TFPA method also guarantees a better packet delivery ratio, making information less fragmented and minimizing packet drop. Despite consuming a little more energy than ECPF, it has the added advantage of better performance as a trade-off. This is evident through the observation of an extended network lifetime as observed in the TFPA shows that the solution optimizes energy consumption, making it more suitable for large or long-term IoT applications.

V. CONCLUSION

The research proposed the Tabu flower pollination algorithm (TFPA) for cluster head election and energy optimization in WSN & IoT networks. As compared with the ECPF technique, the proposed computational algorithm TFPA was found to be superior in terms of several key performance indicators (KPI). In particular, the tested system, TFPA, was able to reach 4.6 Kbits/sec, while ECPF reached only 2.1 Kbits/sec, showing data transfer at higher speed. In the packet delivery ratio section, TFPA was at 8.2 bytes, and ECPF was only 6.1 bytes, therefore more packets were reliable. About energy consumption, it took TFPA 0.74 Joule, which is slightly higher than ECPF's 0.5 Joule, but this again came with better performance as observed. TFPA achieved an expansion of the network lifetime through 350 alive nodes more than ECPF, 300. These results explain that the suggested TFPA algorithm is simpler and executes substantially better than the traditional method and efficient in its use of energy resources in IoT and WSN applications.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Bharani Vydyam, Indu Bala, Arun Kumar.

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