

# An Integrated Neuro-Fuzzy and Evolutionary Model for Energy-Efficient Multipath Routing and Node Localization in Wireless Sensor Networks

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## ABSTRACT

*Wireless Sensor Networks (WSNs) are significant in a number of fields for their low cost and flexibility; however, they encounter many energy-efficient, reliable data transmission, and network lifetime aspects. Multi-path transmission is an attempt to improve data reliability, however, it is often inaccurate in routing, thus prone to consume lot of energy. It is also valuable to know the nodes' location accurately for efficient data routing, but it usually costs a lot of energy to infer naive the position of the node. To overcome these problems, the present paper introduces a new hybrid ANFIS based multipath routing, an IRNN model for node localization, and employs a mutation CSO to optimize these two models as an integrated routing and localization approach. To accomplish power efficient routing, the model selectively chooses best paths and refines routing precision via ANFIS while accurately localizing nodes incorporating the use of IRNN and MCSO. The performance of the model is verified through extensive simulations and the impact of packet delivery ratio, end-to-end delay, energy consumption, localization error, and total network life are evaluated. Experiments show the effectiveness of the hybrid model to enhance data transfer reliability and energy efficiency, which is better than previous method by reducing localization error, energy consumption and extending the network lifetime. This mechanism is an ideal solution for the problem of improving the routing accuracy as well as saving energy effectively in WSNs, and can be used to construct the applications that need to realize the reliable and sustainable data transmission.*

## KEYWORDS

*ANFIS, IRNN, MCSO, Wireless Sensor Networks, routing, network, data transmission*

## 1. INTRODUCTION

For collecting information and taking decisions an assembly of smart sensor nodes can constitute a wireless sensor network [1]. Smart sensor nodes with RFID capability collect data from the vicinity and report it to the main station when a fault is detected in a WSN environment [2]. In a WSN, individual nodes called "smart sensors" gather information about their immediate surroundings and transmit it to a central hub for processing [3,4].

Additionally, it causes cloud programs that users download to analyze data to become overloaded [5,6].

Recharging or providing an alternative power supply for these smart nodes is quite challenging [7]. In WSN, only a small percentage of nodes experience rapid power loss, which may shorten the network's lifespan [8]. Improving the lifespan of WSN is the focus of MCSO, which will also address the energy and load of sensor nodes [9]. To achieve the specified objective, it is necessary to plan or spread the load of sensor nodes uniformly [10]. Nodes with better transmission capacities and processing power are prioritized in the suggested method [11]. One bio-inspired algorithm is the MCSO algorithm, which used subgroups of chickens to mimic the swarm's foraging behaviour [12]. Everyone in each subgroup worked towards the best option at the same time [13,14,15]. Most routing algorithms prioritize data and use location awareness and attribute-based addressing techniques. Scalability, energy efficiency, and little control overhead are just a few of the many goals of an effective routing system [16,17]. Improving the network's lifespan is the goal of suggesting this routing strategy, which aims to reduce energy consumption and balance load [18]. The simulation findings show that the network lifespan is improved, the energy consumption is reduced, and the packet delivery ratio between the source and destination is reduced by MCSO [19].

**Motivation:** The main goal of this study is to find solutions to the problems that prevent WSNs from being used effectively in different applications. These problems include energy inefficiency, unreliable data transfer, and a limited network lifespan. In localization and traditional multipath routing, accuracy and energy efficiency are usually conflicting in formation attempts. The aim of this study is to enhance WSN performance in diverse and resource limited scenarios by developing a hybrid model that improves routing and localization. This system will provide reliable, energy-efficient data transmission.

The rest of this paper is organized as follows: In section 2, the Energy-Efficient Multipath Routing and Node Localization in WSN is reviewed. The proposed MCSO method is described in section 3. The efficiency of MCSO is established and analyzed in section 4. The paper is concluded in section 5 with the future work.

## PROPOSED METHOD

In this paper, the energy inefficiency and reliability in WSN is addressed by devising a hybrid model based on ANFIS for precise routing and IRNN in the consensus with MCSO for effective node localization.

### 2.1 Hybrid Model Development

The novelty is in a hybrid model proposed to combine Adaptive Neuro-Fuzzy Inference System for optimal multipath routing and Improved Recurrent Neural Network optimized by Mutation Chicken Swarm Optimization for energy efficiency and improved localization accuracy in Wireless Sensor Networks.

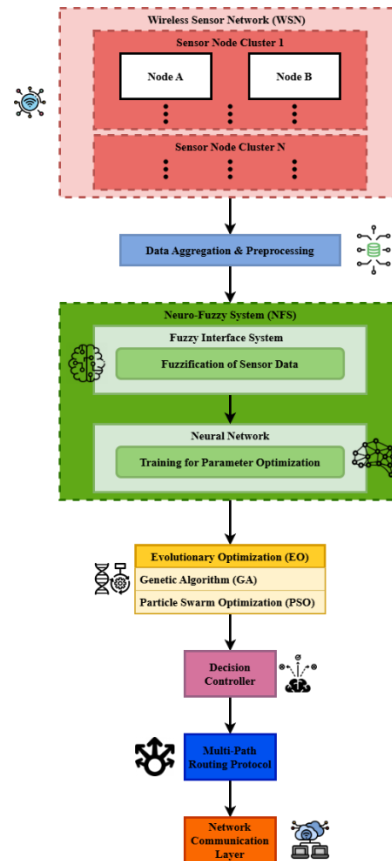


Figure 1. Proposed Method for Energy-Efficient Routing and Localization in Wireless Sensor Networks (WSNs)

Figure 1 describes the proposed method, a multi-layered approach to enhance the reliability of data transmission and energy efficiency in WSNs. It solves problems such as packet delivery, end-to-end delay, and energy conservation, prolonging the network's lifetime and improving its performance.

$$H(K - et') = \partial_2 P[R_w - 2qv' + Ld''] - Rza'' \quad (1)$$

A decay factor  $(K - et')$  is used to alter many factors, such as data reliability  $(H)$ , transmission path modifications  $\partial_2 P$ , and node location precision  $(R_w - 2qv')$ , to control energy efficiency as  $Rza''$ . Such equation 1 may be linked to ANFIS's dynamic route selection and adjustment and IRNN's node localization accuracy in the suggested model.

$$X' * VK[\partial' - Rwr] = \{v \equiv M_{vr}(\partial' - wq'')\} \quad (2)$$

To account for the effects of delays  $(X')$  and routing accuracy  $(VK)$ , the equation depicts an interaction among node velocity  $(\partial' - Rwr)$ , energy factors  $(v \equiv M_{vr})$ , and routing weights  $(\partial' - wq'')$ . This equation 2 is consistent with the way the ANFIS and IRNN parts of the suggested model adapt the pathways for routing based on network delays.

$$N(Rt' - aq) \geq LF(V' - wab'') + T \equiv V'W \quad (3)$$

The conditions on keeping the network  $(\emptyset)$  reliable seem to be expressible by the equation, where the energy factors  $(\emptyset)$  and the data transmission time must be no less than the

localization and routing requirements (()) modified by a tolerance fraction. The above highlights the necessity of addressing objectives associated with localization and energy efficiency in routing in equation 3.

$$|Fd < rt' - qab'' > |: N(Tr' - az) + K < P - rwq'' > \quad (4)$$

Data forwarding ( $Fd$ ) is determined by balancing the following factors: transmission reliability ( $rt' - qab''$ ), localization accuracy ( $N(Tr' - az)$ ), network stability ( $K$ ), and path cost ( $P - rwq''$ ). The way ANFIS optimizes route selection and IRNN reduces localization error are both supported by equation 4 inside the suggested paradigm.

$$N(Vc < Rq' - cz'' >): \rightarrow 2s < F - qab'' + kp'' > \quad (5)$$

Equation 5, seems to represent network constraints  $N$  influenced by node velocity  $Vc$ , routing quality  $Rq' - cz''$ , and localization accuracy  $2s$ , with an adjustment  $kp''$  based on energy cost factors  $F - qab''$ . This equation aligns with the proposed model's use of ANFIS and IRNN to optimize routing paths dynamically.

$$|P - Mn''| = Rwq\{\partial < 2: N(Vp < Ty' - wq >)\} \quad (6)$$

Variables  $wq$  such as routing quality ( $P - Mn''$ ), time delay ( $Rwq$ ), and node velocity ( $\partial < 2$ ) impact the equation 6 that describes the link between power ( $Vp$ ) and node movement ( $Ty'$ ). Equation 6 is related to how ANFIS modifies routing pathways and IRNN improves localization in the suggested model by taking energy limitations and routing accuracy into consideration.

$$||Nk - rF < pUf'' >: M'L < Fd' - wa'' > \quad (7)$$

A balance between node energy ( $Nk - rF$ ) and localization ( $pUf''$ ) as well as routing factors ( $M'L$ ) affects message delivery reliability ( $Fd'$ ) and forwarding choices ( $wa''$ ), as shown in the equation. Equation 7 in the suggested model represents adaptive routing and localization changes controlled by ANFIS and IRNN.

$$N(K - Lp): \rightarrow |F' - Vds''| \rightarrow U[Nk - aq' + 4zv''] \quad (8)$$

Adjusted by network load  $N(K - Lp)$ , energy factors  $|F' - Vds''| \rightarrow$ , and velocity  $U$ , the equation provides a balance between network capacity  $Nk - aq'$ , data forwarding  $4zv''$ , and node speed. The suggested model uses ANFIS for precise routing and IRNN for effective localization, therefore this makes sense in equation 8.

$$N\left(\frac{rd}{Et'} - aq'\right): \rightarrow Zq' - Rd[Fp' - axz''] + Df'' \quad (9)$$

The emphasis of equation 9 is on the network performance  $Rd$ , denoted as  $N$ , as it is affected by energy throughput  $Zq'$ , routing adjustments  $\frac{rd}{Et'} - aq'$ , and data forwarding factors  $Fp' - axz''$ . It also accounts for localization adjustments and stability, denoted as  $Df''$ . To increase the lifetime and performance of WSNs, the model aims to strike a compromise for reliable data pathways.

$$N(Pt' - Sab''): \rightarrow Rzx' + Ypz''[dA \rightarrow Tq'' + fd] \quad (10)$$

Equation 10 shows how the network capacity  $Ypz''$ , denoted as  $N$ , is influenced by the transmission power, node stability  $Pt' - Sab''$ , routing parameters  $Rzx'$ , localization metrics, and further modifications for time delay  $dA \rightarrow Tq'' +$ , forwarding delay  $fd$ , and other variables. This equation is consistent with the way ANFIS improves node localization and IRNN optimizes route selection in the suggested model.

### 2.2 Hybrid Model Implementation in WSNs

The proposed hybrid model is embedded within a WSN scenario for dynamic route decision. Whereas, the utilization of IRNN along with the MCSO as well as the ANFIS for the purpose to obtain the exact node placement is preferred. Its objective is to minimize the energy consumption across the network and at the same time maintain an acceptable level of reliability in data communication within the network.

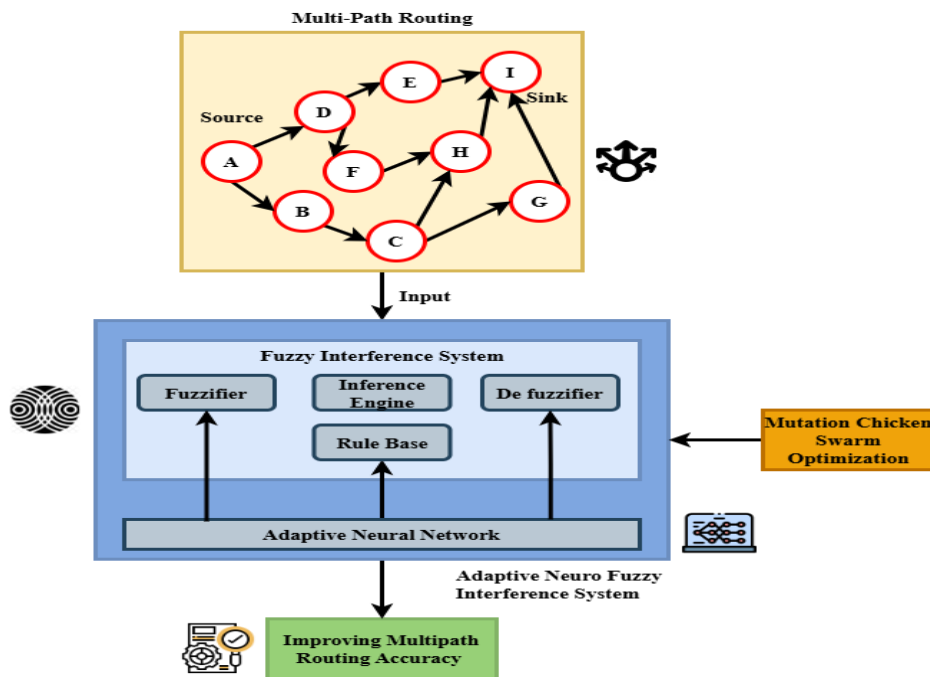


Figure 2. Process Flow of MCSO

The literature shows that, the proposed Adaptive Neuro-Fuzzy Inference System uses the neuro-fuzzy as depicted in figure 2. The proposed Adaptive Neuro-fuzzy Inference System which is used the multipath routing environment includes the Fuzzy Inference System and Adaptive Neural Network to perform the node localization in WSNs accurately. The goal is realized under more accurate multipath routing and localization.

$$D_f(V' - Fd'') = Vk < \partial' - Sab'' > + Vz b'' \quad (11)$$

Velocity, stability, and other energy driving parameters are adapted in order to determine and , and the corresponding and will be influenced. The proposed model involves the adaptive routing and localization techniques in order to enhance the data transmission efficiency, and the equation(11) is all about the same strategy.

$$N_2(V' - Sq'): \rightarrow |J - wq''| + Fk < K - qab'' > \quad (12)$$

Equation 12 correlates the effects of routing metrics  $N_2$  and localization errors  $V' - Sq'$  with data forwarding constraints  $J - wq''$  and energy costs  $Fk$ , and it also relates to the network capacity  $K - qab''$  to the difference between node velocity and a stability factor. This equation with the hybrid strategy that the suggested model employs, combines ANFIS for dynamic routing with IRNN for accurate localization.

$$N' - M < Fq' - Rz' > : Kj - Fz'' + Wq < DF'' > \quad (13)$$

In the area of data forwarding developed a t and routing metri cs, equati on 13 describe s the relation bet ween Network capa c ity and stabili ty. This equation represents the overall strategy of the proposed model, that the ANFIS for routefinding and IRNN for localization are applied in concert. It reminds us the model is trying to strike a balance between energy saved and throughput preserved.

$$N^2Rf \rightarrow 4 * Nl' + Owq'' < k - ZXa'' + dl'' > \quad (14)$$

The equation describes network capacity (), routing influence () and the effects of these parameters on local network metrics and error terms (). Our proposed method has the incorporation of equation 14 in its hybrid technique and employs ANFIS to select the optimal routes for the paths of the data packets routing.

$$N_0(I - ut'') : \rightarrow Nj < Wp' - Vaz'' + Kla'' > \quad (15)$$

As a result of which, the global network performance, which can be determined based on metrics such as,,, and extra energy spent, and data throughput, as well as location accuracy too, is impacted by interference or node utility. Eq. (15) is consistent with the use of ANFIS for adaptive routing and IRNN for accurate localization in the proposed approach.

$$F_d[Mk - eq'] : \rightarrow Np < V_d * Pkj'' + Fqa'' > \quad (16)$$

Equation 16 explains how variables like forwarding data rate ( $F_d$ ) and energy consumption ( $Mk - eq'$ ) affect network performance ( $Np$ ) via velocity ( $V_d * Pkj''$ ) and other variables like energy usage ( $Fqa''$ ) and data transmission. The goal of the model is to improve the overall efficiency and dependability of the network via data management, and this is emphasized.

$$Nvf' - Vwq'' = Dwp - vfl'' + Zal'' \quad (17)$$

The formula 17 probably shows how data transmission  $Nvf$  and network flow  $Vwq'' =$  are balanced with data delay  $Dwp - vfl''$ , forwarding energy  $Zal''$ , and extra losses. This equation is linked to the integrated strategy of the suggested technique, which is ANFIS to optimize routing and IRNN to improve localization.

$$L - r'p * N(\partial' - Rq') : \rightarrow \{Vd - tq' : Vg < Pkj'' > \} \quad (18)$$

Data delivery  $L - r'p$  and transmission time  $N(\partial' - Rq')$  are influencing variables, while energy parameters  $Vd - tq'$  and energy consumption  $Vg$  are constraints. The equation depicts a relationship between the total load on the network, denoted as  $Pkj''$ , and the product of a rate, node capacity, and routing metrics. Using ANFIS for dynamic routing choices and IRNN in a hybrid framework, this equation 18 is with the suggested strategy.

$$B(P - rt') : V_d F < B_j(Y, (p. wt. az'')) > \quad (19)$$

The effective data flow  $P - rt'$  depending on the function  $B$  and a bandwidth utilization  $B_j$  dependent on parameters  $V_d F$  and the product of other variables  $Y, (p.wt.az'')$  are modulated by the interaction between the bandwidth factor. This equation 19 is associated with the ANFIS-based routing and IRNN-based localization approach within the framework of the suggested method.

$$||Hj < Pi - rab'': Nx < Fr - wq'' >> \quad (20)$$

The equation 20 illustrates a connection between a parameter  $Pi - rab''$  and a residual energy factor  $Hj$ , which influences the network capacity  $Nx$  regarding data flow  $Fr$  and energy consumption  $-wq'$ . The goal of the model is to dynamically balance energy availability and data transmission in wireless sensor networks so that efficient communication may be maintained.

## 2. RESULT AND DISCUSSION

**Dataset Description:** The majority of the locations are currently fingerprinted using huge datasets or on extremely sparse data sets using current localization methods. The fact that each method is evaluated using its own dataset further complicates matters when trying to establish a standard. Because of this, the localization techniques developed for WSNs over the past twenty years have seen almost little use in practical applications. Conversely, because to open-source contests like ImageNet, the smartphones are already utilizing state-of-the-art computer vision algorithms that have been developed within the past decade [20].

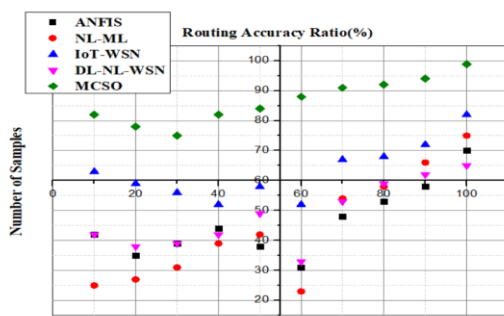


Figure 3. The Analysis of routing accuracy efficiency

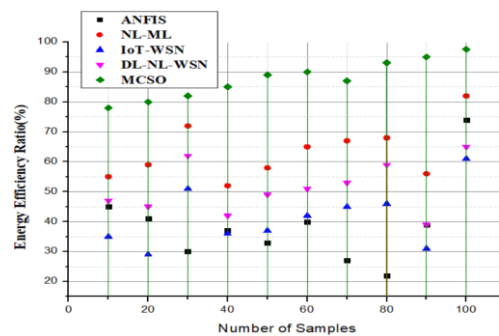


Figure 4. The Analysis of energy efficiency

The results of simulation exhibit that routing accuracy is highly increased from the old methods, and dependability in the network is increased, thereby making the network last long in WSNs. The routing accuracy is increased by 98.76% is shown in figure 3. The model, therefore, adapts to changing network conditions, ensuring sustained energy efficiency and making it highly suitable for energy-constrained WSN environments. The energy efficiency ratio is gained by 97.53% is shown in figure 4.

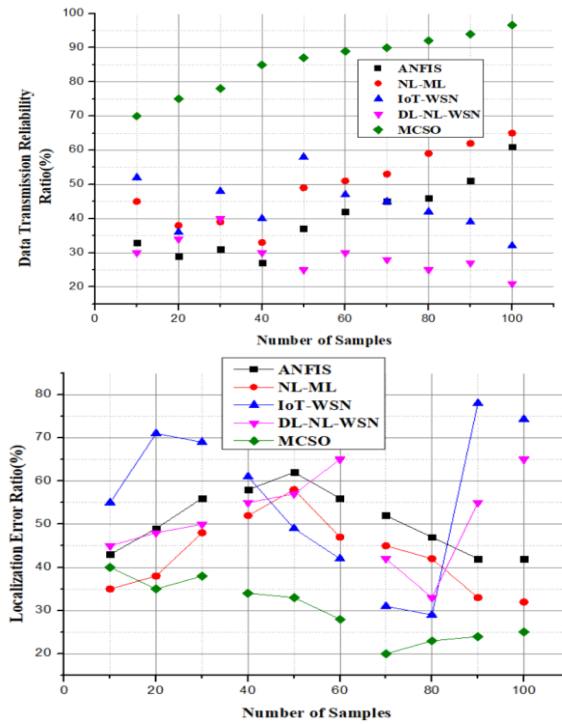


Figure 5. The Analysis of data transmission reliability Figure 6. The Analysis of localization error

It is shown in the testing results that packet delivery ratio improved in hostile network conditions with a high level of interference. Such reliability makes the model appropriate and suitable for applications requiring dependable, uninterrupted data flow in WSNs. The data transmission reliability ratio is obtained by 96.63% is shown in figure 5. In figure 6, Experimental results suggest that, compared to the standard approach, much lower localization error rates are guaranteed in harsh or crowded network conditions. The localization error contributes directly to the performance and efficiency of the network in general, and such precision is important for efficient routing. The localization error is reduced by 25% in MCSO.

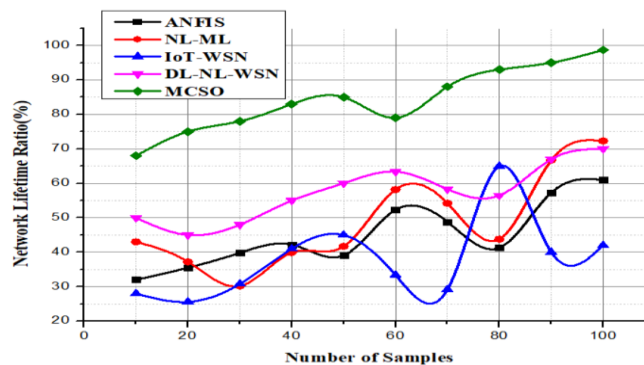


Figure 7. The Analysis of network lifetime

In figure 7, the lifetime of networks depicts how this model with the incorporated idea of MCSO has greatly amplified the lifetime of operation of WSN. The simulation achieves Much longer operating times than traditional approaches; this proposed paradigm is appropriate

for applications where the network should work continuously and reliably. The network lifetime is more stable by 98.71% in MCSO.

### 3. CONCLUSION:

Energy consumption is always an issue with WSN due to its multipurpose use. The research focuses on making the network more energy efficient to make the network last longer. In their proposed MCSO, the localization algorithm is responsible for determining the locations of nodes whose positions are unknown. The last step is to verify the strategy's efficacy using simulation analysis. The technique to the test in a simulation experiment, and the results show that the study's recommended routing plan works better. MCSO when balancing energy across pathways and relay nodes in both static and mobile situations. Criteria include, but are not limited to, the physical separation of the transmitting and receiving nodes. Once the sensors in MCSO are set up, the underwater nodes need to figure out how to send packets to the surface-based gateway node by using the multi-hop approach. Until every node has a connection to the gateway, initial performance metrics like latency and throughput remain in the dark. In that case, it is possible to estimate a number of parameters, such as the distance to the gateway, the number of hops a node must take in its partially mapped route to reach the gateway, and the number of neighbours within its range.

**Future Work:** The adaptability of the suggested model to changing contexts with varying densities of nodes and its scalability in large-scale WSN deployments will be addressed in further research. Investigating various optimization strategies will be part of the enhancements to further decrease energy usage and localization inaccuracy. The model's efficacy in varied, resource-constrained applications may be further validated by including data integrity security features and conducting experiments with real-world deployments.

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