An Efficient multipath routing in Wireless Sensor Network using Adaptive Neuro Fuzzy Inference System

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ABSTRACT

Multi-path transmission can well solve the data transmission reliability problems and life cycle problems caused by single-path transmission. However, the accuracy of the routing scheme generated by the existing multi-path routing algorithms is difficult to guarantee. In order to improve the accuracy of the multi-path routing scheme, this paper innovatively proposes a multi-path routing algorithm for a Wireless Sensor Network (WSN) based on machine learning model. In this work design and implement an Adaptive Neuro Fuzzy Inference System (ANFIS) for multi-path routing in wireless sensor networks. Proposed model is evaluated in terms of packet delivery ratio, end to end delay and throughout. Then, prove that ANFIS has advantages in improving the accuracy of the multi-path routing scheme through comparative experiments.

Keywords: Wireless Sensor Network (WSN), Efficient Multipath Routing (EMPR), Adaptive Neuro Fuzzy Interference System (ANFIS).

INTRODUCTION

Wireless Sensor Network (WSNs) are made up of densely dispersed sensor nodes with limited processing capabilities, power supply, and communication bandwidth. Sensor networks have numerous potential applications in both civil and military spheres [1]. WSNs can be implemented/organized in places where they would be costly to deploy in the absence of a wireless network and used in a variety of applications such as intelligent transportation systems, smart agriculture, military applications, disaster recovery, wildlife monitoring, community networking, vehicular computing, and so on [2].

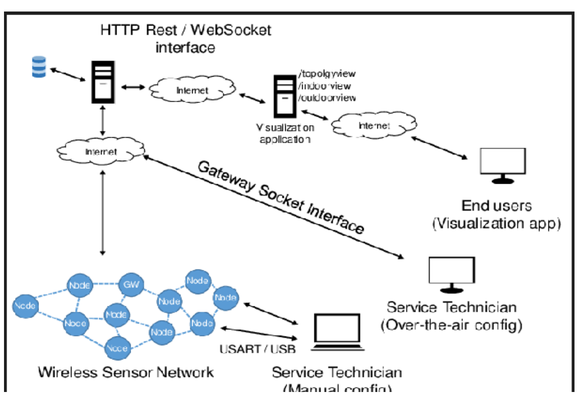

Figure 1 Structure of Wireless Sensor Network (WSN)

A WSN is made up of sensor nodes that have limited memory, CPU power, and energy capacity. Sensors run a variety of applications for a variety of purposes, including tracking, localization, monitoring, and event detection is represented in Figure 1. [3]. As a result, in order to properly monitor and enhance network quality, it is important to analyse the overall performance of the network state of the entire network to assist the user in controlling the network's working status in real time [4].To improve fault tolerance in wireless sensor networks, the multipath routing technique is typically employed to replace the original routing system [5]. Router with a single path. Packets can be routed across two or more pathways in multipath routing [6,7], which reduces packet loss. Furthermore, multipath routing can prevent packet tampering or malicious attacks in the routing process and increase data transmission security [8,9].

The goal of these studies, the wireless sensor network routing, a multipath routing method based on next hop is proposed in [10], the algorithm transmits messages according to the hierarchical structure of the loop in which the nodes are located and does not take into account the nodes' multipath problem. To address the issue of multipath routing protocols based on three-dimensional space and regional coevolution. Every neighbour in the sensor node's routing table is assigned a transmission probability based on the cost of the path that passes through it. The technique keeps numerous paths but only uses one at a time to avoid stressing a single path and to increase network lifetime. The data transmission reliability challenges and life cycle problems created by single-path transmission are based on this Multi-path transmission. It is difficult to ensure the accuracy of the routing scheme generated by present multi-path routing algorithms.

The research presented an effective multipath routing strategy for wireless sensor networks based on the Adaptive Neuro Fuzzy Interference System (ANFIS) to address these issues. A multi-path search algorithm that is distributed, scalable, and localised to find various node-disjoint paths between the sink and source nodes. The load balancing method enables the sink node to distribute traffic across several paths determined by their cost, which is determined by the energy levels and hop distances of nodes along each path. A fault-tolerant routing system was built using an Adaptive Neuro-Fuzzy Inference System. The numerical estimation-based fault-tolerant routing techniques are discussed. When comparing the metrics: average throughput, packet delivery ratio, average end-to-end delay in packet delivery between source and destination, and average routing overhead, the proposed ANFIS-based strategy offers better results.

LITERATURE REVIEW

Genta et al [11] proposed a routing method for data communication that integrates dynamic cluster creation, cluster head selection, and multipath routing formation to reduce energy consumption and routing overheads. The proposed technique employs a genetic algorithm (GA)-based meta-heuristic optimisation to dynamically select the best path with the least distance and energy dissipation based on the cost function. The suggested algorithm's performance was thoroughly evaluated and compared to three other routing protocols. The performance analysis simulation results demonstrated that the suggested algorithm outperformed the three other routing protocols.

Li et al [12] proposed a multipath energy-efficient routing algorithm for wireless sensor networks (WSN) that takes wireless interference into account. The proposed routing protocol marks nodes in the interference zone of the found path and prevents them from participating in the future routing process. As a result, the quality of wireless communication is increased since the effects of radio interference are reduced to the greatest extent possible. Instead of concentrating on a single way, network load is divided across numerous paths, and node energy costs are more evenly distributed across the entire wireless network. NS2 software simulates the routing protocol. The simulation results suggest that the proposed routing strategy saves energy and extends network lifetime.

Jaiswal and Anand [13] proposed an energy-efficient routing system for wireless sensor network-based IoT applications with high traffic loads. To choose the best path, the proposed protocol takes three factors into account: longevity, reliability, and traffic intensity at the next-hop node. NS-2 has been used for rigorous simulation. In addition, the suggested protocol's performance is compared to that of other modern protocols. The results show that the suggested protocol outperforms other protocols in terms of energy savings, packet delivery ratio, end-to-end delay, and network longevity.

Alghamdi [14] proposed a meta-heuristic-based cuckoo search-inspired attempt at an optimised load-balancing energy-efficient routing protocol. To balance the routing overhead among the various nodes participating in routing, the proposed protocol leverages the cuckoo search technique to select an appropriate routing path based on individual node residual energy. The new protocol was evaluated and compared to energy-aware adaptations of on-demand Multipath Distance vector, packet measure-based routing mechanism, load balancing ad hoc immediately multipath distance vector protocol, boosted metric based ad hoc on demand distance vector protocol, and Ant HocNet routing protocol. The proposed routing architecture demonstrated considerable improvements in packet delivery ratios, greater battery life, and low packet delay time after analysing the simulation-based results

Shahbaz et al [15] Proposed a multipath routing approach for homogeneous WSNs in this paper. The suggested method is divided into three stages: clustering network nodes, identifying pathways between CHs, and maintaining the paths. The wireless sensor network is clustered using the firefly algorithm in the first phase. The second step involves fuzzy logic-based routing between CHs. Routing between CHs creates two paths: the major way and the backup path. CHs send data packets to the base station through primary paths; however, when primary paths fail, CHs use backup paths. The paths are kept in the third phase so that path breaks cause route discovery to recommence.

Chouhan and Jain [16]proposed a multipath routing protocol called Tunicate swarm Grey Wolf optimisation (TSGWO). An IoT assisted WSN network that employs the proposed optimization approach. The multipath routing protocol creates a multipath from a multipath source node to many destinations. The multipath source node sends packets to numerous destinations at the same time. The nodes in the IoT-assisted WSN network are first simulated together and the cluster head is selected using the Fractional Gravitational Search algorithm (FGSA), and then the multipath routing process is performed on the basis of the proposed TSGWO, in which the routing path is selected by considering fitness parameters such as QoS parameters and trust factors. The delay, energy, link lifetime, and distance are all QoS parameters. Using the fitness parameter, the path with the shortest distance is chosen as the optimal path. By combining the parametric aspects of both optimisation algorithms, the suggested optimisation method efficiently accomplishes the multipath routing mechanism. Following that, the route maintenance process in the simulated IoT network is carried out to recover the link breakage based on DRINA. TSGWO surpassed other approaches in terms of maximum average residual energy, maximum link longevity, maximum PDR, and maximum throughput.

Kim et al [17] presented the routing system to facilitate collaboration among the paths with a bridge node. Because the bridge node monitors the packet transfer on the path, it may detect and avoid problems like transmission failure and delay. That is, collaboration via interpatch communication based on the bridge node reinforces multipath. As a result, the suggested strategy might offer real-time, reliability at WSNs used for IoT applications while simultaneously easing energy efficiency constraints by using fewer channels.

Jemili et al [18]proposed a cross-layer multi-path routing approach is proposed to allow important data transfer across duty-cycled WSN networks. This method creates multi-node disjoint pathways with complimentary duty-cycling schedules to assure the continuous availability of an active path capable of transferring essential data. It relies on close collaboration between the routing and MAC layers to change and regulate the wake-up timings of affected nodes throughout the forwarding phase. We demonstrated the accuracy of the proposed scheduling modification rules analytically. Toextensive simulations to demonstrate the CL-NDRECT's capacity to provide a viable trade-off between energy conservation and real-time responsiveness. According to simulation studies, CL-NDRECT saves around total energy during route formation and data transmission when compared to the always-on multipath strategy, at the cost of an increase in reaction time.

Srinivasulu et al [19] proposed a QoS aware energy efficient multipath routing (QEMR) protocol based on an IoT hybrid optimisation method. The first stage is to use a modified teaching-learning-based optimisation (MTLO) strategy to obtain optimal clustering. The cluster head (CH) is then determined using the nonlinear regression-based pigeon optimisation (NR-PO) method. The Deep Kronecker Neural Network (DKNN) is used for routing and identifying the best path. The NS-3 simulation tool is used to model and evaluate the effectiveness of our proposed routing QEMR system. The simulation results of the proposed QEMR method are compared to those of existing techniques such as REER, Rumour, and EOMR in terms of the effects of node density, node speed, and network traffic. In terms of energy consumption and the influence of node density, the proposed QEMR system consumes less energy than the REER, Rumour, and EOMR methods. The proposed QEMR system is used to investigate the application of a problem by increasing network performance and QoS by utilising DKNN-based routing methodology to transmit data from source to destination by finding the ideal path.

Maratha et al [20] proposed sequential quadratic programming (SQP) based multi-path routing formulation focusing on improving lifetime and delay is represented, namely EBDA-DEFL and focuses on improving lifespan and delay. The optimization tool is used to solve the SQP-based formulation once it has been solved using particle swarm optimization (PSO). To alleviate the negative consequences of multi-path routing, a quota mechanism for traffic load distribution is also included. The suggested work is tested and compared to current algorithms to assess its superiority over earlier work. Minimax and PSO were compared in terms of first node death, half node death, last node death, delay, and time consumed. The simulation results validate the superiority of the suggested work over the existing ones.

Olufemi and Pamela [21] we suggested a secure multipath routing protocol to fulfil the performance needs of WSNs in mission and safety-critical systems, based on sectorization and best neighboring node selection models. For dependable data delivery, the protocol can provide optimal multiple-ranked route options. A route management technique is created employing a direct approach for identifying several optimal data pathways for dependable data routing. In addition, to maintain security and privacy during data routing, a basic but efficient lightweight privacy preserving authentication system is presented for the protocol. To determine its efficiency in terms of computing cost, energy usage, and security, computational and security analyses were done. In terms of end-to-end delay, energy usage, and data routing dependability, the results showed that SMRP outperformed the two leading options.

PROPOSED METHODOLOGY

The following is to introduce the efficient multipath routing method based on Adaptive Neuro Fuzzy Inference System.

Multi Path Routing Method:

The routing protocol allows us to determine the best path between the source and destination nodes. Wireless sensor network routing is an important aspect in energy conservation. Multipath routing increases the likelihood of dependable data transfer. The multipath routing protocol encrypts data from sensor nodes and assures network availability. A wireless sensor network's routing can be divided into three groups.

1. Flat-based Routing.
2. Location -based Routing.
3. Hierarchical – based Routing.

Global addressing is not supported in flat-based routing [22]. with contrast, with hierarchical routing, nodes are organised into clusters and data is routed through major nodes are referred to as cluster heads. It is also referred to as cluster-based routing [23]. The benefit of cluster-based routing is data aggregation, which saves energy and boosts efficiency. In the case of location-based routing, the address is determined by the location of the sensor node. Multipath routing takes advantage of network variety and resources to help with things like quality of service QoS, latency metrics, load balancing, and so on. This helps to improve network bandwidth and resource utilisation. Without security improvements, multipath routing is vulnerable to attacks [24].

Figure 2 shows a wireless sensor network with 1 base station and 9 relay nodes. There are two different paths for source node 1 in the network: 1 -> 4 -> 5 -> BS and 1 -> 2 -> 6 -> 9 -> BS. Apart from the source node and the destination node, these paths do not have a single middle node. These two paths are called two independent paths of the node.

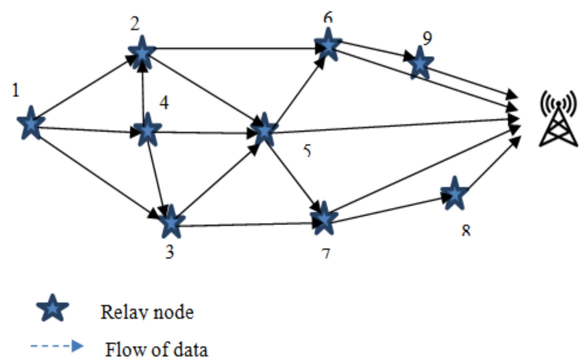

Figure 2 Example of Multipath Routing

Wireless sensor networks are not the same as mobile ad hoc networks. The nodes in a wireless sensor network are static; if a node fails, the topology is modified. As a result, mobile ad-hoc protocols cannot be used directly in sensor networks. This necessitates the use of a secure protocol known as Secure Protocol for Reliable Data Delivery (SPREAD) [25]. This protocol divides the message and sends it to its destination. This message is being routed through multipath routing. This protocol employs a distributed many-to-one multipath discovery technique that is both dependable and secures [26].

Acquisition of data in a wireless sensor network. Based on simulation findings, we may conclude that this protocol is an efficient multipath approach. This protocol consists of three major components: path discovery, traffic allocation, path maintenance, and security. Because of the hostile environment, the energy expended by each node for data transmission will differ. Symmetric key is used in this protocol to secure data transfer between base stations and sensor nodes.

Wireless Sensor Network:

The concept used in the wireless sensor network is defined as follows:

1. $R = \{r1, r2, r3 \ldots., r_m\}$Expresses relay nodes in the wireless sensor network (WSN), which expresses the r_m base station node.
2. Dist(r_i, r_j) defines the spatial distance between node r_i and noder_j.
3. Range defines the relay node communication range.
4. $ComCH(r_i)$ indicates a node where the relay node has a message exchange with the node r_i.

$$ComCH(r_i) = \{r_j \; Dist(r_i, r_j) \leq Range\}, \qquad (1)$$

   Where r_i and r_j belong to R. range defines the communication range on the relay node.
5. K represents the number of different paths in the network.
6. Hop (r_i) represents the next hop from node r_i to the base station node. If r_i can communicate directly with the base station, then $Hop(r_i) = 1. Hop(r_i)$ is defined as follows:

$$Hop(r_j) = \begin{cases} 1, & Dist(r_i, BS) \leq Range \\ 1 + Hop(r_j), & Hop(r_j) = Min\{Hop(r_k)|Dist(r_i, r_k) \leq Range \; \forall r_k\} \end{cases} \qquad (2)$$

   Where r_i,r_j, and r_k belong to R.
7. Falt$(r_{i,}r_j)$represents the sum of packets of all errors that occurred during the transmission from the node $r_{i,}$ to the node r_j.
8. $Engy\ (r_i, r_j)$ represents the sum of energy consumption on all nodes during the transmission from the node r_i to the node r_j.

Figure 3 Describes the Architecture diagram for EMPR-ANFIS. The multipath routing problem in wireless sensor networks is an evolutionary process. Furthermore, when searching for a path, the data transmission and fault tolerance of each network node should be considered in order to pick an ideal path, which can be realised with different layers using ANFIS.

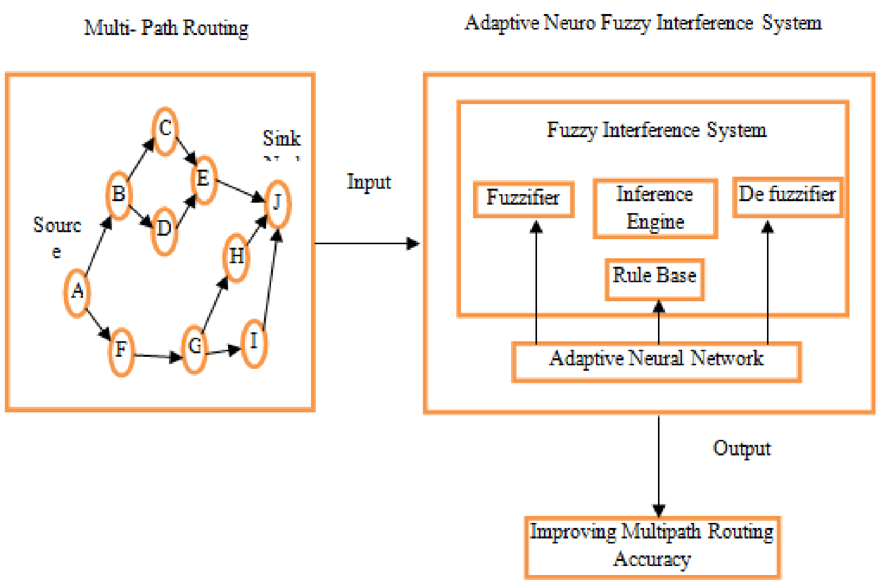

Figure 3 Architecture Diagram for EMPR-ANFIS

Adaptive Neuro Fuzzy Interference System (Anfis):

Adaptive Neuro-Fuzzy Inference Systems, are widely regarded as a universal estimator or Takagi-Sugeno Fuzzy System. The Takagi-Sugeno Fuzzy model is a Type 3 Fuzzy Inference System, where the rule outputs are a linear combination of input variable along with a constant, and the final output is the weighted average of every rule's output.

The IF-THEN rules for a 3-input Takagi-Sugeno system are described as follows.

1. Rule1: $IF\ x\ is\ A_1, y\ is\ B_1, z\ is\ C_1, THEN\ f_1 = p_1x + q_1y + r_1z + s_1$
2. Rule 2: $IF\ x\ is\ A_{2,}\ y\ is\ B_2, z\ is\ c_2, THEN\ f_2 = p_2x + q_2y + r_2z + s_2$

3. Rule 3: $IF\ x\ is\ A_3, y\ is\ B_3, z\ is\ C_3, THEN\ f_3 = p_3x + q_3y + r_3z + s_3$

Where x, y, z are the inputs in the crisp set; $A_{i,} B_{i,} C_i$ are the linguistic labels; $p_{i,} q_i, r_i$ are the consequent parameters; f_1, f_2, f_3 are the output fuzzy membership functions.

The standard ANFIS architecture, as given in Figure 4, consists of five layers of interconnected neurons, evident of artificial neural networks having alike functionalities [27]. The architecture is briefly explained as follows.

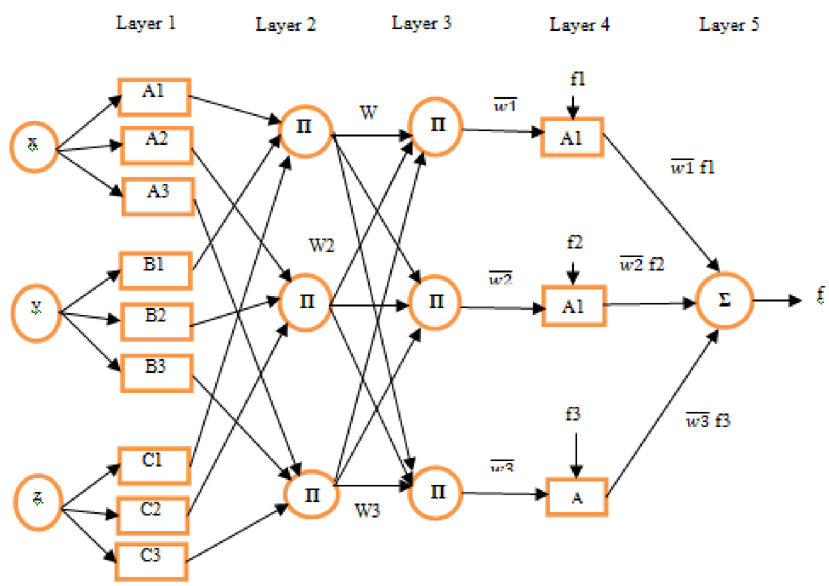

Figure 4 Standard Structures of ANFIS

Layer 1: The Node Layer
It is the Fuzzification Layer where each neuron is an adaptive node and holds the fuzzy value of the crisp inputs. The node output is calculated as follows:

$$O_i^1 = \begin{cases} \mu_{Ai}(x), & \forall_i = 1,2, \\ \mu_{Bi-2}(x), & \forall_i = 3,4, \\ \mu_{Ci-4}(x), & \forall_i = 5,6, \end{cases} \quad (3)$$

Where μ is a membership function for the fuzzy sets A_i, B_i, C_i. Numerous membership functions exist, i.e. Gaussian, Trapezoidal, Triangular, etc. A bell-shaped function in ANFIS. Hence, the gaussian function is the optimum choice. The formula for Gaussian function is

$$f(x) = a.exp\left\{-\frac{(x-b)^2}{2c^2}\right\}, \quad (4)$$

Where a, b, c are the premise parameters for the membership functions of ANFIS

Layer 2: The Membership Layer
This is an Implication Layer where the neurons contain the product of inputs, i.e., the weight of premise parameters. The node output is calculated as follows:

$$O_i^2 = w_i = \mu_{Ai}(x).\mu_{Bi}(x).\mu_{Ci}(x), \quad \forall_i = 1,2,3, \quad (5)$$

Where w_i is the weight of the neuron

Layer 3: The Rule Layer

It is Normalizing Layer where the neurons are fixed and are normalized by the sum of weights of all neurons in this layer. The node output is calculated as follows:

$$O_i^3 = \overline{w_i} = \frac{w_i}{\sum w_i}, \quad \forall_i = 1,2,3, \tag{6}$$

Where $\overline{w_i}$ is the normalized weight of the neuron.

Layer 4: The Defuzzification Layer

This is the Defuzzification Layer where each neuron is also an adaptive node and holds the consequent parameters of the architecture. The node output is calculated as follows:

$$O_i^4 = \overline{w_i} f_i = \overline{w_i}.(p_i x + q_i y + r_i z + s_i), \quad \forall_i = 1,2,3. \tag{7}$$

Layer 5: The Output Layer

It is an Output Layer where a single neuron is present for output, which is the sum of all the inputs. The node output is calculated as follows:

$$\boldsymbol{O_i^5 = f(x,y,z) = \sum_i \overline{w_i} f_i = \frac{\sum_i w_i f_i}{\sum_i w_i}, \quad \forall_i = 1,2,3.} \tag{8}$$

Classical ANFIS favors hybrid learning process, where parameters are updated through two passes and use two different optimization algorithms.

During the forward pass, the consequent parameters are updated, when the inputs are provided to ANFIS, and the premise parameters are kept fixed, using LSE, the consequent parameters are updated in Layer 4, and the final output is calculated accordingly.

As the final output is calculated, the backward pass starts, during which the error is propagated back to Layer 1, and the premise parameters are updated.

In this pass, the consequent parameters are kept fixed [28]. The Algorithm for ANFIS is presented in Algorithm 1.

Algorithm 1: Steps of Anfis Algorithm

1. Defining of data packets for each hardware component.
2. Constructing membership functions for each data packets.
3. Developing knowledge base
4. Fuzzifying the crisp inputs
5. Training process and evaluating knowledge base (database, dataset, and rule base)
6. Combining the output results of each rule
7. De-fuzzifying nonfuzzy outputs

Path Planning Procedure

With the information in the previous parts, it is possible to generate the trajectory for excavator arm which satisfies some requirements about optimization and smooth [29].

The sequence for this process has the following steps:

1. Step 1: get the desired points based on shaped and optimal issues, then use inverse kinematics to obtain the via-points in the joint space as training sample.
2. Step 2: design ANFIS architecture.
3. Step 3: train ANFIS.
4. Step 4: use ANFIS to generate the trajectory for each joint.

RESULTS AND DISCUSSION

In this section, we evaluate the performance of the proposed Multipath routing protocol by means of dynamic simulations. We first briefly describe the simulation model and define the evaluation metrics. Then we show the simulation results.

To consider rectangle region of 150 m by 150 m, in which the sensor nodes are deployed in an ad hoc manner. We generate a variety of sensor fields of different sizes.

We conduct two groups of simulation. In the first group, fixing the number of source nodes to 4, we change the network size by varying the number of nodes from 30 to 130 nodes in increment of 20 nodes. In the second group, we change the simultaneous sources from 2 to 7 while keeping the network size as 100 nodes. Each node has a transmission range of 12 m. Simulation parameters are given in Table 1.

Table Simulation Parameter

Parameter	Value (unit)
Simulation area	150m×150m
Transmission range	10m
Bandwidth	100kbps
Node speed	0 mps
Average TTL	256 sec
Simulation time	150 sec
Percentage of malicious nodes	20%
Packet transmitted	500 packets

The following metrics are used to analyze the performance of various WSN topologies.

Throughput: This is the measure of how fast we can send packets through the network. The number of packets delivered to the receiver provides the throughput of the network. The throughput is defined as the total amount of data a receiver receives from the sender divided by the time it takes for the receiver to get the last packet. The throughput is calculated as:

$$\boldsymbol{G = \frac{\sum B_r \times 8}{T} \times 10^{-6} \quad [Mbps]} \tag{9}$$

Where G is the throughput, B_r is the total number of received bytes, and T is the simulation time.

Packet Delivery Ratio (PDR): The ratio of the data packets delivered to the destinations to those generated by the constant bit rate (CBR) sources. It is the fraction of received packets by destination to the generated packets by source. Packet delivery ratio is calculated as:

$$\boldsymbol{PDR = \frac{\sum N_d}{\sum N_s} \times 100} \quad [\%] \tag{10}$$

Where N_d represents the number of delivered packets and N_s represent the number of sent packets.

End-to-End Delay: It denotes the average time required that a data packet delivers to the destination end.

$$E2E = \sum_{i=1}^{n} (R_i - S_i)/n \quad [seconds] \tag{11}$$

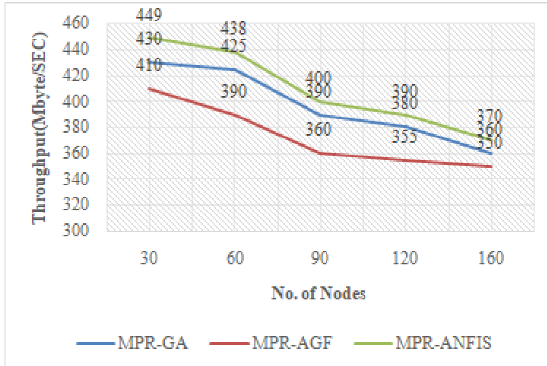

Figure 5 Throughput results

Figure 5 demonstrates the contrast of throughput recital for Multipath Routing- Genetic Algorithm (MPR-GA), Multipath Routing -Adaptive Genetic Fuzzy (MPR-AGF) and Multipath Routing – Adaptive Neuro Fuzzy Interference System (MPR-ANFIS) grounded routing. From the graph it is perfect that the ANFIS grounded routing delivers advanced amount than other replicas owing to the practice of energy and delay aware routing idea. The proposed method achieves higher 370(Mbyte/sec) when compared it with existing methods which are lower 360(Mbyte/sec), 350(Mbyte/sec) respectively.

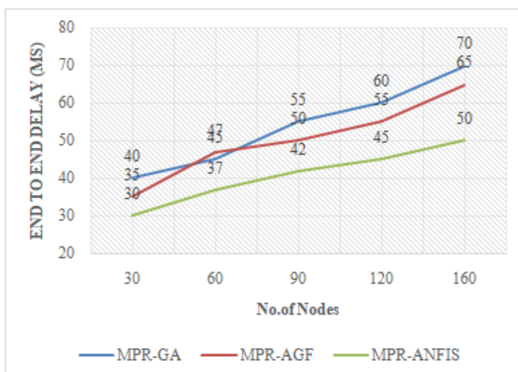

Figure 6 End to End Delay Results

Figure 6 displays the contrast of end to end delay recital for Multipath Routing- Genetic Algorithm (MPR-GA), Multipath Routing -Adaptive Genetic Fuzzy (MPR-AGF) and Multipath Routing – Adaptive Neuro Fuzzy Interference System (MPR-ANFIS) grounded routing. The nodes are changing from 30 to 160 and end to end delay is planned for such nodes in milliseconds (ms). From the graph it is vibrant that the ANFIS grounded routing because of the consumption of delay factor in the assortment of optimal path and outdoes the other replicas with least end to end delay. The proposed methods reach lower 50(ms) and other methods reaches higher 70(ms),65(ms) accordingly.

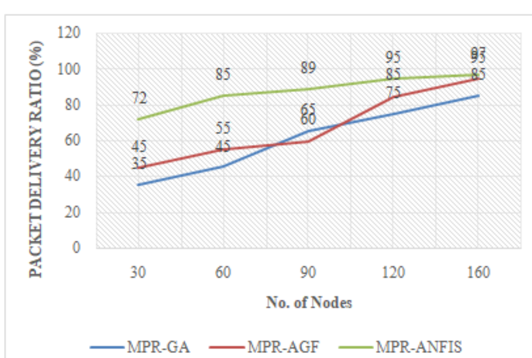

Figure 7 Packet Delivery Ratio Results

Figure 7 displays the contrast of packet delivery ratio recital Multipath Routing- Genetic Algorithm (MPR-GA), Multipath Routing -Adaptive Genetic Fuzzy (MPR-AGF) and Multipath Routing – Adaptive Neuro Fuzzy Interference System (MPR-ANFIS) grounded routing. The nodes are changing from 30 to 160 and packet delivery ratio is planned for certain nodes per seconds. From the graph it is vibrant that the ANFIS grounded routing due to the assortment of optimal path outdoes the other replicas with great packet delivery ratio. The proposed algorithm, reach 0.97(%), compare with existing algorithm reach 0.85(%),0.95(%) respectively.

CONCLUSION

Multipath routing is a popular method for tolerating faults in sensor networks. As a result, in this research article, to provide a multipath routing strategy for WSNs utilising ANFIS and built a wireless sensor network. The nodes communicated and created a list of every neighbour node in order to pick the best path. The effective multipath routing protocol can search for numerous node-disjoint pathways. The load balancing algorithm seeks to optimally assign traffic rates to each path. The ANFIS model has used numerous input parameters for route selection, which improves fault tolerance and network longevity. The performance indicators improve throughput, packet delivery ratio, and end-to-end delay ratio while using this strategy. This model can properly analyse the quality differences of multiple network paths through trials, laying a solid foundation for increasing network performance.

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