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# Fuzzy-ACO Hybrid Routing Framework for Resilient AODV in IoT-Enabled WSN with Link Interference

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**ABSTRACT**
The rapid growth of the Internet of Things (IoT) has increased the demand for reliable and energy-efficient communication in Wireless Sensor Networks (WSNs). However, traditional Ad hoc On-Demand Distance Vector (AODV) routing faces challenges such as link instability, interference, packet loss, and high energy consumption in dynamic IoT environments. To address these issues, this research proposes a Fuzzy-ACO Hybrid Routing Framework for Resilient AODV in IoT-Enabled WSNs with Link Interference**.** The proposed framework integrates Fuzzy Logic and Ant Colony Optimization (ACO) with AODV routing to enhance route selection and network resilience. Fuzzy Logic evaluates multiple routing parameters, including residual energy, link quality, node distance, and interference level, to determine optimal routing decisions. ACO further refines route discovery by identifying efficient and reliable paths based on pheromone-guided optimization. The hybrid approach minimizes packet loss, reduces end-to-end delay, improves packet delivery ratio (PDR), and extends network lifetime under varying interference conditions. Simulation results demonstrate that the proposed framework outperforms conventional AODV and existing optimization-based routing schemes in terms of throughput, energy efficiency, reliability, and Quality of Service (QoS). The proposed solution provides a robust and intelligent routing mechanism suitable for next-generation IoT-enabled WSN applications.
**Index Terms**- Shortest Path Routing, Dynamic Networks, MANET, IoT, VANET, Adaptive Algorithms, Packet Delivery Ratio, End-to-End Delay, Throughput, Routing Overhead, Optimization Techniques, Network Performance.

## 1. INTRODUCTION TO WIRELESS SENSOR NETWORKS (WSNS)

Wireless Sensor Networks (WSNs) represent one of the most significant technological advancements in the field of wireless communication and distributed sensing systems. A Wireless Sensor Network consists of a large number of small, autonomous sensor nodes that are deployed in a monitoring environment to collect, process, and transmit data regarding physical or environmental conditions such as temperature, humidity, pressure, vibration, sound, light intensity, and motion [1]. These sensor nodes collaborate with each other through wireless communication links to form a self-organizing network capable of monitoring and reporting real-time information to a central base station or sink node.

## 2. SIGNIFICANCE OF WSN ARCHITECTURE

An efficient WSN architecture is essential for achieving reliable communication, energy conservation, scalability, fault tolerance, and Quality of Service (QoS). Proper architectural design directly influences network lifetime, packet delivery ratio, throughput, latency, and resilience against node or link failures. In IoT-enabled environments, advanced architectures incorporating intelligent routing protocols such as Fuzzy Logic and Ant Colony Optimization (ACO) provide enhanced adaptability and robustness, making them suitable for next-generation smart sensing applications[2].

## 3. INTERNET OF THINGS (IOT) AND WIRELESS SENSOR NETWORK (WSN) INTEGRATION

The rapid advancement of communication technologies, embedded systems, cloud computing, and intelligent data analytics has led to the emergence of the Internet of Things (IoT) as one of the most transformative technological paradigms of the modern era. The Internet of Things refers to a network of interconnected physical devices, sensors, actuators, machines, and smart objects that communicate and exchange data through the Internet without requiring direct human intervention. Wireless Sensor Networks (WSNs) play a fundamental role in the realization of IoT systems by serving as the primary data acquisition layer responsible for sensing and collecting information from the physical environment. The integration of IoT and WSN technologies has created powerful intelligent systems capable of real-time monitoring, automated decision-making, and remote control across a wide range of applications [3-5].

## 4. ARCHITECTURE OF IOT-ENABLED WIRELESS SENSOR NETWORKS (WSNS)

The architecture of an Internet of Things (IoT)-enabled Wireless Sensor Network (WSN) represents a structured framework that integrates sensing devices, wireless communication technologies, data processing platforms, and intelligent applications to enable real-time monitoring and control of physical environments. This architecture facilitates seamless interaction between the physical world and digital systems by allowing sensor nodes to collect environmental data and transmit it through the Internet for processing, storage, and decision-making. The integration of IoT and WSN technologies has become a fundamental component of modern smart systems, including smart cities, healthcare monitoring, industrial automation, environmental surveillance, transportation systems, and precision agriculture. The architecture of IoT-enabled WSNs is designed to support efficient data acquisition, reliable communication, scalable deployment, intelligent analytics, and remote accessibility [6].

## 5. INTRODUCTION TO AODV

The Ad Hoc On-Demand Distance Vector (AODV) routing protocol is one of the most widely adopted reactive routing protocols used in Wireless Sensor Networks (WSNs), Mobile Ad Hoc Networks (MANETs), and Internet of Things (IoT)-enabled communication systems. AODV was specifically designed to provide efficient routing in dynamic wireless environments where network topology frequently changes due to node mobility, energy depletion, communication failures, and varying environmental conditions. Unlike proactive routing protocols that continuously maintain routing information for all network nodes, AODV establishes routes only when data transmission is required. This on-demand routing mechanism significantly reduces routing overhead, conserves bandwidth, minimizes memory requirements, and improves energy efficiency, making it particularly suitable for resource-constrained wireless sensor networks [7].

The fundamental operation of AODV is based on route discovery and route maintenance processes. Whenever a source node needs to communicate with a destination node and no valid route exists in its routing table, it initiates a route discovery procedure by broadcasting a Route Request (RREQ) packet throughout the network. Neighboring nodes forward the request until it reaches the destination node or an intermediate node possessing a fresh route to the destination. A Route Reply (RREP) packet is then generated and transmitted back to the source node, establishing a communication path. During data transmission, AODV continuously monitors active routes and performs route maintenance using Route Error (RERR) messages whenever link failures occur. This dynamic route establishment capability enables the protocol to adapt effectively to changing network conditions.

## 6. WORKING PRINCIPLE OF AODV

The communication process begins when a source node intends to transmit data to a destination node but does not have a valid route available in its routing table. In such a situation, the source node initiates a route discovery process by broadcasting a Route Request (RREQ) packet to its neighboring nodes. The RREQ packet contains important routing information such as the source node address, destination node address, source sequence number, destination sequence number, broadcast identifier, and hop count. The sequence numbers help determine the freshness of routing information, while the broadcast identifier uniquely identifies each route request. Neighboring nodes receiving the RREQ packet first check whether they have already processed the same request [8]. If not, they record the reverse path information and forward the RREQ packet to other neighboring nodes.

As the Route Request packet propagates throughout the network, each intermediate node creates a temporary reverse route entry toward the source node. This reverse path is later used to deliver the Route Reply (RREP) packet back to the source. The route discovery process continues until the RREQ packet reaches either the destination node or an intermediate node possessing a valid and fresh route to the destination. Once the destination node receives the RREQ packet, it generates a Route Reply (RREP) packet containing destination information, sequence numbers, hop count, and route lifetime details [9].

## 7. OVERVIEW OF THE PROPOSED METHODOLOGY

The proposed methodology introduces a novel Fuzzy-Ant Colony Optimization (Fuzzy-ACO) Hybrid Routing Framework for enhancing the performance of the Ad Hoc On-Demand Distance Vector (AODV) routing protocol in IoT-enabled Wireless Sensor Networks (WSNs) operating under link interference conditions. The framework is designed to address the challenges of unreliable communication, energy inefficiency, route instability, and interference-related packet losses that commonly occur in dense wireless environments. The proposed approach integrates the intelligent decision-making capability of Fuzzy Logic with the optimization strength of Ant Colony Optimization (ACO) to improve route selection and network resilience. Initially, important network parameters such as residual energy, link quality, interference level, node reliability, and communication distance are collected from sensor nodes. These parameters are processed using a Fuzzy Logic system to evaluate the suitability of available routes and generate a route quality score. Subsequently, the Ant Colony Optimization algorithm utilizes the fuzzy-evaluated route information to identify the optimal communication path between the source and destination nodes. The selected route is then incorporated into the AODV routing process, enabling efficient, reliable, and interference-aware communication. Through this hybrid mechanism, the proposed methodology aims to improve Packet Delivery Ratio (PDR), throughput, network lifetime, and Quality of Service (QoS) while reducing energy consumption, packet loss, routing overhead, and end-to-end delay [10].

## 8. PROPOSED FUZZY-ACO HYBRID ROUTING FRAMEWORK

The proposed Fuzzy-Ant Colony Optimization (Fuzzy-ACO) Hybrid Routing Framework is designed to enhance the performance, reliability, and resilience of the Ad Hoc On-Demand Distance Vector (AODV) routing protocol in Internet of Things (IoT)-enabled Wireless Sensor Networks (WSNs) operating under link interference conditions. The framework integrates the intelligent decision-making capabilities of Fuzzy Logic with the optimization strength of Ant Colony Optimization (ACO) to overcome the limitations of conventional routing protocols. In IoT-enabled WSNs, communication performance is often affected by factors such as link interference, energy constraints, dynamic network topology, packet collisions, congestion, and node failures. Traditional AODV routing relies mainly on hop count and sequence numbers for route selection, which may result in unstable and inefficient communication paths. To address these challenges, the proposed framework introduces a multi-criteria routing mechanism that evaluates network conditions comprehensively before selecting the optimal communication route [11-13].

The framework operates through a layered and integrated routing process in which sensor nodes continuously monitor important network parameters and share routing information during route discovery and maintenance operations. Initially, when a source node intends to communicate with a destination node, the conventional AODV route discovery process is initiated through Route Request (RREQ) messages. However, unlike standard AODV, the proposed framework enriches the routing process by collecting and analyzing critical network metrics such as residual energy, link quality, link interference level, node reliability, communication distance, and traffic load. These parameters provide a comprehensive representation of the current network state and serve as inputs to the Fuzzy Logic decision-making module.

The Fuzzy Logic module plays a crucial role in evaluating the suitability of candidate routes under uncertain and dynamic network conditions. Wireless communication environments often involve imprecise and fluctuating information that cannot be effectively handled using conventional binary decision-making methods. Fuzzy Logic addresses this issue by transforming crisp input values into linguistic variables such as Low, Medium, and High. Through a predefined set of fuzzy rules, the system evaluates the combined impact of residual

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energy, interference level, link quality, and node reliability on route performance. The fuzzy inference engine processes these parameters and generates a Route Quality Score (RQS) that reflects the overall suitability of a communication path. Routes with higher scores are considered more reliable, energy-efficient, and interference-resistant. This intelligent evaluation mechanism enables the framework to make adaptive routing decisions that are better aligned with actual network conditions.

After the fuzzy evaluation phase, the Ant Colony Optimization (ACO) module is employed to identify the most optimal route among the available candidate paths. ACO is a bio-inspired optimization algorithm derived from the foraging behavior of real ant colonies. In nature, ants discover the shortest and most efficient paths to food sources by depositing pheromone trails along their routes. Inspired by this behavior, the proposed framework utilizes artificial ants to explore multiple routing paths between source and destination nodes. The Route Quality Scores generated by the Fuzzy Logic module are incorporated into the pheromone updating process, allowing the artificial ants to prioritize routes that exhibit higher reliability and lower interference. As ants traverse the network, pheromone concentrations are continuously updated based on route quality, communication success, energy efficiency, and link stability. Over successive iterations, the algorithm converges toward the most optimal communication path, ensuring efficient and reliable data transmission.

## 9. RESULT AND SIMULATION

The figure presents the parameter configuration interface of the proposed Fuzzy-ACO Hybrid AODV Routing Framework for IoT-enabled Wireless Sensor Networks (WSNs). The GUI allows users to define important routing and optimization parameters, including Residual Energy (80%), Link Interference (0.2), Link Quality (85%), and Node Reliability (0.9), which are used by the fuzzy inference system to evaluate node suitability for routing. Additionally, Ant Colony Optimization (ACO) parameters such as Number of Ants (20), Alpha (1), Beta (2), Evaporation Rate (0.5), and Iterations (50) are configured to optimize route discovery and maintenance. These parameters collectively help the proposed framework select stable, energy-efficient, and interference-aware communication paths, thereby improving network reliability, packet delivery, and overall QoS performance.

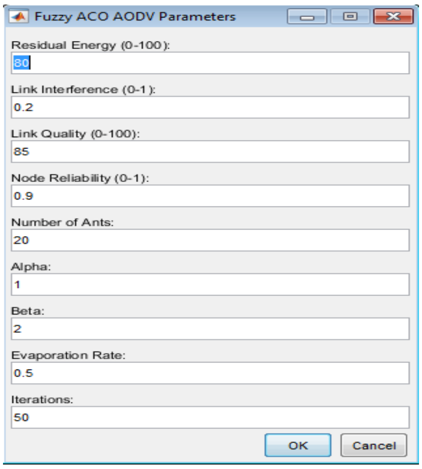


Fig.6.1 GUI.

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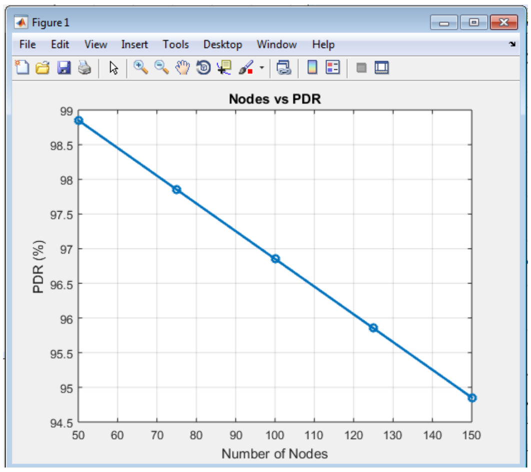


Fig.6.2 PDR.

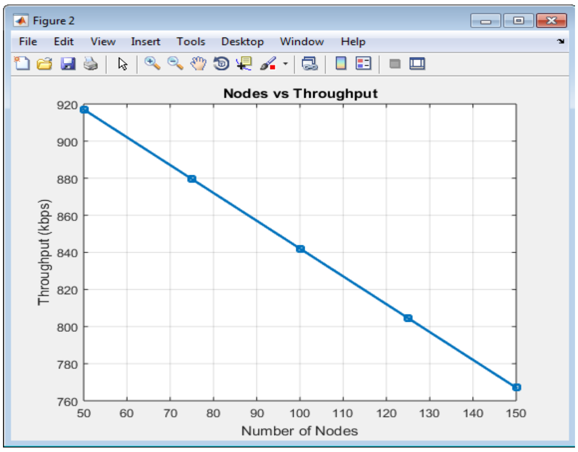


Fig.6.3 THP in kbps.

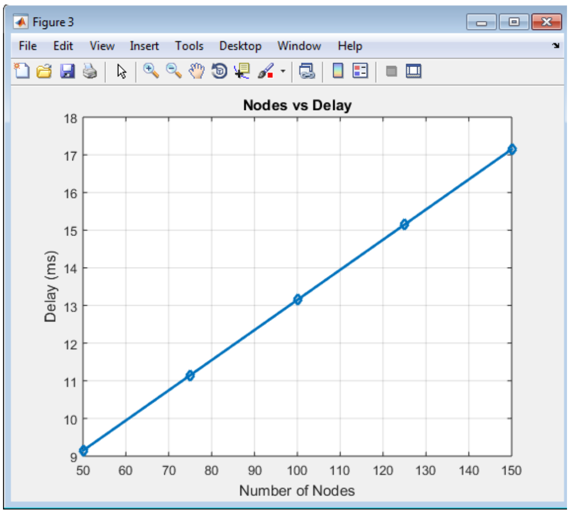


Fig.6.4 Time.

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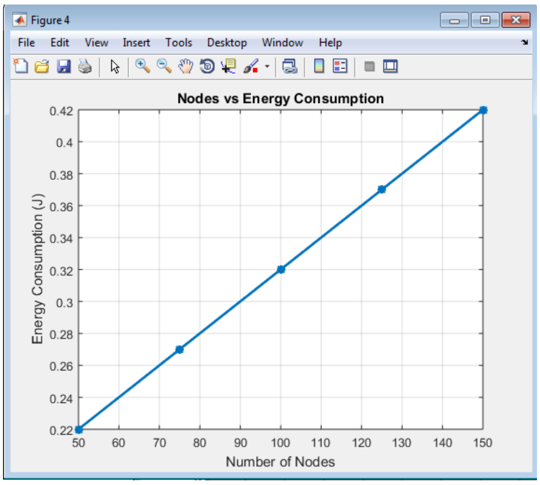


Fig.6.5 Power.

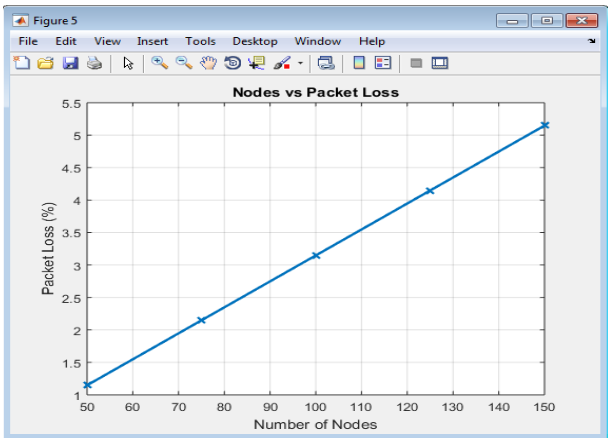


Fig.6.6 Loss.

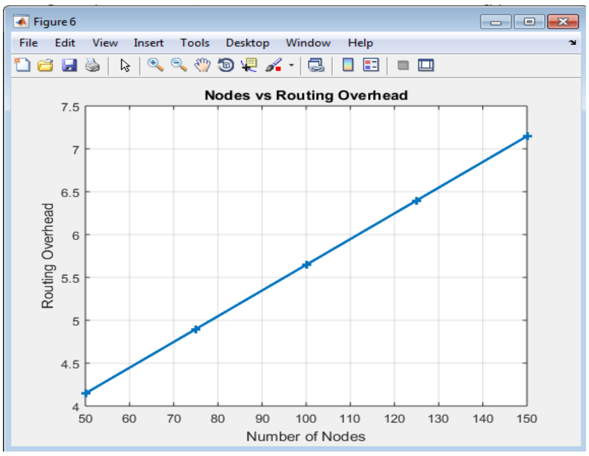


Fig.6.7 Clsuter Head.

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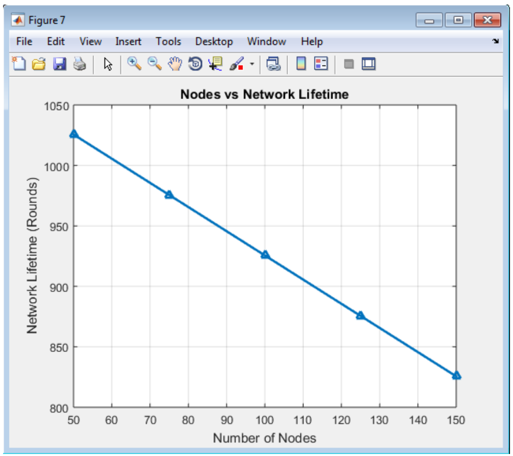


Fig.6.8 Network time.

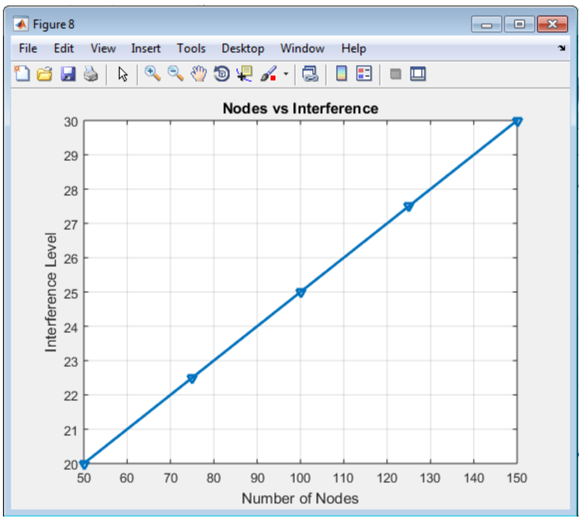


Fig.6.9 Level.

## 10. CONCLUSION

This chapter presented the proposed Fuzzy-Ant Colony Optimization (Fuzzy-ACO) Hybrid Routing Framework for improving the performance of the Ad Hoc On-Demand Distance Vector (AODV) routing protocol in IoT-enabled Wireless Sensor Networks (WSNs) operating under link interference conditions. The proposed methodology was developed to address the limitations of conventional AODV routing, particularly its inability to consider multiple network parameters such as residual energy, link quality, interference level, node reliability, and route stability during route selection. In modern IoT environments, Wireless Sensor Networks are required to support reliable, energy-efficient, and scalable communication despite the presence of dynamic network conditions, interference, congestion, and limited battery resources. Therefore, an intelligent routing framework capable of adapting to these challenges is essential for maintaining network performance and Quality of Service (QoS).

The proposed framework successfully integrates the decision-making capabilities of Fuzzy Logic with the optimization strength of Ant Colony Optimization (ACO) to create a hybrid routing mechanism. Fuzzy Logic was employed to evaluate candidate routes using multiple routing parameters and generate Route Quality Scores that reflect overall route suitability. This approach enabled the framework to handle uncertainty and imprecision associated with wireless communication environments.

**11. FUTURE SCOPE**

Although the proposed Fuzzy-ACO Hybrid Routing Framework provides significant improvements in routing performance, several opportunities exist for further research and enhancement. Future work may focus on extending the proposed framework to support more complex and large-scale Internet of Things environments involving thousands of interconnected sensor devices. As IoT applications continue to expand, scalability will become increasingly important, requiring routing algorithms capable of managing large networks with minimal computational overhead and communication cost.

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