IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 6, May 2026
Impact Factor: 8.2

Improving Quality of Service (QoS) in Wireless Sensor Networks Using

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Abstract: *Wireless Sensor Networks (WSNs) play an important role in environmental monitoring, industrial automation, healthcare, and smart communication systems. However, maintaining Quality of Service (QoS) in WSNs is challenging because of energy limitations, node failures, network congestion, delay, and routing issues. This paper proposes a Hybrid Approach for improving QoS in Wireless Sensor Networks by integrating hardware and software methodologies. The proposed system utilizes Improved LEACH Protocol, Crawling Pattern Technique, and Authoritative Sensor Node (ASN) identification to reduce delay, optimize energy consumption, and improve network reliability. MATLAB and NS-2 Simulator are used for simulation and performance analysis, while a hybrid hardware testbed is developed for real-time environmental monitoring using temperature, humidity, and light sensors. The Quality of Service parameters such as Reliability, Availability, and Serviceability (RAS) are evaluated mathematically and experimentally. Experimental results demonstrate improved network coverage, reduced delay, optimized routing efficiency, and enhanced QoS performance compared with conventional approaches.*

Keywords: Wireless Sensor Network, QoS, LEACH Protocol, Hybrid Approach, MATLAB, NS-2 Simulator, Reliability, Availability, Serviceability, Crawling Pattern, ASN.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) have emerged as a key technology for monitoring and data collection in a wide range of applications, including environmental monitoring, healthcare systems, industrial automation, and smart cities. A typical WSN consists of a large number of sensor nodes deployed over a geographical area to sense, process, [1], [2].

Node density plays a crucial role in determining the efficiency and reliability of a WSN. An increase in the number of sensor nodes generally improves coverage, connectivity, and fault tolerance of the network. Higher density allows multiple communication paths, and congestion, thereby degrading network performance and increasing energy consumption [3], [4].

Similarly, transmission range significantly affects the communication behavior of sensor nodes. A shorter transmission range reduces power consumption and extends node lifetime but requires multi-hop communication, which may increase latency and routing complexity. On the other hand, a longer transmission range reduces the number of hops and improves connectivity but results in higher energy usage and increased signal interference [5], [6]. Therefore, achieving an optimal balance between node density and transmission range is essential for efficient WSN operation.

Another major challenge in WSNs is the presence of noise and signal distortion during wireless communication. These factors can lead to inaccurate data transmission, reduced throughput, and increased packet losss [7], [8].

The Adaptive BF-LMS algorithm enhances signal estimation by continuously adjusting filter parameters based on the error between the desired and received signals. This adaptability makes it suitable for WSN applications where network conditions frequently change due to node mobility, varying density, and environmental factors. By improving signal clarity and reducing transmission errors, the algorithm contributes to better network performance and reliability [9].

In this paper, we present the design and implementation of a Wireless Sensor Network under varying node density and transmission range conditions using the Adaptive BF-LMS algorithm. The results demonstrate that integrating adaptive filtering techniques significantly enhances the robustness and performance of WSNs in dynamic scenarios [10].

II. PROBLEM STATEMENT

Wireless Sensor Networks (WSNs) have become an essential technology for real-time monitoring and communication in various application areas such as environmental monitoring, healthcare systems, industrial automation, military surveillance, smart agriculture, and Internet of Things (IoT) environments. These networks consist of multiple sensor nodes that are responsible for sensing, processing, and transmitting data wirelessly to a base station. Although WSNs provide flexibility and low-cost deployment, maintaining Quality of Service (QoS) during data transmission and reception remains a major challenge due to the limited resources and dynamic nature of the network.

One of the major problems in Wireless Sensor Networks is excessive delay during data transmission. As the number of sensor nodes increases, the network experiences congestion, packet collisions, and communication overhead, which lead to increased transmission delay and reduced network efficiency. Delay becomes more critical in real-time applications where continuous and timely data delivery is required. Existing routing protocols are often unable to manage heavy traffic efficiently, resulting in poor QoS performance.

III. OBJECTIVE

- Evaluation of various Sensor Data in MATLAB using Profiler Tool**.**
- Identification of the algorithms that fit for producing better results over realistic data sets to improve Quality Parameters.
- Design and evaluation of various crawling patterns related to the sensor nodes to identify Authorative Sensor Node using NS-2 Simulator.
- Testing and measuring the Quality of Service Parameter by using Hybrid Testbed.
- Justify QoS Parameters such as Reliability, Availability and Serviceability (RAS)..

IV. LITERATURE SURVEY

Title: An Enhancement Approach for Reducing the Energy Consumption in Wireless Sensor Networks
Authors: Mohamed Elshrkawey
Summary: Science Direct, 30(2), 259-267**,** the author's of this paper discussed about the reduction in the energy consumption in wireless sensor network. The authors are used the enhanced approach for reducing the energy consumption. The cluster head selection method used to reduce the energy consumption. The reduced energy consumption helps to increase the WSN lifetime. In this paper, emphasized on the sensor node deployment challenges and issues.

Title: A Scalable Multitasking Wireless Sensor Network Testbed for Monitoring Indoor Human Comfort
Authors: Emanuele Lattanzi
Summary: 17952-17967, in this paper, an author introduced the design of testbed for indoor environment monitoring with the human comfort. This approach used to improve the QoS of WSN. The solution is based on the sensor nodes with their application of multiple number task ability. The flexibility in the design of WSN is represented by the experimental used of defined approaches.

Title: QoS in Wireless Sensor Networks", Sensors
Authors: Nathalie Mitton
Summary: in this paper, an author discusses about the increased demand of wireless sensors with improved quality of service during the process. An author focus on the use of WSN in the field of urban health monitoring. The paper work is focused on the challenges and issues occurred during the process affect the quality of service. The challenges and issues to be overcome by the authors are unreliable characteristics of the WSN and hardware limitations of devices.

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Volume 6, Issue 6, May 2026
Impact Factor: 8.2

Title: Joint Hybrid Transmission and Adaptive Routing for Lifetime Extension of WSNs
Authors Chih-Min
Summary: in this paper an author introduced the hybrid approach where the concept of multi hop and single hop data transmission is used. The discussed approach used the adaptive routing. An author represents a systematical decision model which contains a various group of functional blocks. These functional blocks use to determine the optimum probability of each sensor node.

V. PROPOSED SYSTEM

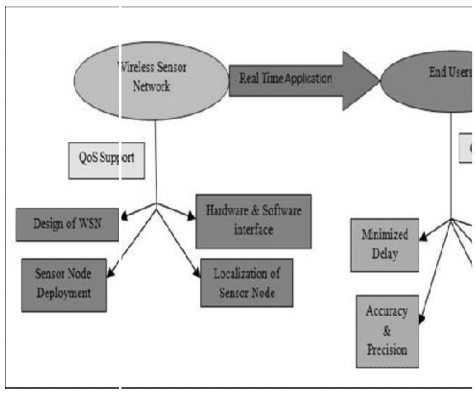

Fig 1: Block Diagram

a) Software-Based Design of Wireless Sensor Network

The software-based design of Wireless Sensor Networks (WSNs) provides an efficient platform for implementing, monitoring, and analyzing network operations in a virtual environment. Software simulation helps researchers observe the behavior and performance of sensor nodes during data transmission and reception. It also provides graphical and statistical outputs that simplify the understanding of network activities and Quality of Service (QoS) performance.

b) Simulation and Protocol-Based Algorithms

The design of WSNs in software platforms mainly depends on protocol-based simulation algorithms. These algorithms consider important parameters such as the number of sensor nodes, cluster head formation, routing paths, transmission rounds, and probability of data transfer. Simulation tools help evaluate network behavior under different operating conditions and support efficient analysis of real-time applications without requiring physical deployment.

c) Clustering and Routing Mechanism

Software-based WSN design requires clustering and distributed algorithms for proper sensor node arrangement. Routing protocols are designed to optimize communication between nodes and avoid limitations related to bandwidth, energy consumption, and node localization. Efficient routing mechanisms also help in fault tolerance and improve the overall reliability and stability of the network during operation.

d) Limitations of Software-Based WSN Design

Although software simulation provides easy visualization and performance analysis, it has certain practical limitations. Virtual models cannot fully represent real-time environmental conditions and hardware-related constraints. Issues such as hardware failures, communication disturbances, sensor inaccuracies, and practical deployment challenges are difficult to evaluate completely through software simulation alone.

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DOI: 10.48175/568

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e) Hybrid Approach for WSN Design

To overcome the limitations of both hardware and software systems, a Hybrid Approach is introduced in Wireless Sensor Network design. The hybrid model integrates hardware implementation with software simulation to provide better accuracy and practical feasibility. This approach reduces hardware resource limitations such as restricted power supply, memory size, bandwidth, and network lifetime while also minimizing the limitations of software visualization and virtual analysis.

f) QoS Evaluation Using Hybrid Approach

The Hybrid Approach evaluates the static and dynamic performance of Wireless Sensor Networks effectively. The static model represents the hardware arrangement, including sensors, processor units, Wi-Fi modules, and Printed Circuit Board (PCB) assembly. The dynamic model represents software analysis using graphical and statistical outputs. This combined approach helps measure important QoS parameters such as Reliability, Availability, and Serviceability (RAS). As a result, the Hybrid Approach improves network performance, reduces real-time operational issues, and enhances the efficiency of Wireless Sensor Network applications.

VI. SYSTEM DESIGN

a) Overall Architecture of Wireless Sensor Network

The proposed system is designed using a Hybrid Approach that combines both hardware and software components for improving the Quality of Service (QoS) in Wireless Sensor Networks (WSNs). The system consists of multiple sensor nodes, routing mechanisms, communication modules, and a monitoring platform. Sensor nodes are deployed within a specific network area to sense environmental parameters such as temperature, humidity, and light intensity. The sensed data is transmitted wirelessly to the Base Station (BS) through optimized routing paths. The overall architecture focuses on reducing delay, minimizing energy consumption, and improving network reliability.

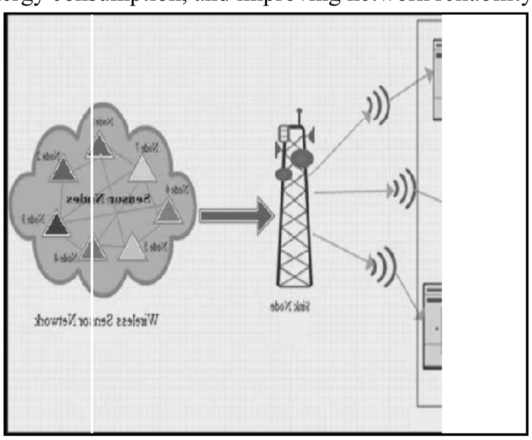

Fig 2: Wireless Sensor Network Process

b) Sensor Node Design

The sensor node is the basic unit of the Wireless Sensor Network. Each node consists of sensing elements, microcontroller unit, power supply, memory unit, and wireless communication module. Environmental sensors are used to collect real-time data from the surroundings. The microcontroller processes the sensed information and forwards it to neighboring nodes or the base station. The sensor node is designed to consume minimum power while maintaining efficient communication and data accuracy.

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DOI: 10.48175/568

c) Cluster Formation and Routing Design

The proposed system uses an Improved LEACH Protocol for cluster formation and routing. Sensor nodes are grouped into clusters, and a Cluster Head (CH) is selected for each cluster based on energy efficiency and communication capability. The Cluster Head collects data from member nodes and forwards it to the base station. This routing mechanism reduces communication overhead and balances energy consumption among sensor nodes. The system also uses Crawling Pattern routing to optimize data flow and reduce network congestion during transmission.

d) Authoritative Sensor Node (ASN) Identification

The system design includes the identification of an Authoritative Sensor Node (ASN), which is considered the most efficient node in the network. The ASN is selected based on parameters such as maximum coverage area, minimum delay, high transmission speed, and low energy consumption. The optimized path selection algorithm identifies the best routing path for data communication. This design improves transmission efficiency and enhances the Quality of Service of the network.

e) Hardware and Software Integration

The proposed system integrates hardware implementation with software simulation to achieve realistic performance analysis. The hardware section includes sensors, Wi-Fi modules, processor units, relay circuits, LCD display, and PCB assembly. The software section includes MATLAB and NS-2 Simulator for network simulation, data analysis, graphical representation, and routing evaluation. This hybrid integration allows accurate monitoring of network behavior under real-time operating conditions.

f) QoS Monitoring and Performance Evaluation

The final system design focuses on evaluating QoS parameters such as Reliability, Availability, and Serviceability (RAS). During operation, the system continuously monitors sensor node performance, failure rate, transmission delay, energy consumption, and communication efficiency. Mathematical calculations and simulation analysis are used to measure network reliability and availability. The hybrid testbed provides both graphical and statistical outputs for validating the proposed system performance. This design ensures improved QoS and better efficiency for real-time Wireless Sensor Network applications.

VII. RESULT

Graph 1: Node Density vs Packet Delivery Ratio (PDR)

This graph illustrates the relationship between node density and Packet Delivery Ratio (PDR). As node density increases from low to moderate levels, the PDR improves significantly due to better connectivity and availability of multiple communication paths. However, beyond an optimal density (around 30 nodes), the PDR starts to decline slightly. This degradation is caused by increased interference, packet collisions, and network congestion in dense environments. The results demonstrate that while higher node density enhances reliability initially, excessive density negatively impacts network performance.

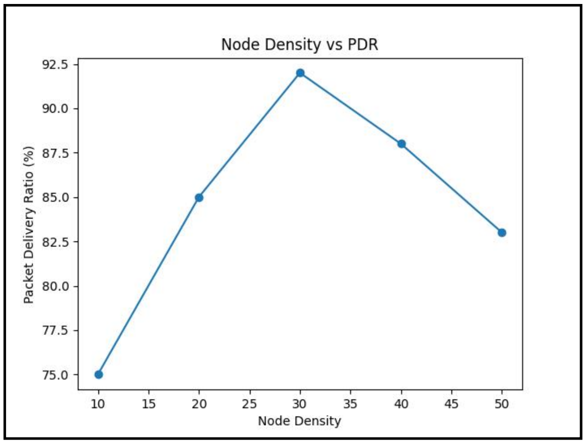

Fig 2: Graph1

Node Density	PDR (%)
10	75
20	85
30	92
40	88
50	83

Graph 2: Transmission Range vs Throughput

This graph shows the effect of transmission range on network throughput. As the transmission range increases, throughput initially improves due to reduced multi-hop communication and better connectivity between nodes. The peak throughput is achieved at an optimal range (around 150 meters). Beyond this point, throughput begins to decrease slightly due to higher interference, signal attenuation, and increased energy consumption. This result highlights the importance of selecting an appropriate transmission range to balance communication efficiency and network stability.

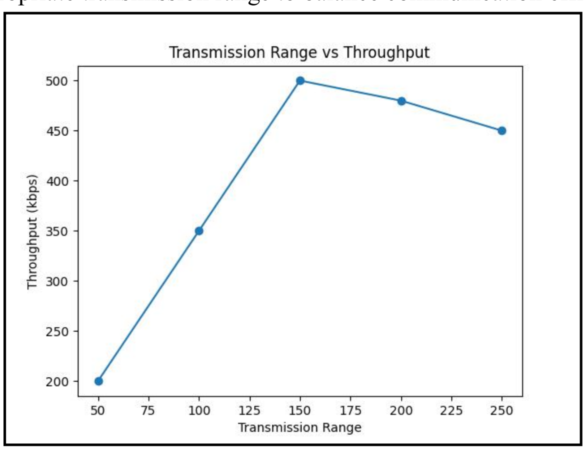

Fig 3: Graph 2

Transmission Range	**Throughput (kbps)**
50	200
100	350
150	500

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200	480
250	450

Graph 3: Node Density vs Energy Consumption

This graph represents how energy consumption varies with node density. As the number of nodes increases, overall energy consumption rises steadily. This is due to increased communication overhead, frequent transmissions, and higher chances of collisions requiring retransmissions. In dense networks, nodes consume more energy for maintaining connectivity and handling interference. The results indicate that energy efficiency decreases with higher node density, emphasizing the need for optimization techniques such as adaptive algorithms to prolong network lifetime.

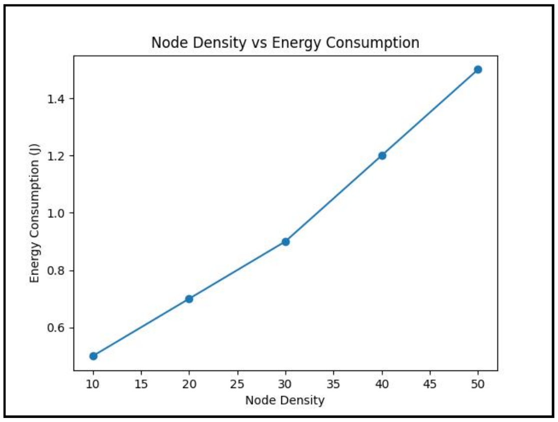

Fig 4: Graph 3

Node Density	Energy Consumption (J)
10	0.5
20	0.7
30	0.9
40	1.2
50	1.5

VII. CONCLUSION

Wireless Sensor Networks (WSNs) have become an important communication technology for real-time monitoring and data transmission in various applications such as environmental monitoring, healthcare, industrial automation, smart agriculture, and Internet of Things (IoT) systems. However, maintaining Quality of Service (QoS) in WSNs remains a major challenge due to limitations such as high energy consumption, communication delay, node failure, limited bandwidth, and unstable routing mechanisms. These issues directly affect the performance, reliability, and lifetime of the network.

The proposed research work focuses on improving the Quality of Service of Wireless Sensor Networks using a Hybrid Approach that combines both hardware and software techniques. The system integrates Improved LEACH Protocol, Crawling Pattern routing, and Authoritative Sensor Node (ASN) identification to optimize network performance. The use of MATLAB and NS-2 Simulator helps in analyzing network behavior, evaluating routing efficiency, and measuring important QoS parameters under different operating conditions..

IX. FUTURE SCOPE

The proposed Hybrid Approach for improving Quality of Service (QoS) in Wireless Sensor Networks provides an effective foundation for further research and development in advanced communication systems. Although the present work focuses on reducing delay, optimizing energy consumption, and improving Reliability, Availability, and Serviceability (RAS), several enhancements can be incorporated in the future to improve network intelligence, scalability, and security.

In future research, Artificial Intelligence (AI) and Machine Learning (ML) techniques can be integrated with Wireless Sensor Networks to develop intelligent routing and decision-making systems. AI-based algorithms can automatically predict network congestion, sensor node failures, and energy depletion conditions, which will help in improving network reliability and performance dynamically. Machine learning models can also be used for adaptive cluster head selection and optimized routing path identification.

The proposed system can be extended toward Internet of Things (IoT)-based smart applications such as smart cities, smart healthcare, smart agriculture, industrial automation, and environmental monitoring systems. Integration of cloud computing and edge computing technologies with WSNs can further improve data processing speed, remote monitoring capability, and real-time communication efficiency..

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