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# Simulation Of Enhanced Receiver-Initiated MAC Protocol In WSN

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***Abstract -*** Wireless Sensor Networks (WSNs) play a crucial role in real-time data collection and communication but are highly constrained by limited energy resources, communication overhead, and latency issues. The Receiver-Initiated Medium Access Control (RI-MAC) protocol has been widely adopted for energy-efficient unicast data transmission in asynchronous duty-cycled WSNs. RI-MAC enables receivers to initiate communication by periodically broadcasting beacons, allowing senders to transmit only after receiving permission. While RI-MAC performs well for unicast traffic, its performance degrades in broadcast and multicast scenarios due to short wake-up durations, increased collisions, and higher retransmission rates, leading to reduced throughput and increased energy consumption. To address these limitations, we propose an Enhanced Receiver-Initiated MAC (EnRIMAC) protocol, which improves energy efficiency and network performance by optimizing beacon scheduling and introducing a collision-avoidance mechanism. EnRIMAC leverages the broadcast nature of the wireless medium, reduces duplicated transmissions, and minimizes retransmissions, thereby improving reliability in both unicast and multicast traffic. Furthermore, EnRIMAC adopts a low-duty-cycle mechanism that allows nodes to remain in sleep mode longer, significantly conserving energy. To evaluate the performance of the proposed Enhanced Receiver-Initiated MAC (EnRIMAC) protocol, we conducted extensive simulations using the NS2 network simulator and compared its results with the traditional RI-MAC protocol. The evaluation considered four critical performance metrics: Packet Delivery Ratio (PDR), Energy Consumption, and Throughput.

***Keywords:*** Wireless Sensor Networks, RI-MAC, EnRIMAC, NS2 Simulation, Throughput, Packet Delivery Ratio, Energy Efficiency.

## I. INTRODUCTION

Wireless Sensor Networks (WSNs) are distributed systems comprised of spatially dispersed, battery-powered sensor nodes capable of sensing, processing, and wirelessly transmitting environmental data to a central base station. They have found extensive use in applications ranging from environmental monitoring and industrial automation to smart agriculture and healthcare. The core challenges in WSN design revolve around energy constraints, node autonomy, and scalability. focused on smart buildings, energy optimization at multiple layersincluding hardware architecture, operating systems, networking protocols, and duty cyclingis crucial for maximizing system longevity and resilience in resource-constrained deployment [1].

Energy efficiency remains one of the most pressing concerns in WSNs, prompting a surge of research into clustering, routing, and energy-harvesting mechanisms. A neighborhood-aware clustering protocol (NaISEP) tailored for agriculture-based WSN-IoT integration, enhancing energy distribution and network lifetime in farm environment [2]. K-Nearest Neighbours (KNN)–based clustering optimization approach, which improved energy utilization and extended longevity across heterogeneous networks by refining cluster-head selection mechanisms for established protocols like LEACH, SEP, TEEN, and DEC [3].

Security and data integrity also have become prominent focal areas in recent WSN research. Integrating Machine Learning and Blockchain technologies into WSNs strengthens intrusion detection and data authentication, while maintaining lightweight performance suited to the constrained nature of sensor devices [4]. Complementing this, a emphasized data aggregation techniques that both conserve energy and assure security—leveraging plain-text and encrypted aggregation schemes to reduce traffic overhead without compromising confidentiality, especially in IoT-enabled WSN scenarios [5].

Receiver-Initiated MAC (RI-MAC) is an asynchronous duty-cycled medium access control protocol for wireless sensor networks that enhances energy efficiency and channel utilization by allowing the receiver to govern communication synchrony—each node awakens periodically to broadcast a beacon, prompting sender nodes to initiate data transmission only after receiving that beacon. This receiverdriven mechanism significantly reduces idle listening and preamble overhead relative to sender-centric schemes, and improves collision detection through adaptive beacon-based back-off signalling [6]. For example, the RIMAC variant demonstrates how receiver-initiated strategies can be fine-tuned for wireless personal area networks by incorporating cooperative frame identification to further alleviate contention while maintaining low-energy operation. Moreover, comparative evaluations such as those involving RI-MAC and its refinements (e.g., in MAR-RI-MAC) reveal that receiver-initiated designs consistently yield better latency performance and energy savings in high-contention WSN environments [7].

The Receiver-Initiated Medium Access Control (RI-MAC) protocol is widely used in wireless sensor networks (WSNs) for its energy-efficient design, where receivers periodically broadcast beacons to initiate communication. While RI-MAC performs effectively for unicast communication in low-traffic environments, it faces several limitations when applied to broadcast, multicast, and convergecast scenarios. Due to asynchronous wake-up schedules, sender nodes must wait for receiver beacons, leading to higher end-to-end delays and reduced efficiency in dense networks. Additionally, RI-MAC suffers from frequent collisions when multiple sender nodes respond to the same beacon, resulting in increased retransmissions and higher energy consumption under heavy traffic conditions. Moreover, RI-MAC's inability to efficiently handle broadcast and multicast traffic further limits its applicability in large-scale IoT-enabled WSNs where real-time data dissemination and energy conservation are critical. To address these limitations, we propose an Enhanced Receiver-Initiated Medium Access Control (EnRIMAC) protocol, which builds upon the strengths of RI-MAC while introducing significant performance optimizations. EnRIMAC incorporates optimized beacon scheduling, adaptive duty-cycling, and a collision-avoidance mechanism to support both unicast and broadcast communication effectively. Unlike RI-MAC, EnRIMAC leverages the broadcast nature of the wireless medium to minimize duplicate transmissions and reduce congestion, resulting in improved Packet Delivery Ratio (PDR), Throughput, and Energy Efficiency. The protocol also integrates an intelligent sleep-wake mechanism to balance energy conservation with timely data delivery, achieving lower delays and longer network lifetime

## II. LITERATURE REVIEW

The Medium Access Control (MAC) protocol is a critical component in wireless sensor networks (WSNs), directly influencing key performance metrics such as energy consumption, delay, collisions, and throughput. Among various proposed solutions, the Contend Node Restricted Joint Consecutive Packet Transmissions Receiver-Initiated (CNR-CPT-RI) protocol introduces an energy-efficient and collision-aware mechanism designed for wake-up radio-enabled WSNs. By allowing the sink node to control the participating nodes within its one-hop range, CNR-CPT-RI effectively minimizes contention, enhances network lifetime, and improves throughput. Additionally, its adaptive node participation strategy maintains an optimal contention range, while the Consecutive Packet Transmissions (CPTs) technique reduces repeated competition, resulting in better utilization of network resources. Experimental results demonstrate significant improvements compared to baseline protocols, achieving up to 67.5% collision reduction, 22.6% lower energy consumption, and 32% lower delay. However, the protocol still faces several limitations, including restricted scalability since it is primarily designed for single-hop networks, dependence on sink node control, and reduced efficiency under high-density or multi-hop environments where contention dynamics become complex. These limitations highlight the need for enhanced receiver-initiated protocols, such as EnRIMAC, that can address broadcast and multicast inefficiencies, minimize collision overhead, and improve energy performance in large-scale, heterogeneous WSN deployments [8].

Terahertz (THz) communication is emerging as a promising future technology enabling terabit-per-second data rates with features like high throughput and ultra-low latency. However, challenges such as high path loss, scattering, and reflection limit communication distance, making antenna directionality essential to enhance performance. These unique characteristics render traditional MAC protocols inefficient, creating the need for novel MAC designs to support efficient channel access, mobility management, link establishment, and blockage mitigation. This survey analyzes existing Terahertz MAC protocols, their design considerations, and classifications based on network topology, channel access methods, and communication strategies (transmitter- and receiver-initiated). It also explores various macro- and nano-scale applications, highlighting open research challenges and future directions for achieving optimized Terahertz MAC protocol designs [9].

The Underwater Wireless Sensor Network (UWSN) enables efficient communication in aquatic environments, addressing the limitations of traditional terrestrial MAC protocols. Due to high propagation delays, limited bandwidth, and energy constraints, specialized receiver-initiated duty-cycled asynchronous MAC protocols have gained attention for their better performance compared to sender-initiated and synchronous approaches. However, existing UWSN MAC protocols still face challenges such as frequent retransmissions, energy loss, protocol overheads, and longer duty cycles, which degrade overall network efficiency. To address these issues, the Predictive Wake-Up Based Optimized MAC (PWO-MAC) protocol is proposed, integrating a predictive wake-up scheduling mechanism with an additive increase and multiplicative decrease (AIMD) technique. This approach dynamically adjusts transmission rates, minimizes retransmissions, reduces protocol overhead, conserves energy, lowers delays, and improves network throughput, offering a more efficient solution for UWSN communication [10].

## III. PROPOSED METHODOLOGY

### 3.1 Problem Statement

Receiver-Initiated Medium Access Control (RI-MAC) protocol is widely used in Wireless Sensor Networks (WSNs) due to its energy efficiency and asynchronous communication mechanism. In RI-MAC, the receiver initiates communication by periodically waking up and broadcasting beacons to signal its availability for data reception. The sender node holding pending data waits for the beacon and transmits the data once the beacon is received. While this mechanism reduces idle listening and improves energy efficiency, it suffers from significant limitations when handling broadcast and multicast communication. Since each node follows its own independent wake-up schedule and wake-up durations are short, synchronization between multiple nodes becomes challenging. As a result, packet collisions, increased latency, and reduced throughput occur under high-traffic conditions. These limitations make RI-MAC less effective in dense network environments and delay-sensitive applications, necessitating the design of an enhanced protocol that ensures efficient data delivery, reduced energy consumption, and improved performance for both unicast and multicast communication scenarios

### 3.2 EnRIMAC

#### 3.2.1. Network Initialization & Node Deployment

The setup of the wireless sensor network environment. It includes the deployment of sensor nodes with predefined attributes such as position, radio range, energy levels, and node IDs. Each node is equipped with sensing, communication, and processing capabilities. The network topology is established, and initial parameters such as duty-cycle settings, beacon intervals, and communication types (unicast, broadcast, multicast) are configured. The module also includes initialization routines for energy tracking and synchronization mechanisms necessary for simulating scheduled wake-up and rendezvous times.

#### 3.2.2. Enhanced Receiver-Initiated Communication

This is the core of the EnRI-MAC protocol implementation. Unlike traditional sender-initiated communication, this module ensures that receivers initiate communication by periodically sending beacons. Senders wait for these beacons before transmitting data, thereby avoiding idle listening and reducing energy usage. This module is extended to handle diverse traffic types—unicast, broadcast, and multicast—by incorporating scheduled rendezvous times. Nodes intending to send broadcast or multicast data will synchronize with receivers based on predefined schedules, allowing multiple senders to share the channel efficiently and avoid duplicated transmissions.

#### 3.2.3. Collision Avoidance and Energy Management

This module is responsible for implementing collision reduction strategies and managing node energy consumption. It includes algorithms to handle backoff mechanisms, channel contention, and data acknowledgment. It optimizes the use of beacon timing and rendezvous scheduling to reduce packet collisions, especially during broadcast and convergecast traffic. It also updates the energy status of nodes after each transmission, reception, or idle listening event, allowing the protocol to evaluate energy savings accurately. This module ensures the longevity of the network by balancing communication reliability with energy-efficient practices.

#### 3.2.4. Performance Evaluation

Using the ns-2 simulator, this module models and evaluates the performance of the EnRI-MAC protocol under varying network loads and traffic patterns. It collects metrics such as duty-cycle ratio, delivery latency, packet delivery ratio, and energy consumption across different traffic types. It compares these results with the traditional RI-MAC protocol to validate improvements. This module also visualizes the behavior of nodes during communication and provides logs for analyzing protocol efficiency under both light and heavy traffic conditions. The insights from this module help refine and validate the effectiveness of the EnRI-MAC protocol in real-world WSN scenarios.

### 3.4 Algorithm

**Algorithm Name -** EnRI-MAC Algorithm
**Input -** WSN with N Number of Nodes
**Output -** Performance Evaluation
**Assumptions-** Source Node SN, Destination Node DN, Intermediate Node IN.

1. Start
2. Establish WSN with N Nodes
3. Design EnRI-MAC
4. Configure Energy Model
5. Optimal Routing with EnRI-MAC
6. Configure Event Scheduler

Initiate Data Transmission

7. SN Send packets to DN
8. Data packets transformed through the optimal path

```
SN->IN1-->IN2-> IN3 ------ DN
If (Collision Occurred == True) {
Recall EnRI-MAC
}
Performance Evaluation
Calculate Throughput
Calculate PDR
Calculate Energy
End
```

### 3.3 System Architecture

The Enhanced Receiver-Initiated Medium Access Control (EnRI-MAC) protocol in Wireless Sensor Networks (WSNs) is designed to optimize data transmission while minimizing energy consumption and interference. It achieves energy efficiency management by optimizing the sleep/wake cycles of sensor nodes, reducing idle listening and overhearing, which are major causes of energy wastage. The proposed model architecture given in Fig 1.

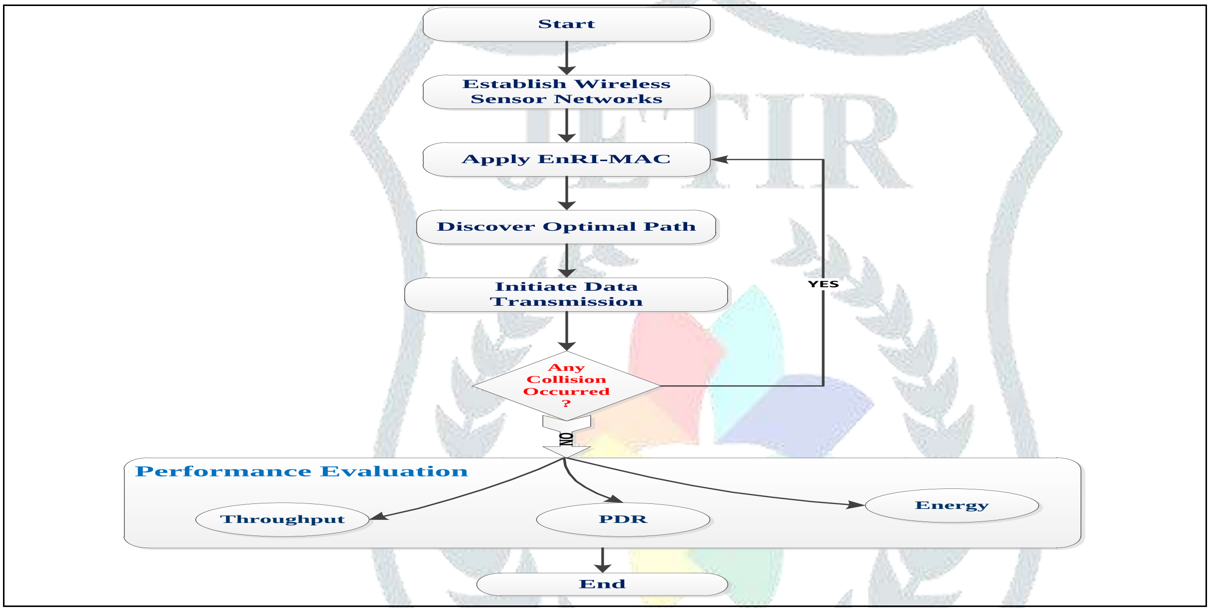


Fig 1. Proposed Architecture of EnRI-MAC

For reliable data transmission, EnRI-MAC ensures a high Packet Delivery Ratio (PDR) by minimizing packet loss and retransmissions through efficient recovery mechanisms. It incorporates collision and interference detection techniques to identify potential conflicts and employs interference-aware strategies to maintain seamless communication. Additionally, the protocol enables optimal path discovery by dynamically selecting the best communication route based on metrics such as link quality, residual energy, and network congestion. Finally, EnRI-MAC enhances dynamic channel access by adapting channel parameters to varying network conditions and supporting multi-channel communication, thereby reducing congestion and packet collisions while improving overall network performance.

## V. RESULTS ANALYSIS

### 4.1 Environment

The implementation and evaluation of the Enhanced Receiver-Initiated Medium Access Control (EnRIMAC) protocol are carried out using the NS-2.35 network simulator on Ubuntu 20.04 LTS with GCC and Make tools, while Python and gnuplot/Xgraph are used for trace analysis and result visualization. The simulation environment consists of a 2000×2000 m network area with 50 wireless sensor nodes and one sink, using the AODV routing protocol and CBR traffic over UDP with a data rate of 1 Mbps and a 512-byte packet size. The MAC layer is enhanced by modifying the standard 802.11 DCF model to implement EnRIMAC features such as receiver-initiated beacons, duty-cycle-based sleep scheduling, adaptive beacon intervals, and collision-avoidance mechanisms with limited retransmissions and ACK-by-beacon support. The simulation time is set to 50 seconds, and the energy model assigns an initial energy of 100 J per node, with specific power consumption values for transmission, reception, idle, and sleep states to evaluate energy efficiency. The network uses the TwoRayGround propagation model, OmniAntenna, and DropTail/PriQueue with a queue length of 50. The performance of EnRIMAC is analyzed based on key metrics such as throughput, packet delivery ratio (PDR), end-to-end delay, energy consumption, and control overhead, and its results are compared against the traditional RI-MAC protocol under identical traffic, topology, and energy configurations to ensure fair evaluation and reproducibility.

### 4.2 Performance Evaluation

#### 4.2.1 Throughput

EnRI-MAC shows a rapid increase in throughput within the first 10 seconds, reaching a peak of around 12768 bytes, and increasing to 14896, then decreasing to 12768 and the same cycle repeats, high throughput at the 50-second simulation and maintain constant. This demonstrates its ability to achieve stability and provide consistently high performance. In contrast, RI-MAC exhibits a more gradual increase, its performance fluctuates slightly, remaining lower than EnRI-MAC throughout the simulation. The variability in RI-MAC's performance suggests challenges in maintaining consistent communication shown in Fig 2.

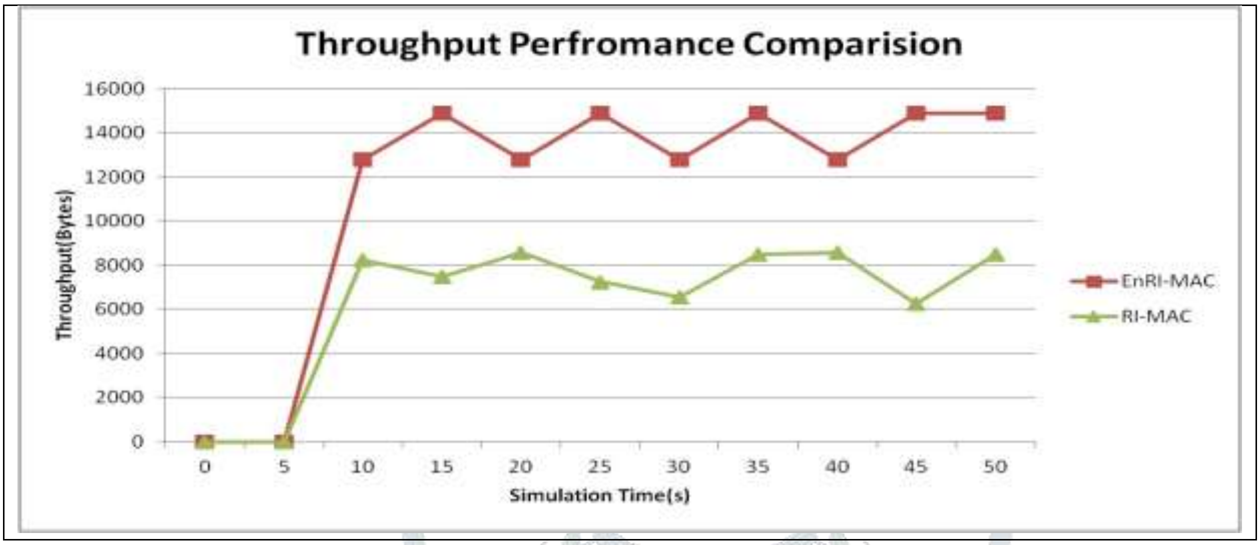


Fig 2. Comparison of Throughput Performance

#### 4.2.2 Packet Delivery Ratio

EnRI-MAC demonstrates a significantly higher and consistently increasing PDR, starting from 0% and reaching nearly 80% by the end of the 50-second simulation. In contrast, RI-MAC shows a much slower increase in PDR, peaking at around 50% after 50 seconds. This indicates that EnRI-MAC provides a far superior packet delivery rate, with much more efficient and reliable data transmission compared to RI-MAC, which exhibits considerably lower PDR performance throughout the simulation is shown in Fig 3.

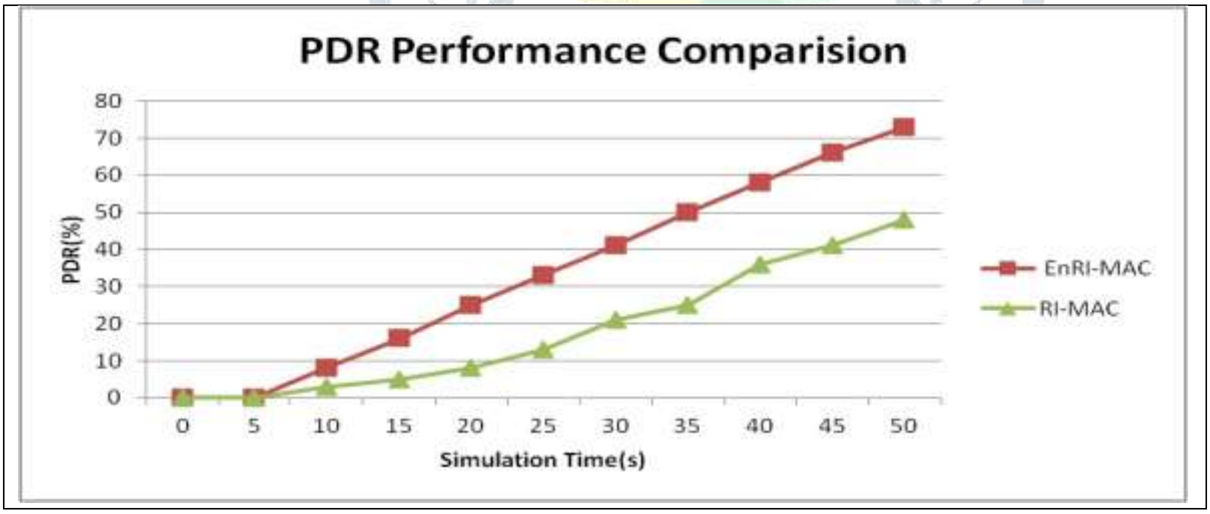


Fig 3. Comparisons of PDR Performance

#### 4.2.3 Energy

EnRI-MAC consistently maintains higher energy levels throughout the simulation. Starting at 100% energy for both protocols, EnRI-MAC experiences a gradual and stable decrease, with energy levels remaining above 90% throughout the 50-second period. In contrast, RI-MAC shows a steeper decline in energy performance, dropping to approximately 76.58% by 5 seconds and fluctuating around 73% to 77% during the remainder of the simulation. At the 50-second mark, EnRI-MAC still holds 91.44% of its energy, whereas RI-MAC drops to 69.69% is shown in Fig 4.

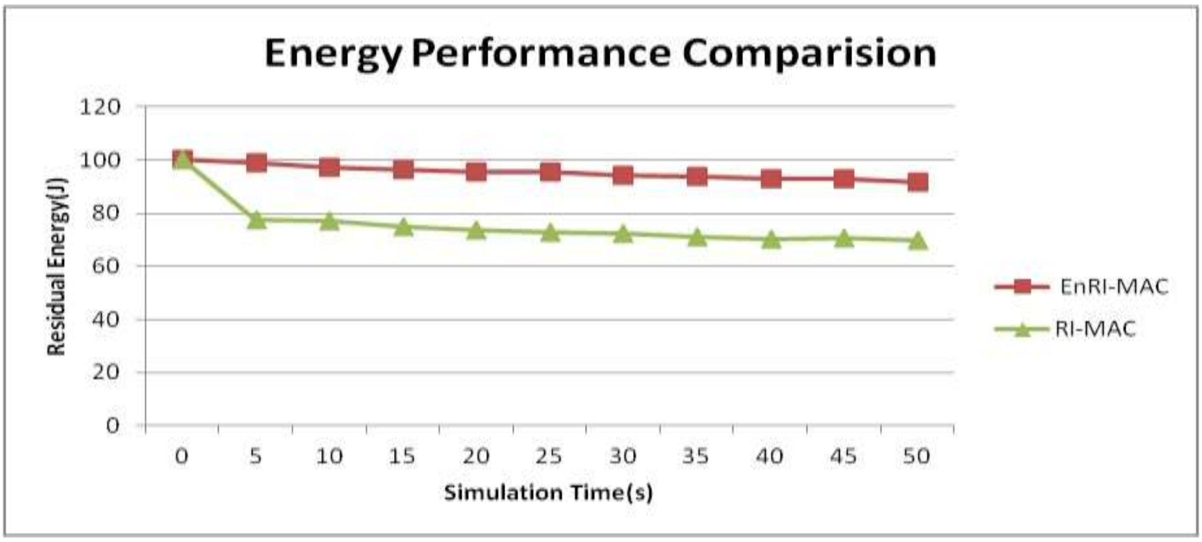


Fig 4. Comparison of Energy Performance

## V.CONCLUSION

The Enhanced Receiver-Initiated Medium Access Control (EnRI-MAC) protocol is an advanced improvement over the traditional Receiver-Initiated MAC (RI-MAC) protocol in Wireless Sensor Networks (WSNs), designed to optimize energy efficiency, reliability, and overall network performance. By leveraging key features such as energy-efficient sleep/wake scheduling, dynamic channel access, optimal path discovery, and efficient collision avoidance mechanisms, EnRI-MAC effectively minimizes idle listening, reduces retransmissions, and enhances seamless communication. Performance evaluations show significant enhancements in critical metrics, including a 60% improvement in total network throughput (from 69,838 bytes in RI-MAC to 125,552 bytes in EnRI-MAC), a 25% increase in Packet Delivery Ratio (PDR) from 48% to 73%, and a 16% improvement in energy efficiency, with average remaining energy increasing from 75.39 J to 91.44 J. Additionally, EnRI-MAC introduces advanced support for broadcast, multicast, and convergecast traffic, making it highly adaptable to diverse WSN applications. These results confirm that EnRI-MAC offers superior throughput, improved reliability, reduced latency, and optimized energy consumption, positioning it as a highly efficient and robust MAC protocol for next-generation Wireless Sensor Networks.

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