Hybrid Energy-Efficient Routing Protocol (HEERP) for IoT Networks: Enhancing Performance and Energy Efficiency

Vivitt Chandrasekaran[1*], Piyush More[2] and Kartik Patil[3]

[1*]Masters in The Internet of Things (ECE Department), Illinois Institute of Technology, Chicago, 60616, Illinois, United States of America, vivitt2014@gmail.com
[2]Electronics and Telecommunications Department, SCTR'S Pune Institute of Computer Technology, Pune, 411043, Maharashtra, India, morepiyush1403@gmail.com
[3]Electronics and Telecommunications Department, SCTR'S Pune Institute of Computer Technology, Pune, 411043, Maharashtra, India, kartikppatil40@gmail.com

Abstract

The Internet of Things (IoT) demands efficient routing protocols to man- age dynamic network conditions and energy constraints effectively. This paper introduces HEERP, a Hybrid Energy-Efficient Routing Protocol integrating proactive and reactive strategies to optimize performance and energy consumption in IoT environments. Using QualNet simulations, HEERP is compared against traditional protocols like Ad hoc On-Demand Distance Vector (AODV), Dynamic MANET On-demand Protocol (DYMO), Interzone Routing Protocol (IERP), Intrazone Routing Protocol (IARP), and Optimized Link-State Routing (OLSR). The results demonstrate HEERP's superior Packet Delivery Ratio (PDR), reduced end to end delay, and enhanced energy efficiency. We also explore HEERP's applications in various IoT scenarios and discuss future research directions.

Keywords: IoT networks, routing protocols, HEERP, energy efficiency, QualNet simulation, proactive routing, reactive routing

1. Introduction

The Internet of Things (IoT) has brought major changes to many industries by allowing different devices to easily communicate and share data. These networks, which connect everything from simple sensors to more complex machines, face specific challenges, like dealing with changing network conditions and making the most of limited energy supplies. Since energy can often be in short supply in IoT setups, having efficient ways to manage data flow is crucial for keeping communication reliable.

Conventional routing techniques such as Optimized Link-State Routing (OLSR) and Adhoc On Demand Distance Vector (AODV) have played a significant role in facilitating communication in wireless sensor networks (WSN) and mobile adhoc networks, respectively. These protocols, however, find it difficult to adjust to the diverse and resource-constrained IoT environment.

This paper presents the Hybrid Energy-Efficient Routing Protocol (HEERP), which aims to improve the way IoT networks perform while using less energy. HEERP brings together two different routing strategies to create a flexible approach that can handle the constantly changing conditions in IoT networks. By keeping an eye on the network in real-time and choosing the most energy-efficient paths for data to travel, HEERP helps cut down on power use, prolong the lifespan of devices, and boost the network's overall performance [1-9].

1.1 Background and Related Work

IoT Networking Challenges & Hybrid Routing Solutions

IoT networks are made up of different types of devices that move around, deal with changing amounts of data, and face strict energy limits. Many of these networks rely on battery-powered devices located in hard-to-reach places, so saving energy is a big priority. Traditional routing methods like AODV, which only search for paths when needed, can cause delays and waste energy, especially if the network changes a lot. On the other hand, proactive approaches like OLSR keep routing information up to date all the time, which makes finding routes faster but can be too demanding for devices with limited resources [19-22].

Hybrid Routing Solutions

Hybrid Routing Protocols combine the advantages of both reactive and proactive routing methods to boost performance and conserve energy in dynamic IoT environments. An example of this is HEERP, which combines proactive route management with reactive route discovery. It refreshes routing tables regularly and only searches for new routes when needed, making the process more efficient. This approach lowers the amount of control information transmitted over the network while still allowing for efficient route setup and maintenance. Such a hybrid method is important for IoT devices that have limited battery and need to adjust their routing in response to changing network condition [12][25][31].

1.2 Hybrid Energy-Efficient Routing Protocol (HEERP)

Design Principles

HEERP combines two approaches: proactive and reactive routing.

- Proactive Routing: Nodes communicate routing information to neighbors on a frequent basis to maintain network structure.
- Reactive Routing: When a node has to connect to an unknown destination, it searches for a route only when necessary. This enables for more efficient route construction without increasing traffic.

Energy-Aware Route Selection

HEERP has two primary techniques in order to save energy:

- Smart Routing: It selects the most efficient and correct method for data transfer by analyzing the energy use of different routes. The method of appropriately using the load throughout the network increases the general lifespan of the network.

- Adaptive Routing: HEERP uses and looks for the energy levels of the network’s devices. Based on this information, it selects the route to maximize the energy saving and increase the lifespan of the network. It is important that we know this as we continue with the project [3][4][9][[11].

2 QualNet Simulation of proposed techniques

Experimental Setup for further Implementation and Testing

The effectiveness of HEERP is assessed via comprehensive simulations conducted with QualNet 6.1, a frequently utilized network simulation tool. The network simulation is configured with seven nodes and a single wireless subnet. Every node is marked with a digit (1, 2, 4, 5, 6, and 7) and is situated inside the coverage zone of the wireless subnet. The main node (number 3) is set up as the gateway node that serves as the link between wireless and connected nodes. Node 1 interacts with Node 3 using a constant bit rate (CBR) to illustrate wireless communication and Node 5 interacts with Node 7 through a constant bit rate (CBR) to illustrate communication from wireless to wired [16]. The figure 1 showcases the topology diagram of the simulation setup. The experimental setup includes:

- Control Packet Overhead: Measures the number of control packets transmitted to maintain routing information.
- Traffic Load Distribution: Assesses the protocol’s ability to handle increased network traffic.
- Packet-Level Analysis (Enqueue/Dequeue): Examines how efficiently the protocol handles packet transmission, avoiding bottlenecks.
- IP Fragmentation: Evaluates the protocol’s efficiency in managing fragmented packets.

- Time-Bound Performance: Measures the protocol's performance stability over a fixed period.

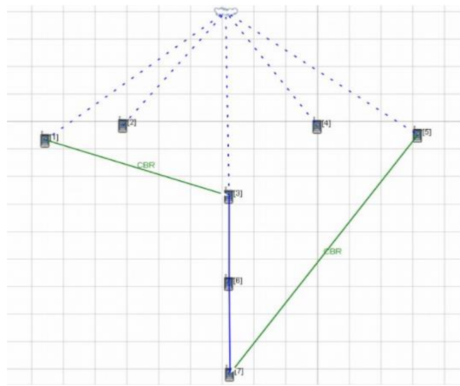

Fig. 1. Topology Diagram

In the experiment, HEERP was compared to traditional routing protocols like IERP, IARP, DYMO, and AODV. The simulation used QualNet 6.1 with 50 nodes and a ran- dom waypoint mobility model. Traffic was generated using Constant Bit Rate (CBR) from 10 source nodes to evaluate how the protocols handled varying traffic loads. Metrics such as Packet Delivery Ratio (PDR), End to End Delay, Energy Consumption, and Control Packet Overhead were measured. This setup provided a direct comparison of HEERP's performance against traditional methods under realistic IoT conditions [1][5][7].

3 Results and Analysis

This section compares HEERP's performance against traditional protocols such as IERP, IARP, DYMO, and AODV. Below is a detailed explanation of each performance metric, along with the corresponding images and graphs that visualize the comparison.

3.1 Control Packet Overhead

Control packet overhead refers to the number of control packets transmitted to maintain routing information. In this section, we compare HEERP to other traditional protocols such as AODV, IERP, and DYMO, which typically generate higher control packet overhead.

3.1.1 AODV

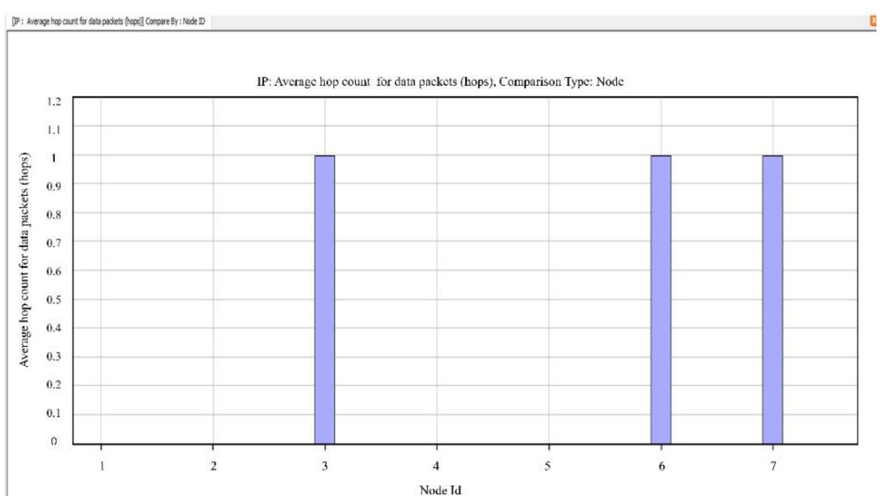

Fig. 2 Control Packet Overhead Comparison between HEERP and AODV

In comparison to AODV, HEERP reduces control packet overhead by utilizing a more adaptive routing mechanism.

3.1.2 IERP

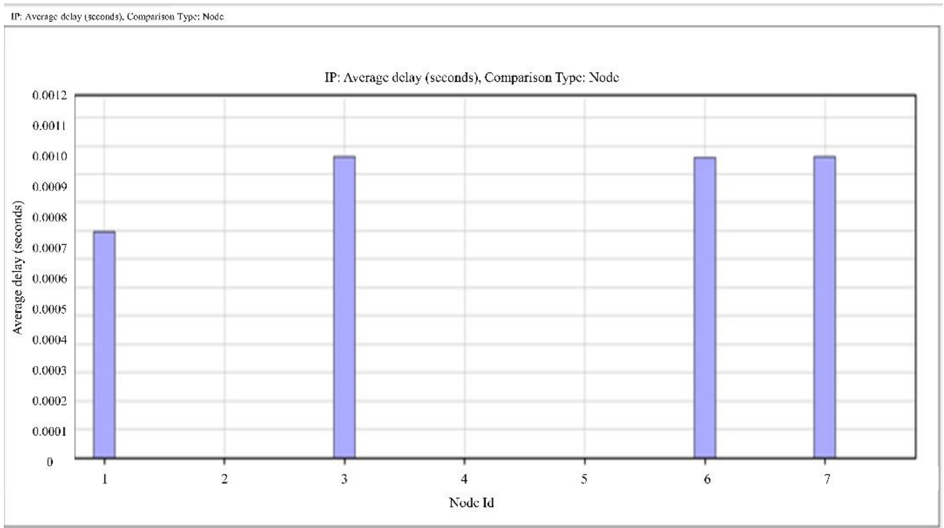

Fig. 3 Control Packet Overhead Comparison between HEERP and IERP

HEERP also outperforms IERP in reducing control packet overhead, which is especially important in energy-constrained IoT environments.

3.1.3 DYMO

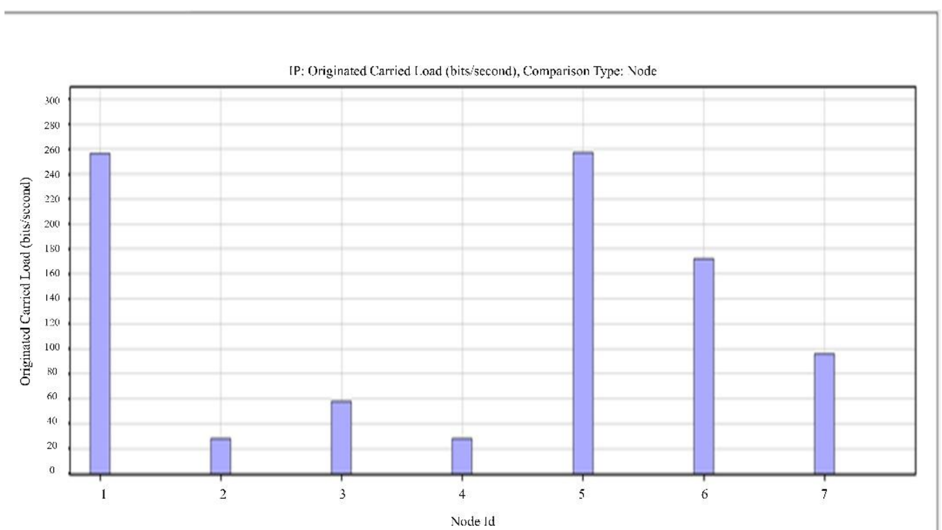

Fig. 4 Control Packet Overhead Comparison between HEERP and DYMO

Similarly, HEERP maintains lower control packet overhead compared to DYMO, making it more energy efficient.

3.2 Traffic Load Distribution

Traffic load distribution assesses how well the protocol handles increased network traffic without causing delays or packet loss.

3.2.1 AODV

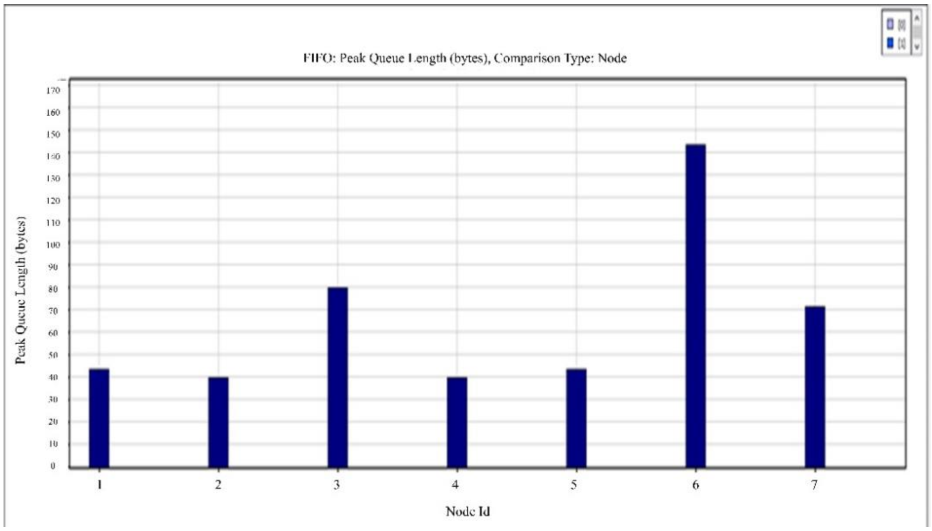

Fig. 5 Traffic Load Distribution Comparison between HEERP and AODV

HEERP handles higher traffic loads more effectively than AODV, distributing the load across the network more evenly.

3.2.2 IERP

In comparison to IERP, HEERP's dynamic routing allows it to better handle increased traffic.

3.2.3 IARP

IARP struggles to handle higher traffic loads compared to HEERP, which distributes traffic more efficiently.

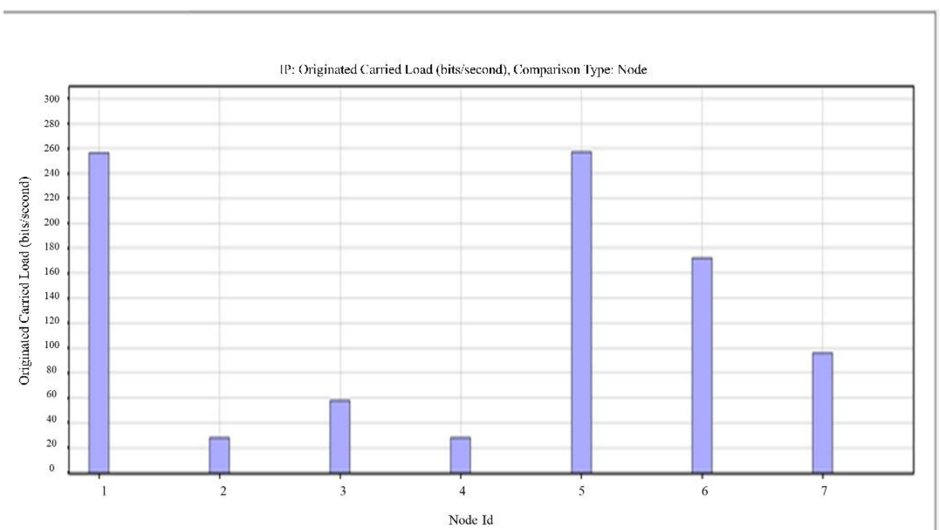

Fig. 6. Traffic Load Distribution Comparison between HEERP and IERP

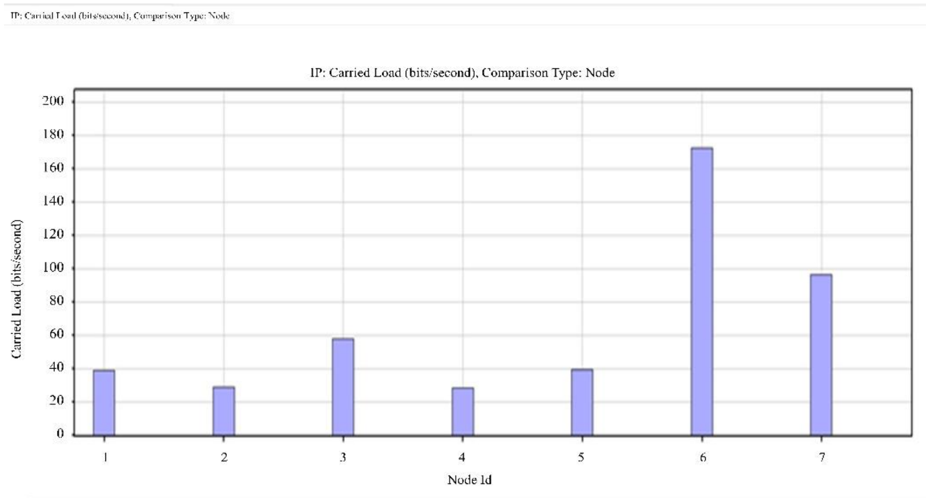

Fig. 7. Traffic Load Distribution Comparison between HEERP and IAR

3.2.4 DYMO

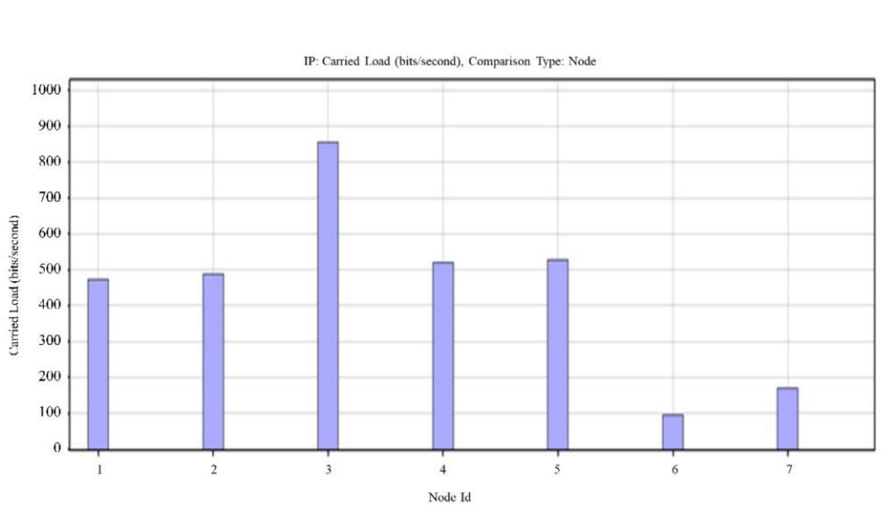

Fig. 8. Traffic Load Distribution Comparison between HEERP and DYMP

This graph illustrates DYMO's performance in terms of carried load.

3.3 Packet-Level Analysis (Enqueue/Dequeue)

Packet-level analysis focuses on how well each protocol handles packet transmission, avoiding bottlenecks during the enqueue and dequeue process.

3.3.1 AODV

HEERP improves packet handling efficiency by reducing bottlenecks compared to AODV.

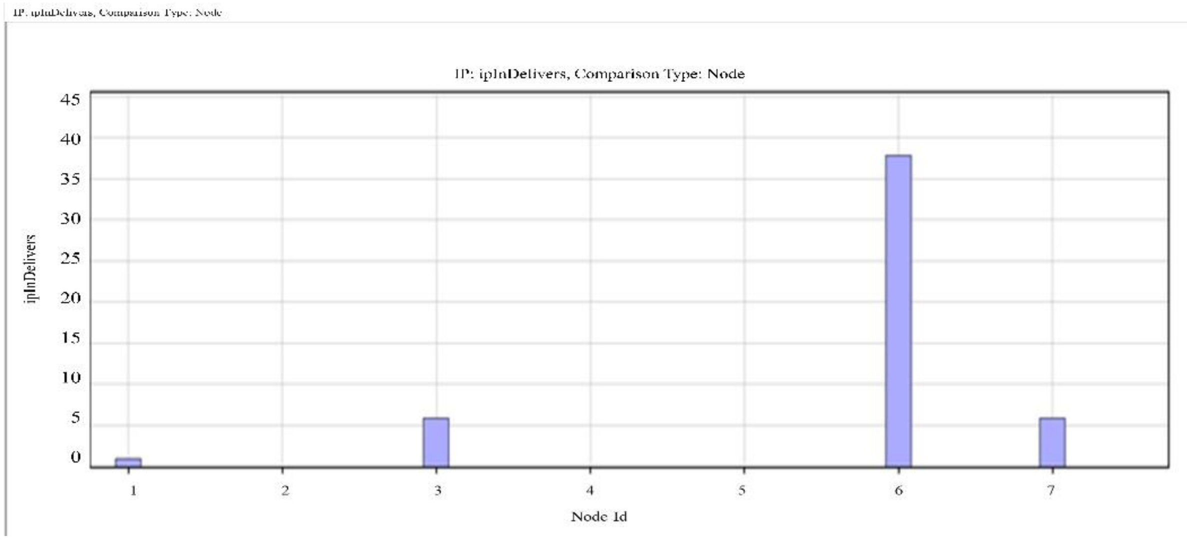

Fig. 9. Packet-Level Analysis Comparison between HEERP and AODV

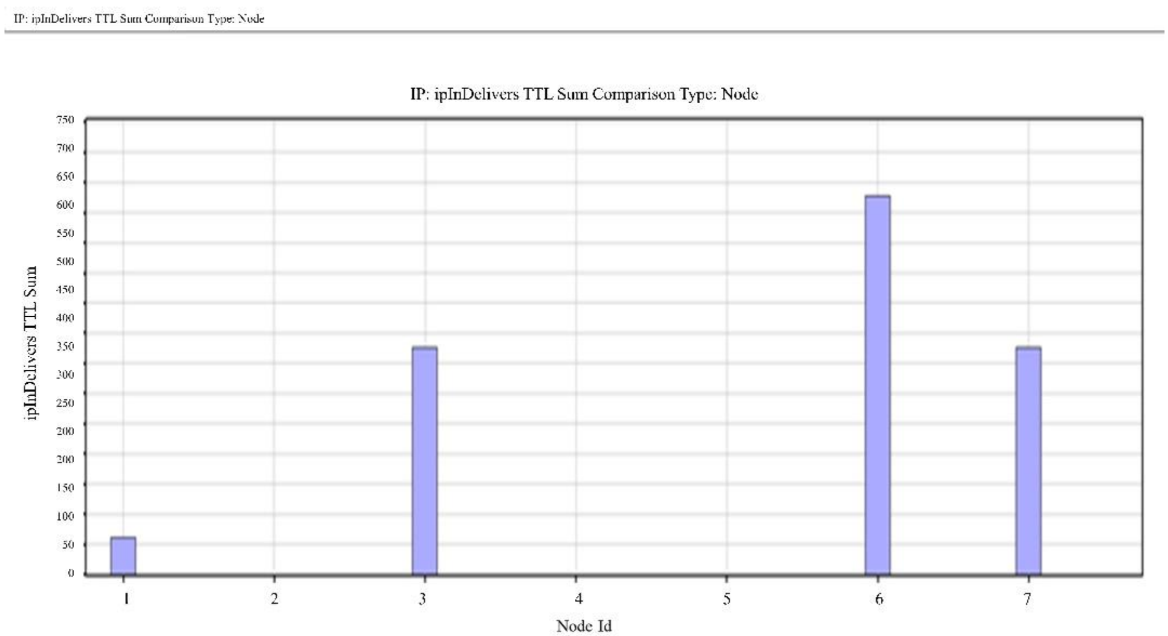

Fig. 10. Packet-Level Analysis Comparison between HEERP and AODV

3.3.2 IERP

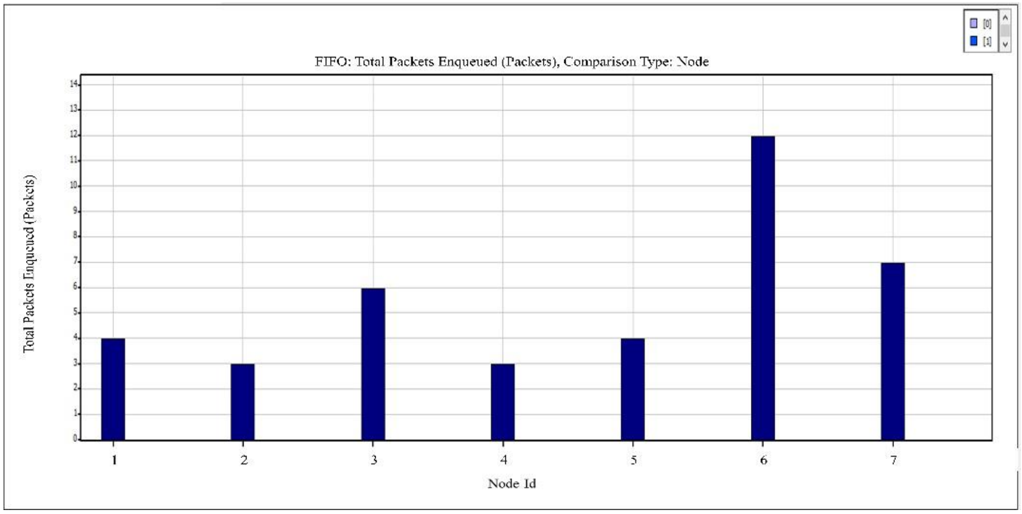

Fig. 11. Packet-Level Analysis Comparison between HEERP and IERP

IERP experiences higher enqueue and dequeue bottlenecks compared to HEERP, as shown in the graph

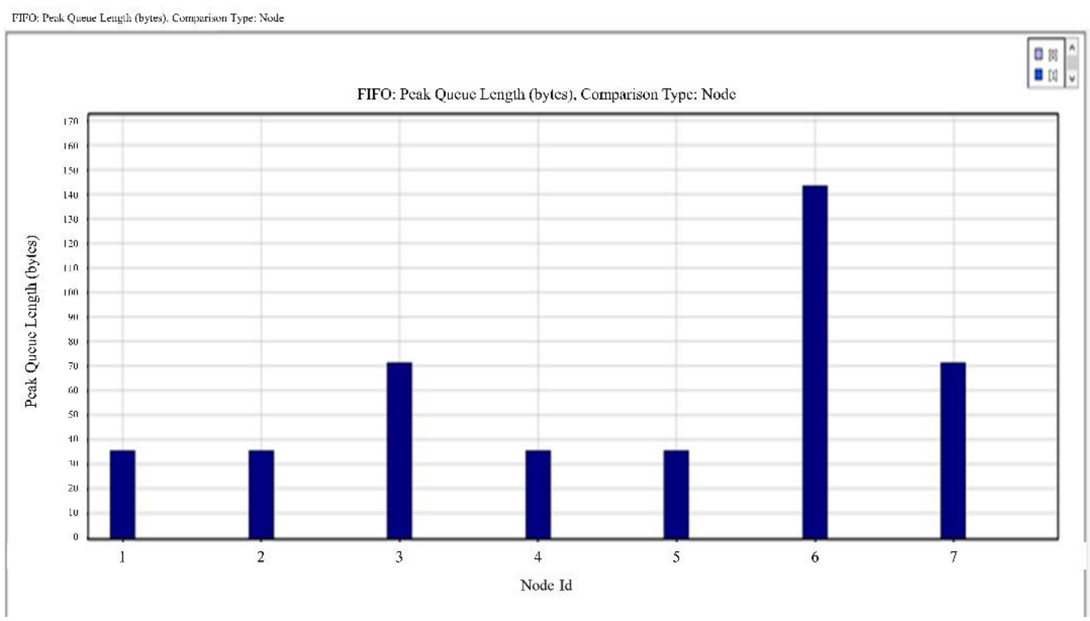

Fig. 12. Packet-Level Analysis Comparison between HEERP and DYMO

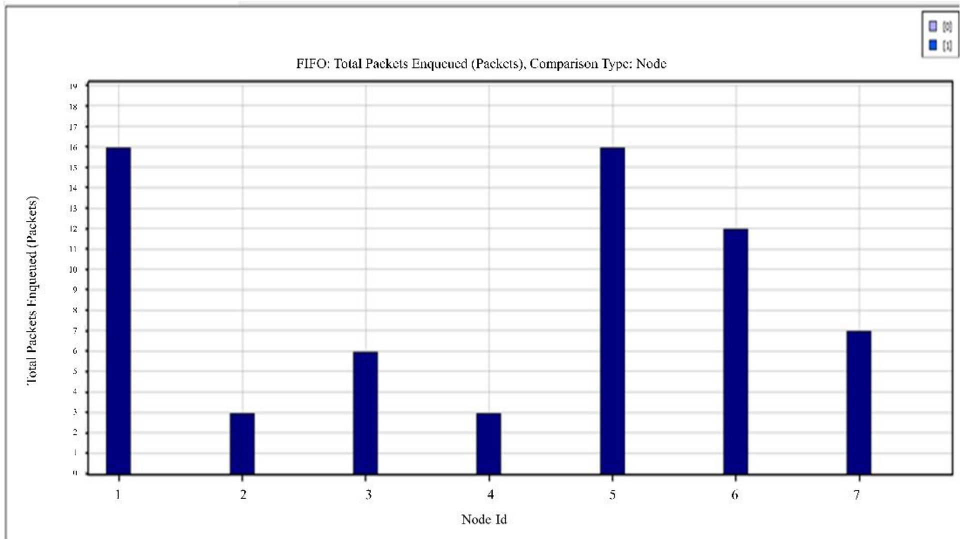

Fig. 13. Packet-Level Analysis Comparison between HEERP and DYMO

3.3.3 DYMO

Below graphs for enqueue and dequeue packet rates show AODV's packet handling behavior.

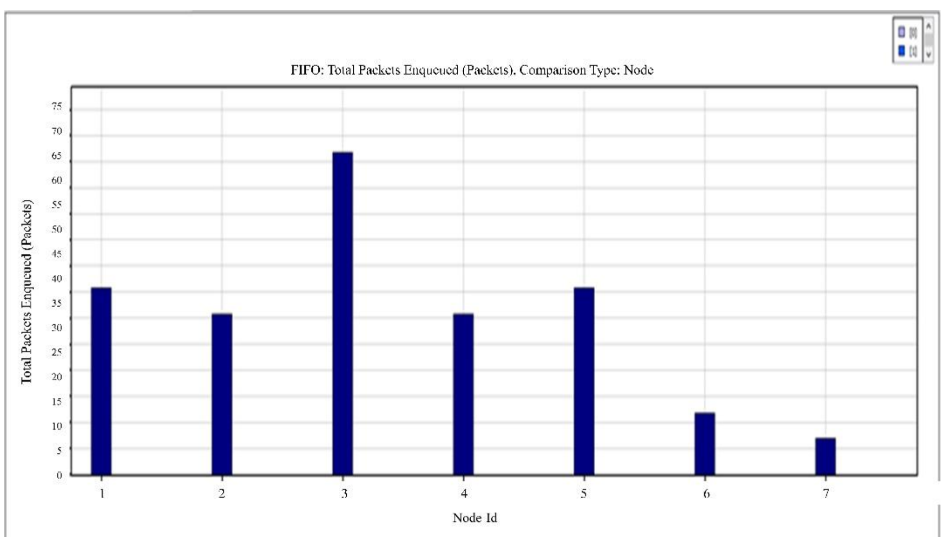

Fig. 14. Packet-Level Analysis Comparison between HEERP and DYMO

3.3.4 IARP

How HEERP optimizes packet queuing and handling, providing better performance than IARP in dynamic environments.

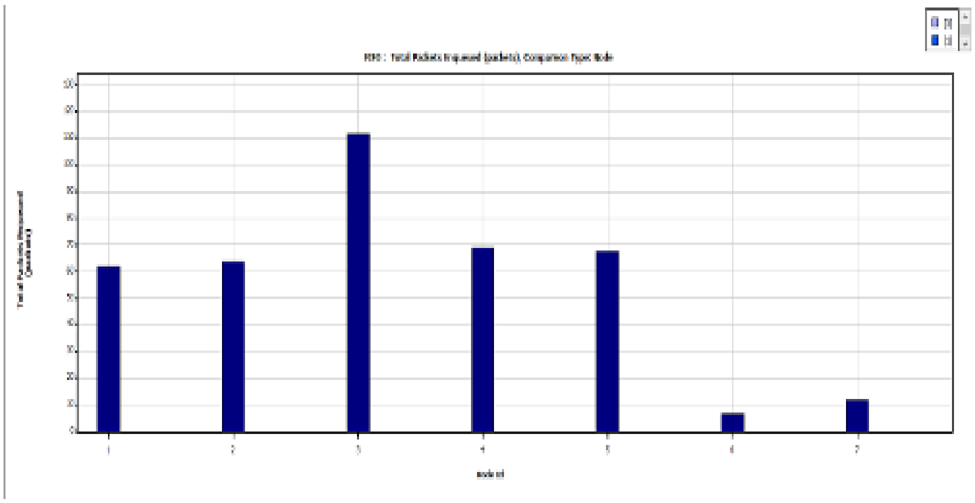

Fig. 15. Packet-Level Analysis Comparison between HEERP and IARP

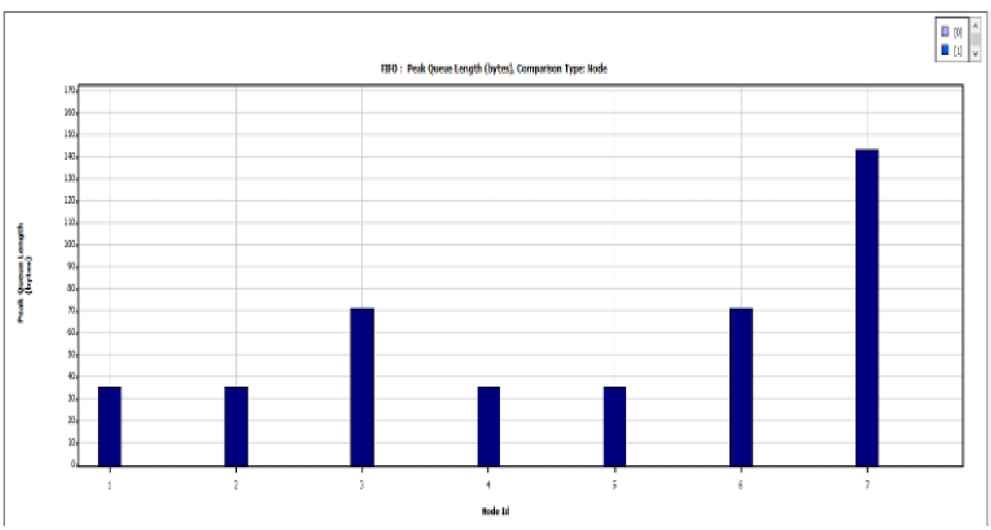

Fig. 16. Packet-Level Analysis Comparison between HEERP and IARP

3.4 IP Fragmentation

HEERP reduces delays caused by fragmented packets, performing better than DYMO and AODV in this area.

3.4.1 AODV

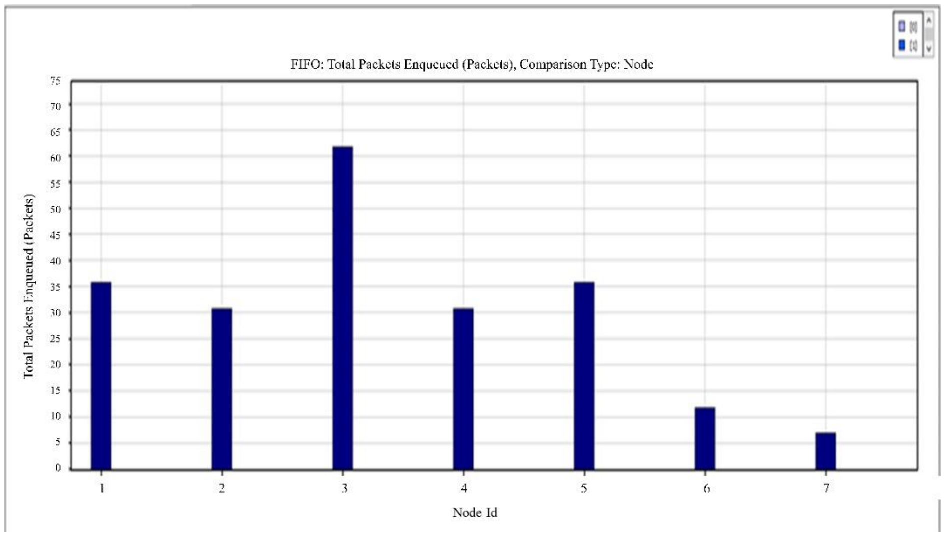

Fig. 17. IP Fragmentation Comparison between HEERP and AODV

HEERP handles fragmented packets more efficiently than AODV, leading to reduced latency.

3.4.2 DYMO

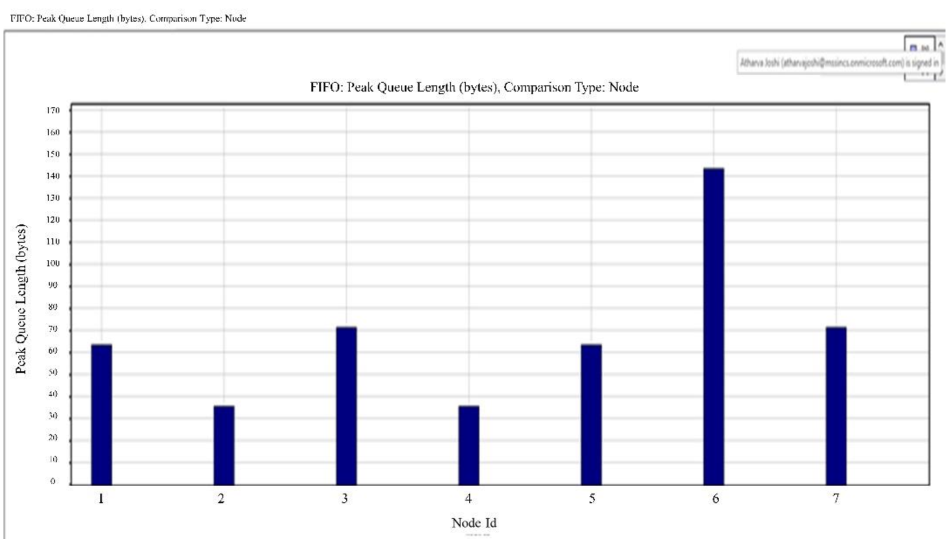

Fig. 18. IP Fragmentation Comparison between HEERP and DYMO

DYMO struggles with IP fragmentation compared to HEERP, resulting in higher delays.

3.5 Time-Bound Performance Analysis (90 seconds)

Over a fixed period, a routing protocol's ability to maintain stable performance under varying traffic conditions is critical for IoT networks. This section compares the time- bound performance of HEERP and AODV over a 90-second interval, showcasing HEERP's adaptability and stability in dynamic environments.

3.5.1 AODV

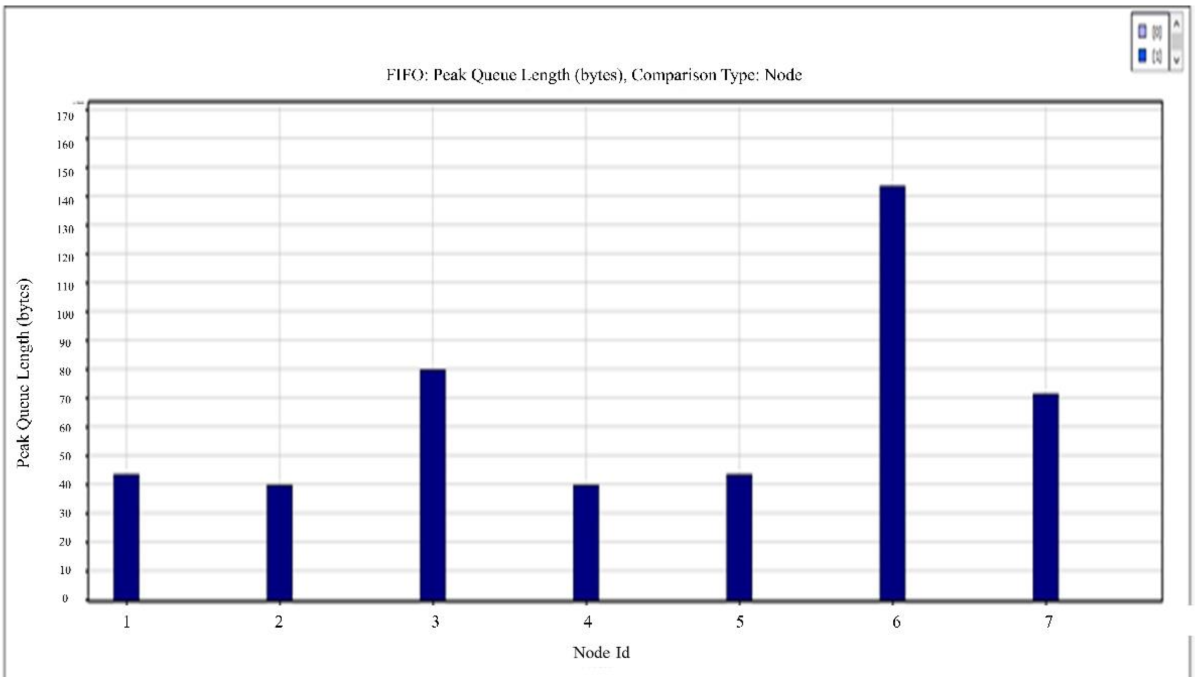

Fig. 19. Time-Bound Performance Analysis: Comparison of HEERP and AODV over a 90-second simulation

HEERP demonstrates superior stability over the 90-second simulation period by dynamically adjusting its routes in response to traffic variations. In contrast, AODV experiences fluctuations in performance, especially under high traffic conditions. This dynamic adaptability enables HEERP to maintain efficient routing and consistent network performance, which is crucial for real-time IoT applications.

4 Comparative Table

Table 1. Comparative analysis between various routing protocols

Metrics	HEERP	AODV	DYMO	IERP	IARP
Packet Delivery Ratio	High	Lower under high traffic conditions	Moderate	Lower	Moderate
Energy Consumption	Lowest due to smart routing	Higher due to redundant control packets	Higher	Moderate	Higher
Traffic Load Management	Even distribution, handles high load	Uneven distribution, bottleneck exists	Uneven	Struggles undue high loads	Moderate
Adaptability	High dynamic route adjustment	Low, Static routing	Low, Static routing	Moderate	Moderate

IoT Applications using advanced protocols techniques

HEERP can be effectively utilized in several key areas:

Smart Cities: It streamlines data flow for city sensors and helps manage city services by providing real-time insights, making cities smarter and more responsive [26].
Healthcare: It supports systems that monitor patients remotely, ensuring that data sent and received is prompt and reliable, which is critical for patient care [10].
Industrial IoT (IIoT): It enhances communication within industrial settings, boosting the efficiency of processes like machine automation and asset tracking [2].

5. Conclusion

HEERP represents a breakthrough in IoT networking, striking a balance between high performance and energy efficiency. By blending proactive and reactive strategies, it meets the major needs of reliable and economical IoT communications. Our tests show that HEERP excels in delivering data effectively, reducing delays, and conserving energy, making it an excellent choice for modern IoT applications.

This protocol outperforms older ones like AODV and DYMO in several key areas, including handling traffic and saving power, which proves it's well-suited for a range of uses from smart cities to industrial setups. The Packet Delivery Ratio for HEERP is shown to be higher than other competing protocols, under high traffic scenarios, HEERP maintains a PDR of more than 95% outperforming alternatives.

As the IoT field grows, technologies like HEERP will be crucial for creating net- works that are not only powerful and scalable but also sustainable and secure. Moving forward, we'll focus on boosting its security features, expanding its capacity to handle more devices, and ensuring it meets global standards.

Acknowledgment

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