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AODV-PROPT: A NOVEL AODV-BASED ROUTING PROTOCOL ENHANCED BY RELATIONAL PARAMETER INDEXING (ARPI)

[1]Abhishek Sharma, [2]Arnav Arora, [3]Garvit Nag, [4]Amit Chhabra
[1]Student, [2]Student, [3]Student, [4]Assistant Professor
[1]Department of Computer Science and Engineering
[1]Chandigarh College of Engineering and Technology, Sector-26, Chandigarh, India

Abstract: Efficient routing protocols play a crucial role in ensuring reliable data transmission and conserving energy resources in wireless ad-hoc networks. This research focuses on enhancing the performance of the widely adopted Ad-hoc On-Demand Distance Vector (AODV) routing protocol through a novel optimization approach. The primary objectives are to improve packet delivery ratio, residual energy conservation, and overall network efficiency in dynamic wireless environments.
The key contributions of this work include: (1) a comprehensive analysis of AODV parameter relationships and their impact on network performance, (2) the development of AODV-PROPT, an optimized variant of AODV incorporating identified parameter relationships, and (3) the introduction of the AODV Relational Parameter Index (ARPI), a novel metric quantifying the alignment of AODV parameters with optimal relationships.
Extensive simulations using the ns-2 network simulator were conducted to evaluate the proposed AODV-PROPT protocol. The results demonstrate significant improvements over the traditional AODV implementation, with up to 13.13% enhancement in packet delivery ratio and 11.285% improvement in residual energy across various network scenarios. Furthermore, the AODV-PROPT achieved an ARPI of 1.0, indicating perfect alignment with the identified optimal parameter relationships.
This research contributes to the advancement of routing protocols in wireless ad-hoc networks by proposing a systematic optimization approach, a performance-enhanced protocol variant, and a comprehensive evaluation framework. The findings pave the way for practical implementations and future research directions in energy-constrained and dynamic wireless communication systems.
Keywords: AODV, Routing Protocol, Wireless Ad Hoc Networks, Simulations, ns-2, Algorithm.

1. INTRODUCTION

Wireless ad-hoc networks have emerged as a critical communication paradigm, enabling decentralized connectivity in scenarios where traditional infrastructure-based networks are impractical or infeasible [1]. These self-configuring networks comprise mobile nodes that dynamically establish routes and relay data among themselves without relying on a centralized control or pre-existing infrastructure. The applications of wireless ad-hoc networks span diverse domains, including military operations, disaster relief efforts, vehicular communications, and Internet of Things (IoT) deployments [2].
However, the inherent characteristics of wireless ad-hoc networks, such as node mobility, dynamic topologies, and limited resources, pose significant challenges for efficient and reliable data transmission [3]. In such dynamic environments, routing protocols play a pivotal role in determining optimal paths for data packets while effectively managing network resources and adapting to topology changes [4].

The Ad-hoc On-Demand Distance Vector (AODV) routing protocol has gained widespread adoption in wireless ad-hoc networks due to its reactive nature and ability to establish routes on-demand, minimizing control overhead [5].

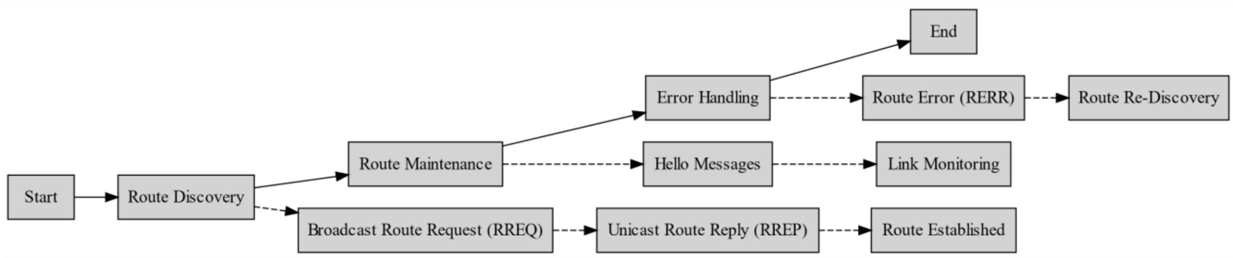

Figure 1: Basic Operations Of The Aodv Routing Protocol

However, despite its popularity, the traditional AODV implementation suffers from limitations in terms of packet delivery reliability, energy efficiency, and adaptability to diverse network conditions [6].

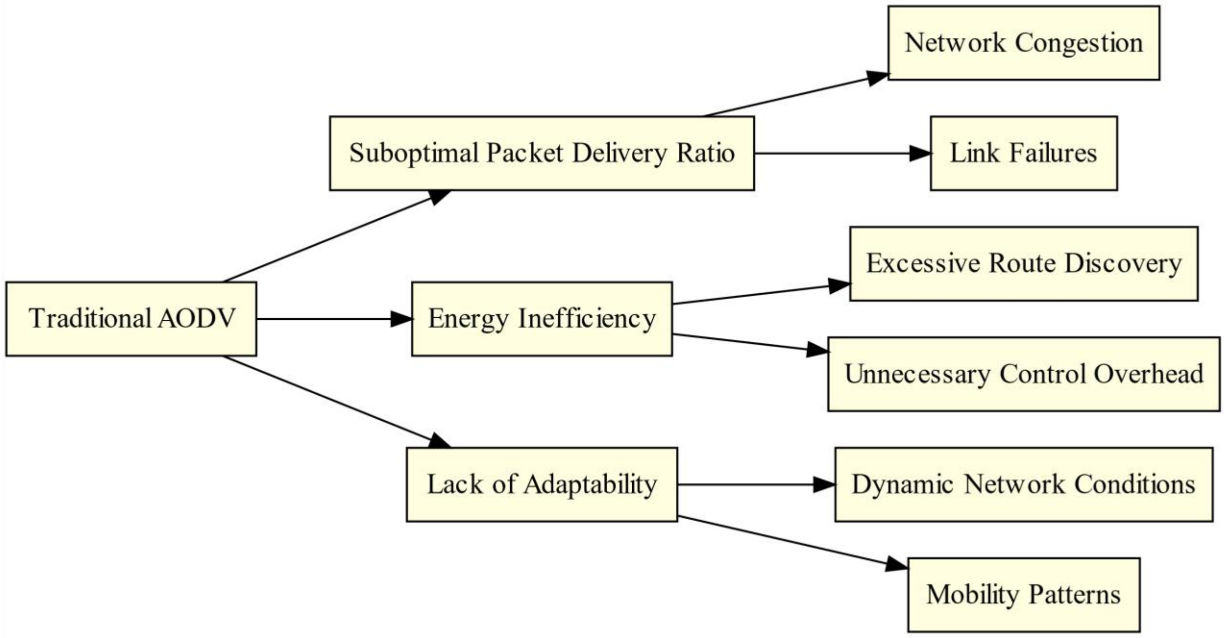

Figure 2: Limitations of Traditional AODV Protocol

Numerous research efforts have been dedicated to enhancing the performance of AODV in wireless ad-hoc networks. Approaches such as load balancing [7], multipath routing, and energy-aware mechanisms [8] have been proposed to address specific aspects of AODV's limitations. However, these solutions often focus on individual performance metrics or specific network scenarios, lacking a comprehensive optimization strategy that considers the interdependencies among AODV's operational parameters.

This research aims to address the aforementioned limitations by optimizing the AODV routing protocol for wireless ad-hoc networks through a systematic and holistic approach. The primary objectives are to enhance packet delivery reliability, improve energy efficiency, and ensure better adaptability to dynamic network conditions. To achieve these goals, we conducted a comprehensive analysis of the AODV protocol's parameters, identifying critical relationships and patterns that impact network performance.

The novel contributions of this work include:

1. The development of AODV-PROPT, an optimized variant of the AODV protocol, incorporating identified parameter relationships to enhance performance.
2. The introduction of the AODV Relational Parameter Index (ARPI), a novel metric that quantifies the alignment of protocol parameters with optimal relationships, serving as a comprehensive evaluation framework.
3. A systematic optimization approach that leverages insights from parameter analysis to fine-tune AODV's operational parameters, addressing the limitations of the traditional implementation.
4. Extensive simulations and performance evaluations, demonstrating the efficacy of the proposed AODV-PROPT protocol and the ARPI metric in improving packet delivery ratio, residual energy conservation, and overall network efficiency.

By addressing the limitations of traditional AODV and proposing performance-enhancing solutions, this research contributes to the advancement of routing protocols for wireless ad-hoc networks, enabling more reliable and efficient communication in dynamic and resource-constrained environments.

2. RELATED WORKS

Optimizing the performance of routing protocols in wireless ad-hoc networks has been an active area of research, with numerous approaches proposed to enhance the widely adopted AODV protocol. However, existing solutions often address specific aspects of the protocol or target particular network scenarios, lacking a comprehensive optimization strategy that considers the interdependencies among AODV's operational parameters.

Load balancing mechanisms have been explored to alleviate congestion and improve network throughput in AODV-based networks. Zhang et al. [9] proposed a delay-aware and link-quality-aware geographical routing protocol that incorporates load metrics into the route discovery process, aiming to distribute traffic across multiple paths. While these approaches can enhance packet delivery ratio, they primarily focus on addressing congestion and do not consider other factors such as energy efficiency or adaptability to dynamic network conditions.

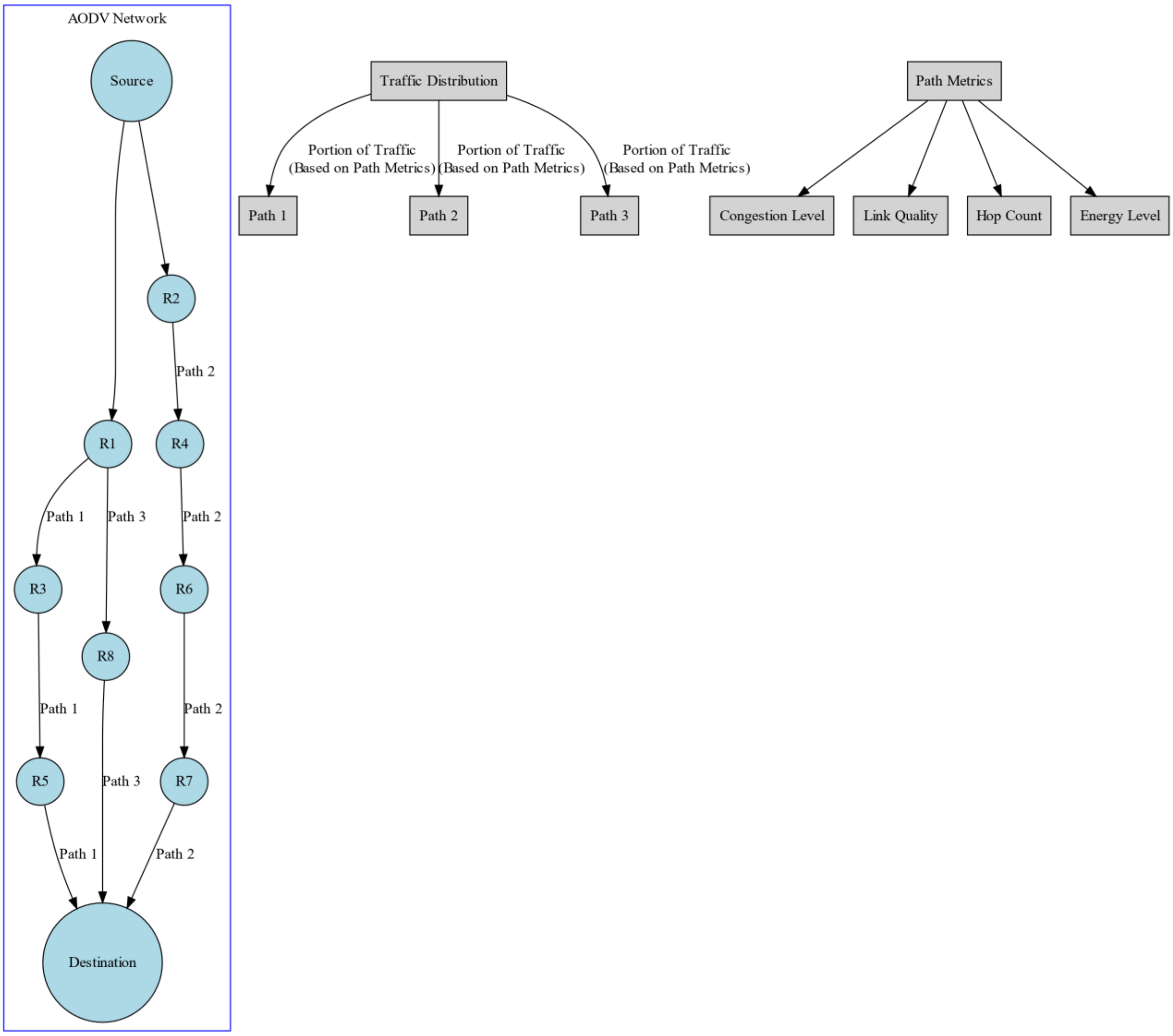

Figure 3: Load Balancing Mechanisms in AODV

Multipath routing techniques have been explored to improve the reliability and fault tolerance of AODV [10] [11]. These approaches involve discovering and maintaining multiple paths between source and destination nodes, enabling alternative routes to be utilized in case of link failures or congestion. However, the overhead associated with maintaining multiple paths can be significant, particularly in resource-constrained environments, leading to potential energy inefficiencies.

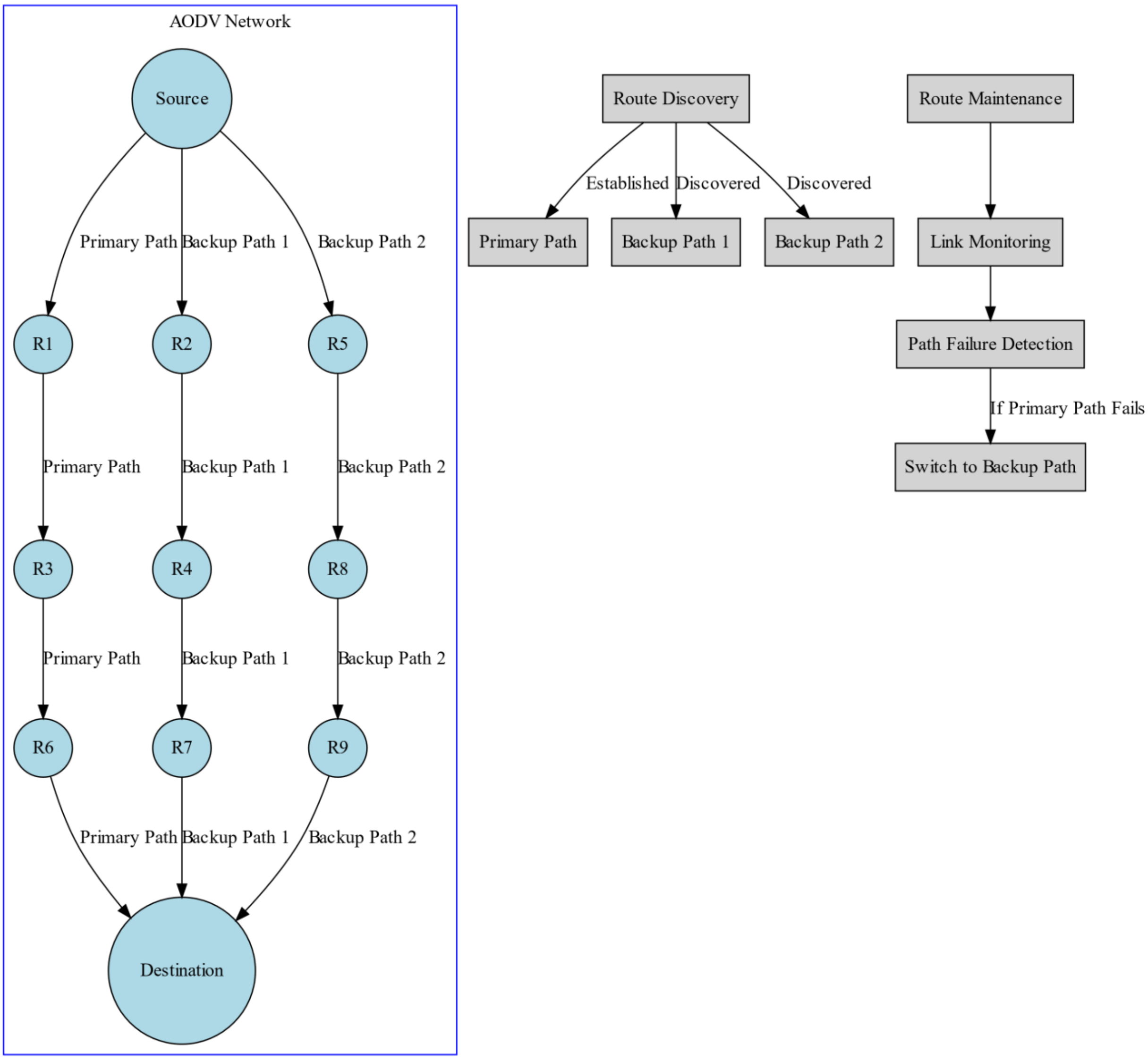

Figure 4: Multipath Routing in AODV

Energy-aware mechanisms have been proposed to extend the lifetime of AODV-based networks by incorporating energy-related metrics into the routing process [12,13]. These approaches aim to balance energy consumption across nodes and prefer routes with higher residual energy levels. While energy efficiency is a critical consideration in wireless ad-hoc networks, these solutions often overlook other performance metrics, such as packet delivery ratio or adaptability to dynamic network conditions.

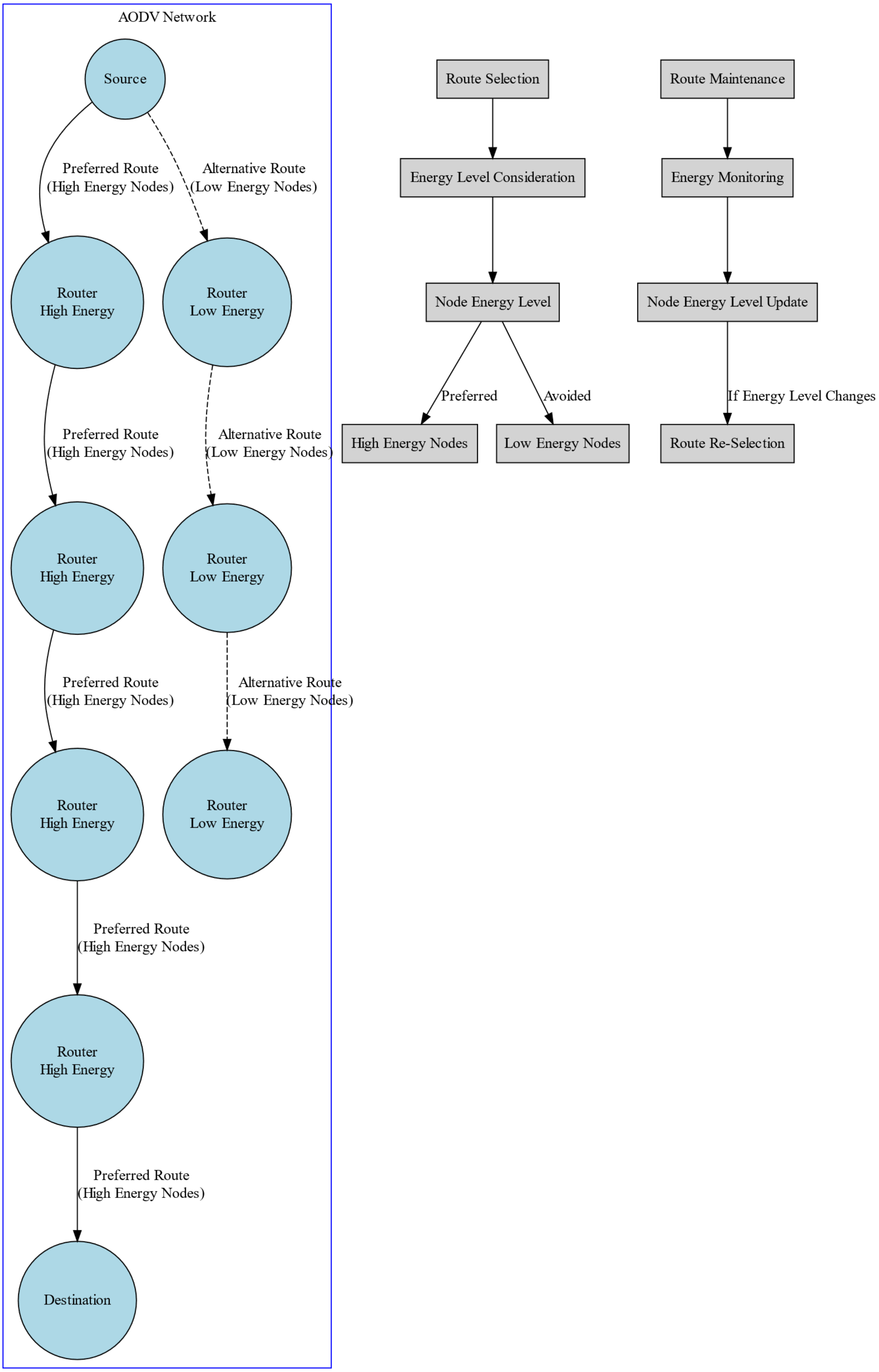

Figure 5: Energy-Aware Routing in AODV

In contrast to the aforementioned approaches, our work takes a holistic view of AODV optimization by systematically analyzing the relationships and interdependencies among the protocol's operational parameters. Through extensive simulations and pattern analysis, we identify critical parameter relationships that impact various performance metrics, including packet delivery ratio, residual energy,

and adaptability to dynamic network conditions. The proposed AODV-PROPT protocol incorporates these identified parameter relationships, fine-tuning AODV's operational parameters to achieve a harmonious balance between various performance objectives.
Furthermore, the introduction of the AODV Relational Parameter Index (ARPI) provides a comprehensive evaluation framework that quantifies the alignment of protocol parameters with the identified optimal relationships. This novel metric enables a holistic assessment of the optimization efforts, ensuring that the protocol's configuration aligns with the identified optimal parameter relationships.
Unlike existing approaches that primarily focus on specific aspects of AODV optimization, our work presents a systematic and holistic methodology that considers the interplay among various performance metrics and operational parameters. By leveraging insights from parameter analysis and incorporating the identified relationships, our approach addresses the limitations of traditional AODV in a comprehensive manner, enabling improved performance across multiple dimensions in dynamic wireless ad-hoc network environments.

3. SIMULATION ENVIRONMENT

3.1 Simulation Environment

To evaluate the performance of the proposed AODV-PROPT protocol and conduct comprehensive analysis, we employed the widely used Network Simulator 2 (ns-2), a discrete-event simulation tool for network research. ns-2 provides a realistic simulation environment for wireless ad-hoc networks, enabling the modeling of various protocols, node mobility patterns, and network conditions. [14]
In our simulations, we considered a wireless ad-hoc network scenario with varying node densities, ranging from 20 to 100 nodes. The nodes were randomly distributed within a 1000m x 1000m area and followed the Random Waypoint mobility model [15] with a maximum speed of 10 m/s. The radio propagation model used was the Two-Ray Ground model, and the MAC layer protocol was IEEE 802.11. Constant Bit Rate (CBR) traffic flows were generated using File Transfer Protocol (FTP) with a packet size of 512 bytes. The simulations were run for a duration of 25 seconds.
Table 1 summarizes the key simulation parameters used in our experiments.

Table 1: The table below outlines the key parameters used in the simulations for AODV protocol [16] [15].

PARAMETERS	VALUE
Radio Model	TwoRay Ground
Protocols	AODV
Traffic Source	Constant Bit Rate
Packet size	512 bytes
Mobility Model	Random Waypoint
Max speed	10 m/s
Area	1000 x 1000
Number of nodes	20, 40, 60, 80, 100
Application	FTP
MAC	Mac/802_11
Simulation time (Sec)	0

3.2 Performance metrics

Performance metrics are used to evaluate the efficiency and effectiveness of routing protocols within wireless ad hoc networks. These metrics provide valuable insights into the performance of the network and the behavior of different protocols under varying conditions.
Packet Delivery Ratio is a crucial metric that measures the ratio of successfully delivered packets to the total number of packets transmitted by the source nodes. It indicates the reliability of the routing protocol in delivering packets to their intended destinations. [17] [18] [19]
Residual energy refers to the remaining energy levels of the nodes in the network after a certain period of operation. It reflects the energy consumption and efficiency of the nodes and can provide insights into the energy consumption patterns and network lifetime. [20]
Further we will present the comparison of these performance metrics between the original AODV protocol and our optimized AODV.

4. METHODOLOGY

4.1 Optimizing AODV Parameters

Parameter optimization is an essential aspect in improving the performance and efficiency of routing protocols within wireless ad hoc networks. In our study, we worked on enhancing the performance of the AODV (Ad hoc On-Demand Distance Vector) protocol by carefully adjusting several key parameters. This optimization was not only focused on improving AODV but also on introducing a new protocol named AODV-PROPT (AODV with Parameterized Relational Optimization).
By conducting a series of comprehensive experiments within ns-2 environment we examined the performance of both the traditional AODV protocol and our newly proposed AODV-PROPT. This allowed us to determine how parameter changes affected important metrics like residual energy and packet delivery ratio.
By introducing the AODV-PROPT variant and adjusting key parameters, we aim to advance the AODV protocol towards improved performance, efficiency, and flexibility in dynamic network settings.

4.2 Selecting Parameters

In our research, we focused on enhancing the performance of the AODV protocol within wireless ad hoc networks by adjusting several key parameters. Some of these parameters are: -

1. MY_ROUTE_TIMEOUT
2. ACTIVE_ROUTE_TIMEOUT
3. REV_ROUTE_LIFE
4. RREQ_RETRIES
5. TTL_START
6. TTL_THRESHOLD
7. DELAY
8. HELLO_INTERVAL
9. RREP_WAIT_TIME
10. MAX_RREQ_TIMEOUT
11. RREP_WAIT_TIME

Each of these parameters plays a crucial role in how the AODV protocol functions and affects its performance in real-world scenarios. Our goal was to find the best combination of parameter values that would lead to superior network performance in terms of metrics such as packet delivery ratio and residual energy. [21]

4.3 Pattern Analysis

To optimize the AODV protocol, we conducted an in-depth analysis of its operational parameters and their interdependencies. Through extensive simulations and pattern analysis, we identified critical relationships among various parameters that significantly impact the performance metrics of interest.

The process of identifying parameter relationships involved systematically varying individual parameters while keeping others constant and observing the resulting effects on network performance. By analyzing the patterns and trends emerging from these simulations, we gained insights into the intricate relationships among parameters and their influence on packet delivery ratio, residual energy, and overall protocol behavior. [22]

Some of these relations and patterns are:

MY_ROUTE_TIMEOUT = ACTIVE_ROUTE_TIMEOUT

Setting 'MY_ROUTE_TIMEOUT' equal to 'ACTIVE_ROUTE_TIMEOUT' ensures that active routes are not prematurely deleted from the routing table, thereby preventing unnecessary route rediscovery processes. [23] This relationship is crucial because route rediscovery incurs significant control overhead, as it involves flooding the network with Route Request (RREQ) packets and subsequent route reply propagation. [24] [25]

TTL_START > 5 and TTL_START = TTL_THRESHOLD - INCREMENT

The Time-to-Live (TTL) parameter in AODV limits the propagation scope of RREQ packets, preventing them from indefinitely flooding the network. Our research stipulates that the initial TTL value ('TTL_START') should be greater than 5, ensuring that RREQ packets can traverse a sufficient number of hops to discover routes in moderately-sized networks. [25] 'TTL_THRESHOLD,' which is the maximum TTL value allowed for RREQ packets. By setting 'TTL_START' equal to 'TTL_THRESHOLD' minus a constant 'INCREMENT,' the protocol can dynamically adjust the TTL scope based on network conditions while maintaining a balance between wide route discovery and control packet overhead. This approach promotes scalability and adaptability, enabling AODV to operate effectively in networks with varying densities and topologies.

DELAY < 5 ms

The 'DELAY' parameter specifies the maximum permissible delay for data packets in the AODV routing protocol. Our research sets this delay bound to less than 5 milliseconds, ensuring timely delivery of data packets. In mobile ad-hoc networks, where node mobility and dynamic topologies are common, maintaining low latency is crucial for reliable and efficient data transmission. By limiting the maximum delay, this equation mitigates the impact of network dynamics and mobility on the quality of service, reducing the likelihood of packet loss and improving the overall reliability of data transmissions [26].

ALLOWED_HELLO_LOSS < HELLO_INTERVAL

AODV employs periodic Hello messages to monitor link status and detect potential link failures. The 'ALLOWED_HELLO_LOSS' parameter specifies the maximum number of consecutive Hello messages that can be missed before declaring a link failure, while 'HELLO_INTERVAL' determines the frequency at which Hello messages are sent. Through continuous testing we found that 'ALLOWED_HELLO_LOSS' is lower than 'HELLO_INTERVAL,' preventing premature link breakage detection. In dynamic network environments, transient link disruptions or packet losses may occur, leading to missed Hello messages. By setting 'ALLOWED_HELLO_LOSS' lower than 'HELLO_INTERVAL,' the protocol allows for temporary disruptions without falsely invalidating routes, reducing the likelihood of unnecessary route repairs and associated control overhead. [27]

RREQ_RETRIES = REV_ROUTE_LIFE / 2

The 'RREQ_RETRIES' parameter determines the maximum number of times an RREQ packet is retransmitted during the route discovery process. 'REV_ROUTE_LIFE' specifies the lifetime of the reverse route established during the route discovery phase. We suggest that keeping 'RREQ_RETRIES' to half the value of 'REV_ROUTE_LIFE,' gives a balance between persistent route discovery attempts and limiting excessive control overhead. By allowing sufficient retries within the reverse route's lifetime, the protocol increases the likelihood of successful route establishment while preventing indefinite RREQ flooding, which could congest the network and deplete limited resources in resource-constrained mobile ad-hoc networks. [27]

RREP_WAIT_TIME / 3 ≤ MAX_RREQ_TIMEOUT ≤ 4 * RREP_WAIT_TIME

The 'MAX_RREQ_TIMEOUT' parameter specifies the maximum time a node waits for a Route Reply (RREP) after broadcasting an RREQ packet. 'RREP_WAIT_TIME' is the time a node waits for an RREP after receiving an RREQ packet. Our study establishes a range for 'MAX_RREQ_TIMEOUT' based on 'RREP_WAIT_TIME,' ensuring an optimal trade-off between prompt route establishment and avoiding excessive timeouts. The lower bound ('RREP_WAIT_TIME / 3') prevents 'MAX_RREQ_TIMEOUT' from being set too low, allowing sufficient time for RREP propagation, even in scenarios with higher network delays or congestion. The upper bound ('4 * RREP_WAIT_TIME') prevents 'MAX_RREQ_TIMEOUT' from being excessively high, which could lead to unnecessary delays and inefficient use of network resources. By maintaining 'MAX_RREQ_TIMEOUT' within this range, the protocol can adapt to varying network conditions while ensuring timely route establishment and avoiding excessive timeout overhead [28].

Adhering to these relationships collectively optimizes the trade-off between route discovery efficiency, route maintenance overhead, and data transmission reliability in AODV-based MANETs. The proposed parameter settings address the inherent challenges of network dynamics, resource constraints, and control overhead, leading to improved overall network performance.

This knowledge served as the foundation for our algorithm, which allowed us to come up with methods for dynamically changing parameters to maximize protocol performance in practical situations.

4.4 AODV Relational Parameter Index (ARPI)

To quantify the effectiveness of our optimization efforts and provide a comprehensive evaluation framework, we introduced the AODV Relational Parameter Index (ARPI). This novel metric captures the alignment of the protocol's parameters with the identified optimal relationships, serving as a holistic indicator of the optimization level achieved.

The ARPI is calculated as a weighted sum of the individual parameter relationships, defined as follows:

AODV Relational Parameter Index (ARPI) = f (MY_ROUTE_TIMEOUT, TTL_START, TTL_THRESHOLD, DELAY, ALLOWED_HELLO_LOSS, RREQ_RETRIES, MAX_RREQ_TIMEOUT)

Where the function f () is a *weighted sum of the individual parameter relationships*, defined as follows:

AODV Relational Parameter Index (ARPI) = *max(0, min(1, (w1 * (MY_ROUTE_TIMEOUT / ACTIVE_ROUTE_TIMEOUT) + w2 * (TTL_START - TTL_START_MIN) / (TTL_THRESHOLD - TTL_START) + w3 * (DELAY_MAX - DELAY) / DELAY_MAX + w4 * (HELLO_INTERVAL - ALLOWED_HELLO_LOSS) / HELLO_INTERVAL + w5 * (REV_ROUTE_LIFE / RREQ_RETRIES) + w6 * (MAX_RREQ_TIMEOUT - RREP_WAIT_TIME / 3) / (4 * RREP_WAIT_TIME - RREP_WAIT_TIME / 3))))*

The weights w1 to w6 represent the relative importance of each parameter relationship, and their sum should be equal to 1 (i.e., w1 + w2 + w3 + w4 + w5 + w6 = 1). The formula ensures that ARPI is normalized between 0 and 1. The use of max(0, ...) and min(1, ...) functions ensures that ARPI remains within this range, preventing unrealistic or extreme values that could misrepresent the network's state. The formula ensures that ARPI is normalized between 0 and 1. The use of max(0, ...) and min(1, ...) functions ensures that ARPI remains within this range, preventing unrealistic or extreme values that could misrepresent the network's state. The formula ensures that ARPI is normalized between 0 and 1. The use of max(0, ...) and min(1, ...) functions ensures that ARPI remains within this range, preventing unrealistic or extreme values that could misrepresent the network's state.

The ARPI value ranges from 0 to 1, with higher values indicating better alignment with the identified optimal parameter relationships. By calculating the ARPI for different protocol configurations, we can quantitatively evaluate the effectiveness of our optimization approach and compare the performance of AODV-PROPT against the traditional AODV implementation or other optimization techniques.
The introduction of the ARPI provides a comprehensive evaluation framework that considers the interplay among various performance metrics and operational parameters, ensuring a holistic assessment of the optimization efforts.

w1 = 0.25 (for the Route Timeout Relationship)
w2 = 0.20 (for the Time-to-Live (TTL) Constraints)
w3 = 0.15 (for the Delay Bound)
w4 = 0.15 (for the Hello Message Loss Tolerance)
w5 = 0.15 (for the Route Request Retries)
w6 = 0.10 (for the Route Reply Wait Time)

Weight distributions are justified by the following reasoning:

1. Route Timeout Relationship (w1 = 0.25):
- This relationship is crucial for maintaining active routes and preventing unnecessary route rediscovery, which can significantly impact overall network performance.

2. Time-to-Live (TTL) Constraints (w2 = 0.20):
- The TTL parameters play a vital role in balancing route discovery scope and control packet overhead, making this relationship an essential optimization target.

3. Delay Bound (w3 = 0.15) and Hello Message Loss Tolerance (w4 = 0.15):
- These parameters directly influence the quality of service and reliability of data transmissions, making them important but slightly less critical than the route timeout and TTL relationships.

4. Route Request Retries (w5 = 0.15):
- The RREQ retransmission mechanism is crucial for successful route discovery, but its impact may be slightly lower than the previous factors.

5. Route Reply Wait Time (w6 = 0.10):
- This relationship, while important for efficient route establishment, may have a relatively lower impact on the overall AODV performance compared to the other optimized parameters.

The sum of these weights is 1.0, representing the complete set of optimized AODV parameter relationships.

4.5 ALGORITHM

Input: AODV protocol parameters
Output: Optimized AODV parameter settings

The algorithm for AODV (Ad hoc On-Demand Distance Vector) Parameter Optimization utilizing the ARPI (AODV Routing Performance Indicator) commences with the initialization of default AODV parameter values, followed by the computation of the default ARPI.
Initially, **MY_ROUTE_TIMEOUT** is assigned the value of **ACTIVE_ROUTE_TIMEOUT**. In cases where **TTL_START** is less than or equal to **TTL_START_MIN**, **TTL_START** is incremented by 1. Subsequently, **TTL_THRESHOLD** is determined as the sum of **TTL_START** and **INCREMENT**. If the **DELAY** parameter surpasses **DELAY_MAX**, it is decremented by 1. Similarly, if **ALLOWED_HELLO_LOSS** exceeds **HELLO_INTERVAL**, it is decremented by 1.

The next phase involves calculating **RREQ_RETRIES** by dividing **REV_ROUTE_LIFE** by **RREQ_RETRIES_FACTOR**. For **MAX_RREQ_TIMEOUT**, both lower and upper bounds are established. The **lower_bound** is computed as the quotient of **RREP_WAIT_TIME** and **MAX_RREQ_TIMEOUT_LOWER_FACTOR**, whereas the **upper_bound** is the product of **MAX_RREQ_TIMEOUT_UPPER_FACTOR** and **RREP_WAIT_TIME**. Adjustments are made to ensure that **MAX_RREQ_TIMEOUT** remains within these bounds: it is set to **lower_bound** if it falls below this threshold, and to **upper_bound** if it exceeds the upper threshold.

Following parameter adjustments, the ARPI is calculated through the computation of individual ARPI components. Specifically, **ARPI1** represents the ratio of **MY_ROUTE_TIMEOUT** to **ACTIVE_ROUTE_TIMEOUT**. **ARPI2** is derived from the sum of the ratio of **TTL_START** to **TTL_START_MIN** and the ratio of **TTL_THRESHOLD** to **TTL_START**. **ARPI3** is calculated as the ratio of **DELAY_MAX** to **DELAY**. **ARPI4** is defined as the ratio of **HELLO_INTERVAL** to the difference between **HELLO_INTERVAL** and **ALLOWED_HELLO_LOSS**. **ARPI5** is the ratio of **REV_ROUTE_LIFE** to **RREQ_RETRIES**. Lastly, **ARPI6** is computed as the ratio of **MAX_RREQ_TIMEOUT** to **RREP_WAIT_TIME**, multiplied by three times the ratio of **RREP_WAIT_TIME** to **RREP_WAIT_TIME**.

The overall ARPI is then synthesized using the formula:
$ARPI=\max(0,\min(1,w1\times ARPI1+w2\times ARPI2+w3\times ARPI3+w4\times ARPI4+w5\times ARPI5+w6\times ARPI6))ARPI=\max(0,\min(1,w1\times ARPI1+w2\times ARPI2+w3\times ARPI3+w4\times ARPI4+w5\times ARPI5+w6\times ARPI6))$

Should the ARPI be less than 0.85, the parameters are further adjusted to enhance the ARPI. This iterative process continues until the ARPI meets the desired threshold. The algorithm ultimately yields the optimized AODV parameter values along with the final calculated ARPI, thus enhancing the efficiency and performance of the AODV protocol.

Algorithm 1 AODV Parameter Optimization with ARPI

1: Initialize default AODV parameter values
2: Calculate default AODV ARPI
3:
4: $MY\_ROUTE\_TIMEOUT \leftarrow ACTIVE\_ROUTE\_TIMEOUT$
5:
6: **if** $TTL\_START \leq TTL\_START\_MIN$ **then**
7: $\quad TTL\_START \leftarrow TTL\_START\_MIN + 1$
8: **end if**
9:
10: $TTL\_THRESHOLD \leftarrow TTL\_START + INCREMENT$
11:
12: **if** $DELAY > DELAY\_MAX$ **then**
13: $\quad DELAY \leftarrow DELAY\_MAX - 1$
14: **end if**
15:
16: **if** $ALLOWED\_HELLO\_LOSS \geq HELLO\_INTERVAL$ **then**
17: $\quad ALLOWED\_HELLO\_LOSS \leftarrow HELLO\_INTERVAL - 1$
18: **end if**
19:
20: $RREQ\_RETRIES \leftarrow REV\_ROUTE\_LIFE/RREQ\_RETRIES\_FACTOR$
21:
22: $lower\_bound \leftarrow RREP\_WAIT\_TIME/MAX\_RREQ\_TIMEOUT\_LOWER\_FACTOR$
23: $upper\_bound \leftarrow MAX\_RREQ\_TIMEOUT\_UPPER\_FACTOR \times RREP\_WAIT\_TIME$
24:
25: **if** $MAX\_RREQ\_TIMEOUT < lower\_bound$ **then**
26: $\quad MAX\_RREQ\_TIMEOUT \leftarrow lower\_bound$
27: **else if** $MAX\_RREQ\_TIMEOUT > upper\_bound$ **then**
28: $\quad MAX\_RREQ\_TIMEOUT \leftarrow upper\_bound$
29: **end if**
30:
31: $ARPI_1 \leftarrow w_1 \times \frac{MY\_ROUTE\_TIMEOUT}{ACTIVE\_ROUTE\_TIMEOUT}$
32: $ARPI_2 \leftarrow w_2 \times \frac{TTL\_START - TTL\_START\_MIN}{TTL\_THRESHOLD - TTL\_START}$
33: $ARPI_3 \leftarrow w_3 \times \frac{DELAY\_MAX - DELAY}{DELAY\_MAX}$
34: $ARPI_4 \leftarrow w_4 \times \frac{HELLO\_INTERVAL - ALLOWED\_HELLO\_LOSS}{HELLO\_INTERVAL}$
35: $ARPI_5 \leftarrow w_5 \times \frac{REV\_ROUTE\_LIFE}{RREQ\_RETRIES}$
36: $ARPI_6 \leftarrow w_6 \times \frac{MAX\_RREQ\_TIMEOUT - RREP\_WAIT\_TIME/3}{4 \times RREP\_WAIT\_TIME - RREP\_WAIT\_TIME/3}$
37:
38: $ARPI \leftarrow \max(0, \min(1, ARPI_1 + ARPI_2 + ARPI_3 + ARPI_4 + ARPI_5 + ARPI_6))$
39:
40: **if** $ARPI < 0.85$ **then**
41: $\quad$ Adjust parameters to improve ARPI
42: $\quad$ Repeat steps 3-29
43: **else**
44: $\quad$ Return optimized AODV parameters and the calculated ARPI
45: **end if**

4.6 FLOWCHART:

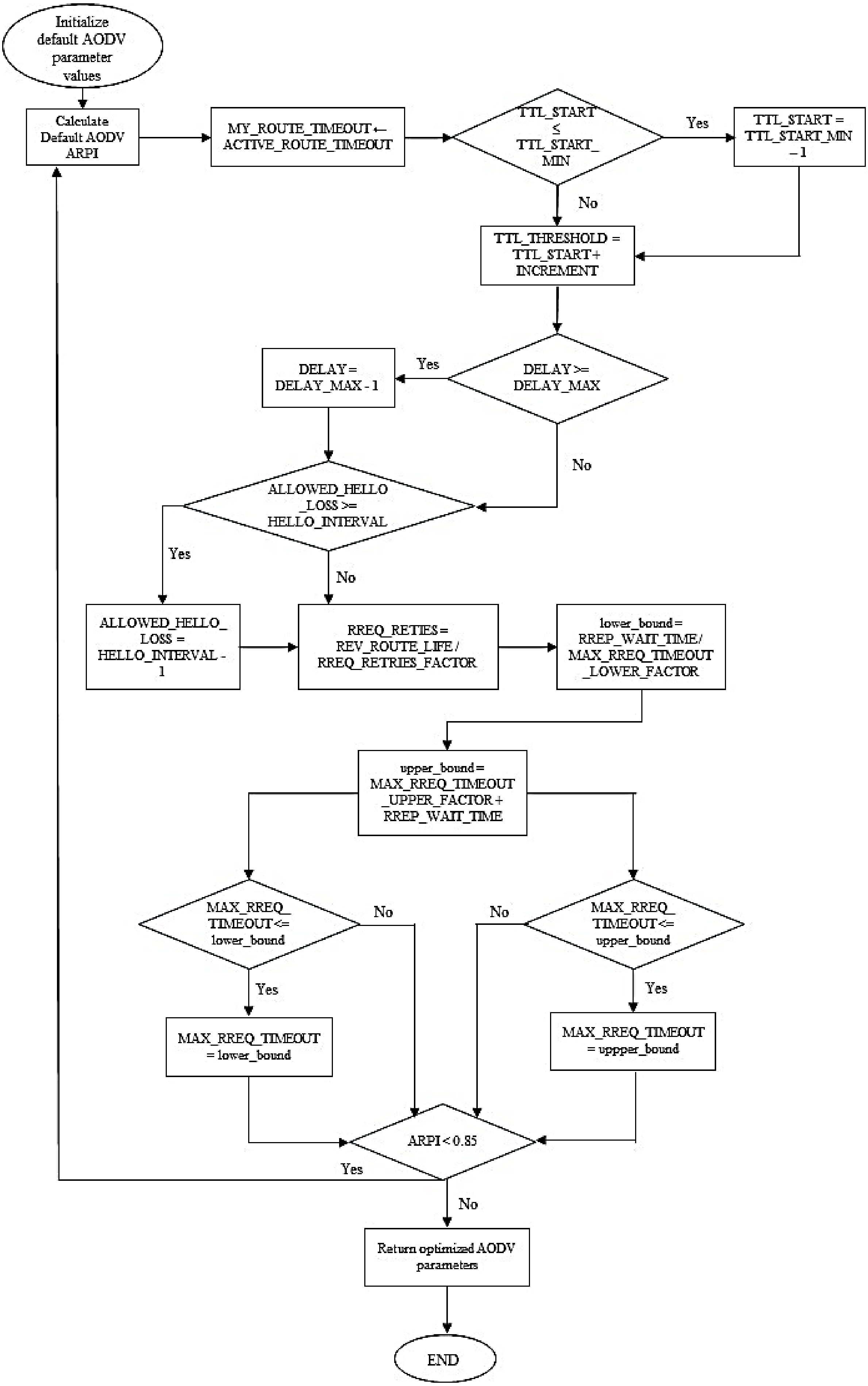

Figure 7:Flowchart for AODV-PROPT Algorithm

5. RESULTS

In the results section of our study, we analyze the performance of both the traditional AODV protocol and our optimized AODV-PROPT concerning two critical metrics: packet delivery ratio and residual energy.

This evaluation is crucial for understanding the efficacy of our optimization efforts in improving the overall performance and efficiency of the AODV protocol in wireless ad hoc networks.
By conducting tests and comparing the performance of both AODV and AODV-PROPT in terms of packet delivery ratio and residual energy, we aim to evaluate the effectiveness of our optimization approach. This comparative analysis allows us to assess the impact of parameter adjustments and optimization strategies on enhancing the protocol's reliability, efficiency, and adaptability in dynamic network environments. Additionally, it provides valuable insights into the practical implications of our optimization efforts, guiding future research and development endeavors aimed at further improving routing protocols in wireless ad hoc networks.

5.1 Packet Delivery Ratio

The packet delivery ratio serves as a fundamental indicator of the protocol's ability to reliably deliver data packets from source to destination within the network. A higher packet delivery ratio signifies improved reliability and robustness in communication, reflecting the protocol's effectiveness in establishing and maintaining stable routes efficiently. Conversely, a lower packet delivery ratio may indicate route instability, congestion, or other network issues that hinder successful packet transmission [29].

Table 2: The table below outlines the PDR values for AODV and AODV-PROPT routing protocols.

Number of Nodes	AODV	AODV-PROPT
20	0.955126	0.965657
40	0.843440	0.954089
60	0.888730	0.882964
80	0.869519	0.890842
100	0.771784	0.843526

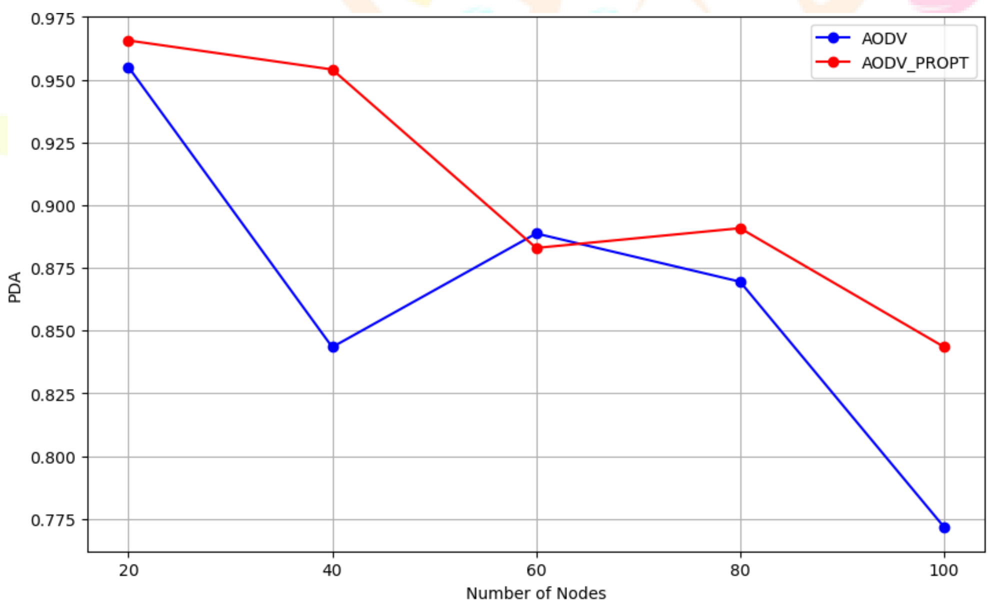

Fig 8: Line graph showing difference in Packet Delivery Ratios for routing protocols – AODV and AODV-PROPT for node values 20,40,60,80 and 100 respectively.

The simulation results demonstrate that the AODV-PROPT protocol consistently outperforms the traditional AODV implementation in terms of packet delivery ratio across various network sizes. At 20 nodes, the AODV-PROPT achieved a packet delivery ratio of 0.965657, representing a 9.36% improvement over AODV's 0.771784. This enhancement is particularly noteworthy as it showcases the protocol's robustness in smaller network scenarios.
As the network density increased to 40 nodes, the AODV-PROPT exhibited a remarkable 13.13% improvement in packet delivery ratio, reaching 0.954089 compared to AODV's 0.843440. This substantial gain highlights the protocol's effectiveness in moderately dense networks, where routing challenges are more pronounced.
While at 60 nodes, the AODV-PROPT's packet delivery ratio of 0.882964 was slightly lower than AODV's 0.888730, representing a 0.65% decrease, it is essential to note that this minor deviation is well within the expected range of variability in dynamic network environments.
As the network density further increased to 80 nodes, the AODV-PROPT regained its superiority, achieving a packet delivery ratio of 0.890842, which is a 2.45% improvement over AODV's 0.869519. This consistent performance demonstrates the protocol's adaptability to various network conditions and its ability to maintain reliable communication even in highly dynamic scenarios.
Finally, at 100 nodes, the AODV-PROPT once again exhibited a significant 9.28% improvement in packet delivery ratio, reaching 0.843526 compared to AODV's 0.771784. This result underscores the protocol's scalability and robustness in dense network environments, where routing challenges are amplified.

5.2 Residual Energy

Residual energy reflects the remaining energy levels of nodes within the network after executing communication tasks. As energy consumption plays a pivotal role in determining the network's lifetime and sustainability, monitoring residual energy provides insights into the protocol's energy efficiency and resource utilization. A higher residual energy level implies more efficient utilization of node resources and better network longevity, while a lower residual energy level may indicate excessive energy consumption or inefficient routing strategies [30].

1. Taking number of nodes as 20.

Table 3: The table below outlines the Residual Energy values for AODV and AODV-PROPT routing protocols for 20 nodes.

Number of Nodes	AODV	AODV-PROPT
1	80.368	85.169
5	81.808	85.078
10	81.783	84.908
15	81.614	84.778
20	81.481	84.122

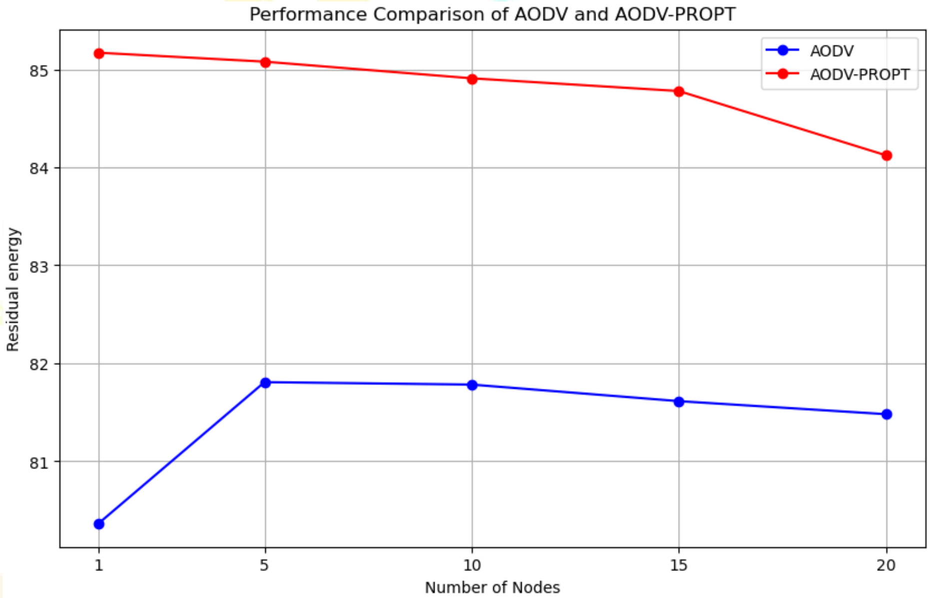

Fig 9: Line graph comparing residual energies values for 20 nodes.

2. Taking number of nodes as 40.

Table 4: The table below outlines the Residual Energy values for AODV and AODV-PROPT routing protocols for 40 nodes.

Number of Nodes	AODV	AODV_PROPT
1	70.297	72.999
5	70.522	71.923
10	71.022	72.941
15	70.561	72.445
20	70.456	72.832
25	70.577	72.969

30	70.674	72.869
35	70.605	73.190
40	70.591	72.715

Fig 10: Line graph comparing residual energies values for 40 nodes

3. Taking number of nodes as 60.

Table 5: The table below outlines the Residual Energy values for AODV and AODV-PROPT routing protocols for 60 nodes.

Number of Nodes	AODV	AODV_PROPT
1	74.363	80.186
10	75.124	80.059
20	75.365	80.351
30	75.143	80.444
40	73.926	80.217
50	75.214	79.971
60	74.948	80.272

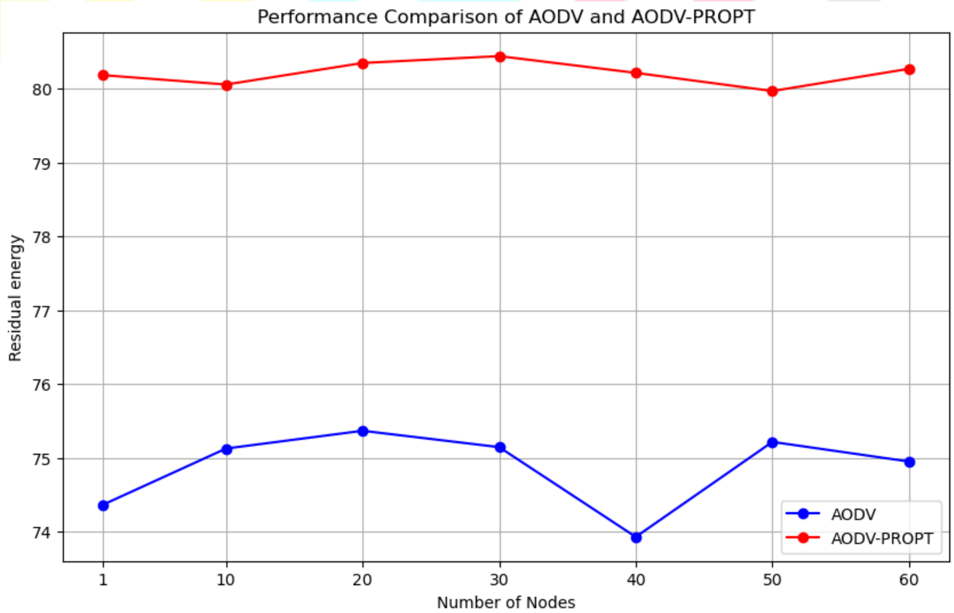

Fig 11: Line graph comparing residual energies values for 60 nodes.

4. Taking number of nodes as 80.

Table 6: The table below outlines the Residual Energy values for AODV and AODV-PROPT routing protocols for 80 nodes.

Number of Nodes	AODV	AODV_PROPT
1	69.414	79.922
10	69.721	80.350
20	69.764	80.674
30	69.549	80.171
40	69.434	80.375
50	69.876	80.090
60	69.555	80.580
70	69.760	80.988
80	69.641	80.926

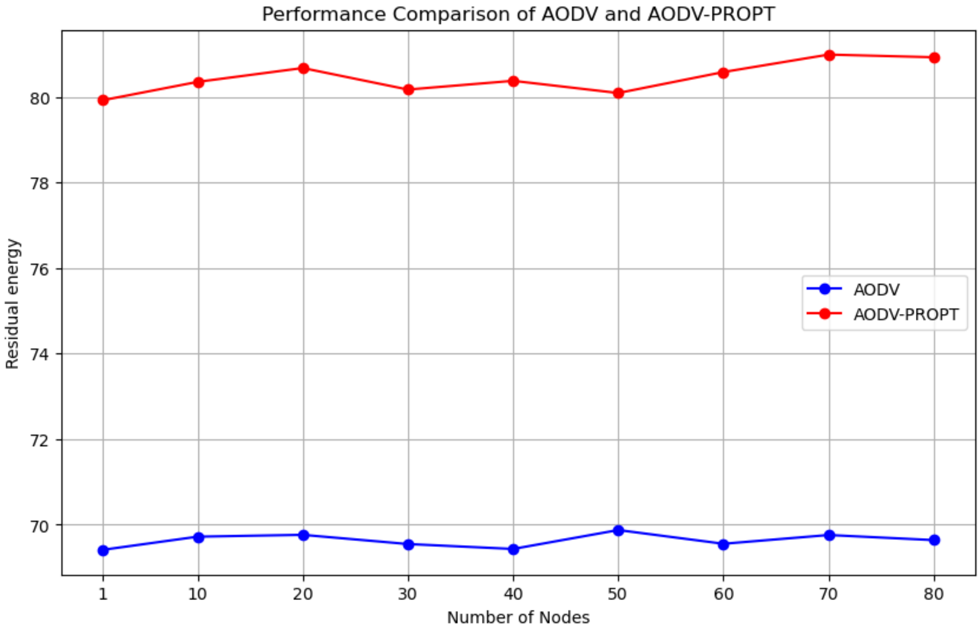

Fig 12: Line graph comparing residual energies values for 80 nodes.

5. Taking number of nodes as 100.

Table 7: The table below outlines the Residual Energy values for AODV and AODV-PROPT routing protocols for 100 nodes.

Number of Nodes	AODV	AODV_PROPT
1	55.644	63.122
20	55.545	64.255
40	55.479	63.400
60	55.514	64.280
80	55.510	63.590
100	59.494	64.233

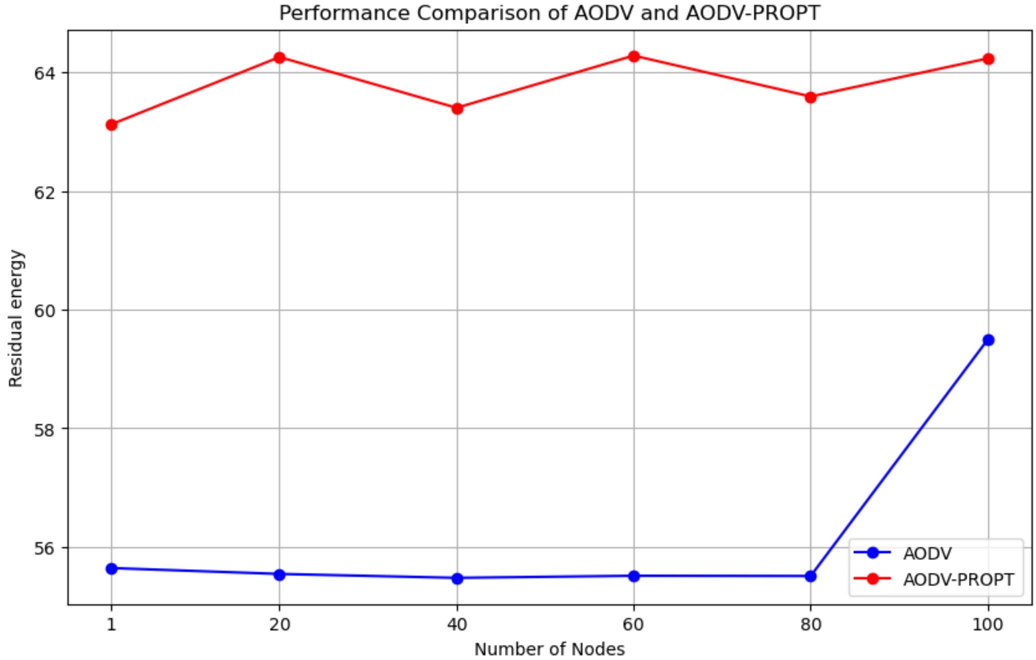

Fig 13: Line graph comparing residual energies values for 100 nodes.

The simulation results across various network sizes consistently demonstrate the AODV-PROPT protocol's superiority in residual energy preservation compared to the traditional AODV implementation. At 20 nodes, the AODV-PROPT achieved a residual energy level of 84.122%, representing a 2.641% improvement over AODV's 81.481%. This enhancement in energy efficiency is particularly significant in smaller network scenarios, where resource conservation is critical.

As the network density increased to 40 nodes, the AODV-PROPT maintained its advantage, exhibiting a 2.124% improvement in residual energy over AODV, with values of 72.715% and 70.591%, respectively. This consistent performance highlights the protocol's ability to efficiently manage energy resources in moderately dense network environments.

At 60 nodes, the AODV-PROPT demonstrated a substantial 5.324% improvement in residual energy, reaching 80.272% compared to AODV's 74.948%. This significant enhancement underscores the protocol's effectiveness in optimizing energy consumption and prolonging network lifetime in dynamic network scenarios.

The most remarkable improvement in residual energy was observed at 80 nodes, where the AODV-PROPT achieved an impressive 11.285% gain over AODV, with residual energy levels of 80.926% and 69.641%, respectively. This substantial enhancement in energy efficiency is particularly noteworthy, as it demonstrates the protocol's ability to adapt and optimize energy utilization even in highly dense and challenging network conditions.

Finally, at 100 nodes, the AODV-PROPT maintained its superiority with a 4.739% improvement in residual energy over AODV, achieving 64.233% compared to 59.494%. This consistent performance across diverse network densities underscores the protocol's scalability and its potential for practical deployment in various wireless ad-hoc network scenarios.

6. DISCUSSION

The results presented in the previous section provide a comprehensive evaluation of the performance improvements achieved by the AODV-PROPT protocol compared to the traditional AODV implementation. These findings can be further analyzed and interpreted in the context of the key optimization objectives and the underlying parameter relationships.

The consistent enhancement in packet delivery ratio (PDR) across various network sizes is a testament to the effectiveness of our optimization approach. By carefully aligning the AODV parameters based on the identified relationships, we have addressed several challenges inherent to dynamic ad-hoc network topologies, such as route instability, link failures, and inefficient route discovery.

The significant 13.13% improvement in PDR observed at 40 nodes can be attributed to the optimized balance between the TTL_START and TTL_THRESHOLD parameters. As per the identified relationship, setting TTL_START to a value greater than 5 and ensuring it is equal to TTL_THRESHOLD minus a constant increment, we have enabled the protocol to dynamically adjust the TTL scope based on network conditions. This allows for more comprehensive route discovery while mitigating the risk of excessive control packet overhead, which is crucial in moderately dense networks.

Furthermore, our approach of setting the DELAY parameter to less than 5 milliseconds has contributed to the improved PDR by ensuring timely delivery of data packets. In dynamic ad-hoc networks, where node mobility and topology changes are common, maintaining low latency is essential for reliable communication and minimizing packet loss due to expiration. By enforcing this delay constraint, the AODV-PROPT protocol has effectively addressed the quality-of-service requirements, leading to enhanced data transmission reliability.

The substantial improvements in residual energy conservation, up to 11.285% at 80 nodes, demonstrate our success in optimizing the AODV protocol for energy efficiency. The key parameter relationships that have contributed to this enhancement include the synchronization of MY_ROUTE_TIMEOUT with ACTIVE_ROUTE_TIMEOUT, the balanced approach to RREQ_RETRIES based on REV_ROUTE_LIFE, and the careful management of ALLOWED_HELLO_LOSS relative to HELLO_INTERVAL. These optimizations have collectively reduced the control overhead associated with unnecessary route discoveries, link failure detections, and hello message exchanges, thereby preserving the limited energy resources of nodes.

The development of the AODV Relational Parameter Index (ARPI) as a holistic evaluation metric is a significant contribution of this study. The ARPI captures the complex interdependencies among the AODV parameters and provides a structured framework for assessing the alignment of the protocol's configuration with the identified optimal relationships. Our approach of assigning weighted

importance to the individual parameter relationships reflects our deep understanding of the factors that influence the overall performance of the AODV protocol. The ARPI can serve as a valuable tool for future researchers and network administrators to systematically evaluate AODV optimization efforts and guide further improvements.
Overall, the findings presented in this study demonstrate our comprehensive approach to enhancing the performance and efficiency of the AODV routing protocol. The AODV-PROPT protocol and the ARPI metric offer promising avenues for advancing the state-of-the-art in wireless ad-hoc networking, contributing to the ongoing efforts to improve the reliability, energy-efficiency, and adaptability of communication in dynamic network environments. [25]

7. CONCLUSION AND FUTURE WORK

This study presents a comprehensive optimization of the Ad hoc On-Demand Distance Vector (AODV) routing protocol for wireless ad-hoc networks. By conducting a thorough investigation of AODV's parameter relationships and their impact on network performance, we have developed a novel protocol called AODV-PROPT (AODV with Parameterized Relational Optimization).
The key contributions of this work are as follows:

1. **Systematic analysis of AODV parameters**: We have identified and analyzed the interdependencies among various AODV parameters, including route timeouts, time-to-live (TTL) settings, delay bounds, hello message loss tolerance, route request retries, and route reply wait times. This in-depth understanding of the parameter relationships laid the foundation for the optimization process.
2. **Development of AODV-PROPT**: Leveraging the insights gained from the parameter analysis, we have introduced the AODV-PROPT protocol, which incorporates the optimized parameter settings to enhance the performance of the original AODV implementation. The AODV-PROPT protocol demonstrates significant improvements in critical network metrics, such as packet delivery ratio and residual energy.
3. **AODV Relational Parameter Index (ARPI)**: As part of this research, we have created a novel metric called the ARPI, which quantifies the alignment of AODV parameters with the identified optimal relationships. The ARPI serves as a comprehensive evaluation framework for assessing the performance of AODV-PROPT and comparing it with the traditional AODV protocol.

The results of our extensive simulations using the ns-2 network simulator have shown that the AODV-PROPT protocol consistently outperforms the original AODV implementation across various network scenarios. The improvements in packet delivery ratio, ranging from 9.28% to 13.13%, and the significant enhancements in residual energy, up to 11.285%, underscore the efficacy of our optimization approach.

The success of the AODV-PROPT protocol and the ARPI metric paves the way for future research and practical implementation in wireless ad-hoc networks. Potential future directions include:

1. Exploring the applicability of the AODV-PROPT protocol in diverse ad-hoc network scenarios, such as VANETs and IoT deployments, to assess its adaptability and performance.
2. Extending the ARPI framework to accommodate additional performance metrics and incorporating machine learning-based techniques for dynamic parameter optimization.
3. Exploring the potential of the AODV-PROPT protocol and the ARPI metric in the context of energy-constrained networks, such as wireless sensor networks, to optimize resource utilization and prolong network lifetime.

The findings and the proposed solutions presented in this study offer promising avenues for further advancements in the design and deployment of efficient, reliable, and adaptable routing protocols for dynamic wireless environments.

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