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Performance Comparison of Routing Protocols for Mobile and Stationary WSNs

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Abstract

Wireless Sensor Networks (WSNs) serve as vital elements in the landscape of Internet of Things (IoT) applications, environmental monitoring, and emergency response systems. Efficient routing protocols are critical for reliable data delivery and energy conservation in WSNs. This research examines routing protocols, specifically the ad-hoc On-Demand Distance Vector (AODV) and the Destination-Sequenced Distance Vector (DSDV) in both Stationary WSNs (SWSNs) and Mobile WSNs (MWSNs). Using the NS-2 simulator, we analysed the network performance under varying node densities (20–60 nodes) and calculated the link budget to ensure connectivity. The metrics encompass throughput, packet delivery ratio, E2E delay, and energy consumption. Statistical analysis using t-tests was used to evaluate the performance differences under random node placement and mobility patterns. The results indicate that AODV outperforms DSDV in SWSNs, whereas both protocols perform comparably in MWSNs. These findings provide guidance for selecting routing protocols based on network mobility and application requirements.

1. Introduction

Wireless ad-hoc networks enable communication without fixed infrastructure [1, 13]. Nodes route and forward data, supporting applications such as disaster recovery, military operations, and Internet of Things (IoT) systems. Wireless Sensor Networks (WSNs) are specialized ad-hoc networks composed of small, cost-efficient nodes capable of sensing, processing, and transmitting environmental data (e.g., temperature, humidity, and motion) (Figure 1). While several studies have compared ad-hoc On-Demand Distance Vector (AODV) and Destination-Sequenced Distance Vector (DSDV) in MANET environments, limited research has conducted a controlled side-by-side evaluation of these protocols under identical simulation settings in both stationary and mobile WSN scenarios [2]. Our study addresses this gap by providing a

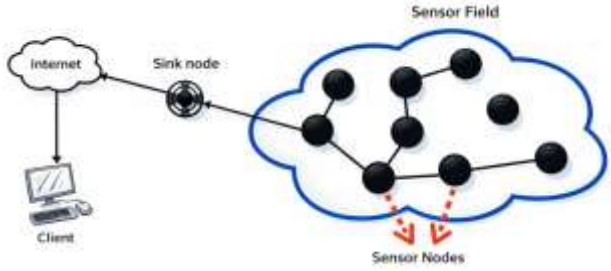


Figure 1. WSN network structure.

comparative statistical analysis across both environments.

1.1 Mobile vs Stationary Wireless Sensor Networks

WSNs can be stationary (SWSNs) or mobile (MWSNs) [3]. SWSNs have fixed nodes, allowing deterministic link budgets and network planning. MWSNs introduce random mobility, causing variability in connectivity and received signal strength [22]. WSNs are characterized by limited energy, dense deployment, constrained storage, self-organization, and fault tolerance [4, 15]. These characteristics influence routing design, particularly in maintaining reliable connectivity and minimizing energy consumption [5].

2. Routing Protocols

Routing protocols govern how data packets traverse the network [24]. Although AODV and DSDV routing protocols were originally designed for Mobile Ad Hoc Networks (MANETs) [6], this study evaluates their performance under WSN constraints to investigate their suitability in both stationary and mobile sensor environments [7].

2.1 Ad-hoc On-Demand Distance-Vector

Ad-hoc On-Demand Distance-Vector (AODV) establishes routes on-demand using sequence numbers to maintain loop-free paths. Routes are discovered via Route Requests (RREQs), and Route Replies (RREPs) are returned by intermediate nodes if a path exists. Route failures trigger Route Error (RERR) messages [8]. The AODV route discovery and route maintenance process is illustrated in Figure 2. AODV is effective in both SWSNs and MWSNs, providing higher throughput and lower latency in mobile scenarios [5,6].

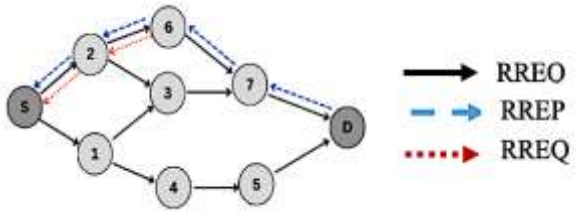


Figure 2. AODV overview structure.

2.2 DSDV (Destination-Sequenced Distance-Vector)

DSDV is a **proactive protocol** using the Bellman-Ford algorithm. Each node periodically broadcasts its routing table, selecting routes with the lowest hop count and updating using sequence numbers. DSDV exhibits low control overhead and reliable packet delivery [9, 10].

Figure 3 shows the DSDV architecture. Nodes periodically exchange hello messages to disseminate updated routing information. Upon receiving these messages, each node updates its routing table [11]. This periodic update ensures adaptability to changes in the network topology. DSDV performs reliably with low control overhead and stable packet delivery in scenarios with moderate mobility. Numerous routing protocols employ diverse algorithms to identify the optimal routes for directing packets to their intended destinations. Table 1 summarises a comparative analysis of routing algorithms utilised by various proactive and reactive routing protocols [12].

3. Simulation Framework

A shorter simulation duration of 30 seconds was selected due to computational constraints. However, each scenario was repeated 10

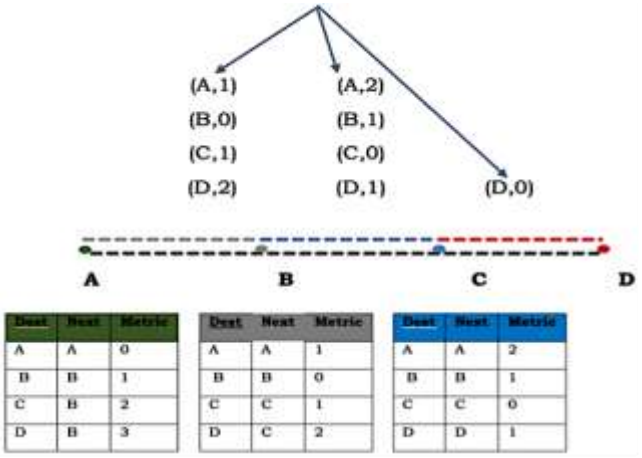


Figure 3. DSDV overview structure.

Table 1. Routing algorithms.

No	Routing algorithm comparisons for DSDV and AODV		
	Parameters	AODV	DSDV
1	Routing category	Reactive	Proactive
2	Routing	Hop-to-Hop (Multi-Route)	Hop-to-hop (single route)
3	Route selection	Destination Sequence Number Shortest path	Sequence number Link State
4	Route update	Neighbor node	Neighbour node
5	Update frequency	On demand	Periodical

independent times to ensure statistical reliability and reduce variability.

This simulation-based evaluation aims to fill the existing research gap by offering a side-by-side comparison of AODV and DSDV in both SWSNs and MWSNs, which is often overlooked in prior literature [3].

3.1 Simulation Parameters

The simulation was carried out using NS-2 with a set of parameters selected to represent the network conditions considered in this study. Table 2 summarizes values adopted for each parameter covering the network configuration, mobility, communication, traffic, energy, and routing settings used throughout the experiments.

The NS-2 Energy Model was configured with transmission power of 0.1 W. The receive power and idle power were set according to default NS-2 wireless energy parameters. Each node was initialized with 5 Joules of energy.

In the MWSN scenario, node speeds were uniformly distributed between 1 m/s and 10 m/s with zero pause time. In the SWSN scenario, node mobility was disabled (speed = 0 m/s).

These simulations were performed over predefined time intervals (Table 2), allowing for a comprehensive analysis of the network behaviors within these temporal boundaries. Multiple simulation iterations were conducted for each scenario to enhance the reliability and validity of the findings. This iterative approach was essential for mitigating potential variations in network conditions, thereby providing robustness to our research outcomes. This stepwise procedure ensured that our conclusions were rooted in a thorough examination of diverse network dynamics and performance characteristics.

3.2 Link Budget and Node Density

To ensure connectivity, the maximum node range was calculated using the TwoRayGround model [15, 16]:

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L} \quad (1)$$

Where:

- $P_r(d)$ = received power at distance
- P_t = transmit power (0.1 W)
- G_t = transmitting antenna gains (assumed 1)
- G_r = receiving antenna gains (assumed 1)
- h_t^2 = antenna heights (1.5 m)
- $h_r^2 = receiving\ antenna\ heights$
- L = system loss (1)

Table 2. Simulation Parameters and Values.

Parameters	Values
Simulator	NS-2
Channel type	WirelessChannel
Wi-Fi Operation Mode	Ad Hoc (802.11b, 2Mbps)
Mobility model	Random Way Point
Radio propagation model	TwoRayGround (pathloss exponent n=4)
Network interface type	WirelessPhy
MAC layer protocol	IEEE 802.11b
Antenna model	Omni Antenna
X and Y network dimension area	500m X 500m
Traffic	Constant bit rate (CBR)
Traffic interval	1 packet per second
Agent	UDP
Number of nodes	20, 30, 40, 50, 60
Packet size	512 bytes
Max speed of Mobile node	10 m/s
Simulation stop time	300 Seconds
Minimum speed	1m/s
Pause time	0s
Speed disribution	1-10m/s
Transmission power	0.1W, RX power
Frequency	2.4GHz
Receiver Sensitivity	-85 dBm
Initial energy for each node	5 Joules
Sink node	1 (fixed position)
Topology	Flat grid
Routing protocols	AODV and DSDV
Number of simulation Runs per Scenario	5 independent runs

Table 3 shows node radius for uniform distribution for a receiver with a sensitivity of -85 dBm.

Observation: Node density 10 (~219 m radius) exceeds WLAN range and was excluded from simulation to avoid isolated nodes.

4. Performance Metrics

This study utilized four performance metrics, namely throughput, packet delivery ratio, end-to-end delay, and energy consumption, to evaluate the performance of MANET protocols. Each of these metrics serves a specific purpose in assessing network performance and is comprehensively explained in this study. By examining these performance indicators, a thorough evaluation of the effectiveness and efficiency of WSNs protocols can be achieved.

Table 3. Node radius distribution

Nodes	Radius (m)	Notes
20	155	Within 2.4 GHz WLAN typical range
30	126	Within range
40	109	Within range
50	98	Within range
60	89	Within range

4.1 End-to-End (E2E) delay

This metric measures the time required for a packet to travel from the source node to the destination node [17]. This reflects the delay or latency experienced by the data during transmission and processing.

$$E2E\ delay = \frac{Total\ delay\ of\ packets}{number\ of\ packets} \quad (2)$$

4.2 Throughput

Throughput measures the amount of data successfully transmitted over a network within a given period. This indicates the network's capacity to handle data traffic and is often measured in bits per second (bps) or packets per second (pps).

$$Throughput = \frac{Total\ data\ transfered}{Total\ time} \quad (3)$$

4.3 Packet Delivery Ratio

PDR measures the percentage of packets successfully delivered to their intended destinations, assess the reliability and efficiency of the network in delivering data. PDR was calculated using this equation:

$$PDR = \frac{Number\ of\ packets\ received}{Number\ of\ packets\ sent} \times 100 \quad (4)$$

4.4 Power Energy Consumption

In wireless networks, energy efficiency is an important metric that measures the amount of energy consumed per unit of transmitted data. This helps evaluate the network's energy utilization and the effectiveness of the energy-saving mechanisms. Energy consumption was calculated using this equation [6, 18]:

$$Power\ consumption = \frac{Data\ transfered}{Energy\ consumed} \quad (5)$$

5 Statistical Analysis

Each metric (PDR, throughput, E2E, power consumption) is considered a random variable due to random node placement and mobility patterns. Mean and variance were computed over 10 simulation runs. Prior to applying the independent samples t-test, the Shapiro-Wilk test was used to confirm that the data distribution was normal, and Levene's test was used to evaluate the homogeneity of variance.

5.1 Hypotheses

Based on the research objectives, the null hypothesis (H0) and alternative hypothesis (H1) were formulated as follows:

- H0: No significant difference in each performance metric (PDR, throughput, E2E delay, energy consumption) between AODV and DSDV.
- H1: There is significant difference in each performance metric (PDR, throughput, E2E delay, energy consumption) between AODV and DSDV.

5.2 Significant Level

To determine statistical significance, the significance level (alpha) was set at 0.05. The T-test was applied to calculate the T-statistic and associated p-value, which are crucial for evaluating the research hypotheses.

5.3 Result Interpretation

The results were interpreted using the T-test results, which included the T-statistic and p-value. It was determined that there was a significant difference in performance between AODV and DSDV routing protocols if the p-value was less than or equal to the significance level (0.05).

5.4 T-Test Formula

To ascertain whether there was a significant difference between the means of two independent groups, the independent samples t-test formula was applied. In our study, we used T-test to compare the performance metrics of two independent groups (AODV and DSDV); we used the independent samples t-test formula as follows:

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\left(\frac{s^2}{n_1} + \frac{s^2}{n_2}\right)}} \quad (6)$$

Where:

$\bar{x}_1$ is the mean performance metric of group A (AODV).

$\bar{x}_2$ is the mean performance metric of Group B (DSDV).

s is the standard deviation of groups A and B.

n_1 is the sample size of Group A.

n_2 is the sample size of Group B.

where t represents the t-value that measures the difference between the means relative to the variation in the data, and s represents the pooled estimate of variance from two independent sample t-test given by

$$s^2 = \frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{n_1+n_2-2} \quad (7)$$

The mean and standard deviation of each group's performance metrics were calculated from the collected data, and these values were then inputted into the formula to obtain the t-value. Once

the t-value is obtained, it can be compared with the critical values from the t-distribution table or statistical software can be used to determine the p-value associated with it. The p-value indicates the probability of obtaining such a difference between means by chance. If the p -value is below a predetermined significance level (e.g., 0.05), we can conclude that there is a statistically significant difference between the performance metrics of the two groups.

6 Experimental results and Discussions

Performance results of the DSDV and AODV routing protocols within the context of both SWSNs MWSNs. The evaluation focused on essential performance metrics and varied the number of nodes within the network.

6.1 E2E Delay

In Figure 4(a), the associated p-value of 0.164 exceeds the standard significance level of 0.05. This indicates insufficient evidence to reject the null hypothesis (H_0), and hence, no significant difference in the end-to-end delay between AODV and DSDV in stationary networks.

Similarly, in Figure 4(b), the p -value also exceeds 0.05, reinforcing that there is no statistically significant disparity in E2E delay between the two protocols under mobile conditions. This suggests that both protocols exhibit comparable delay characteristics regardless of node mobility.

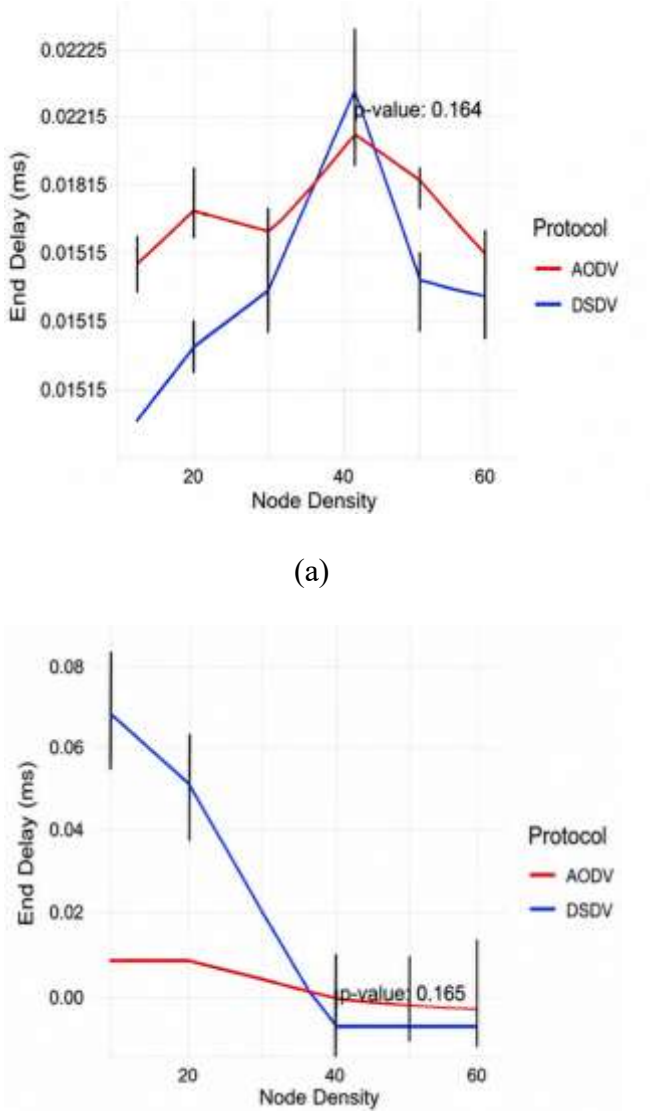
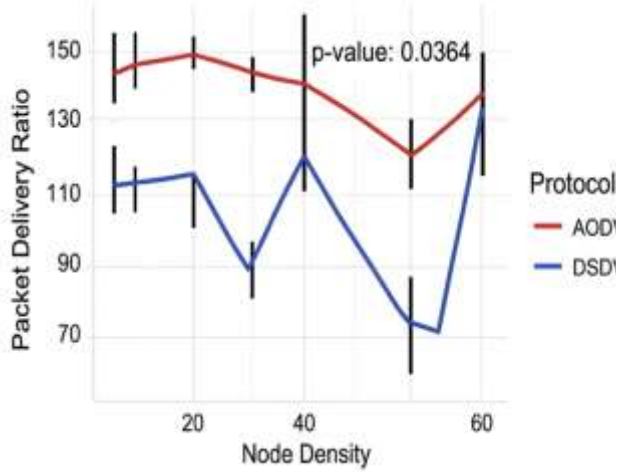


Figure 4. E2E Delay for AODV vs DSDV on (a)SWSNs (b)MWSNs.

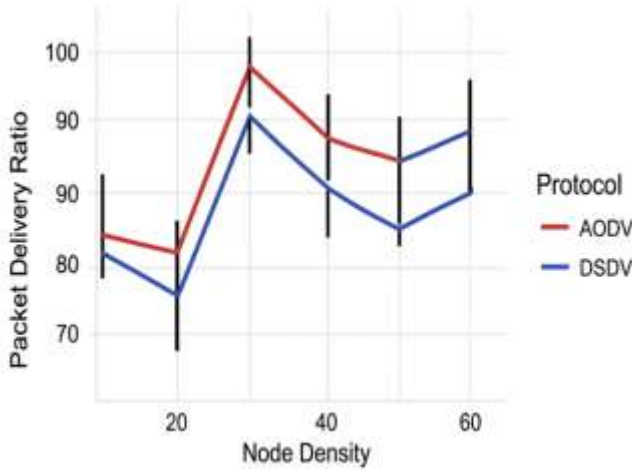
6.2 Packet Delivery Ratio (PDR)

In Figure 5(a), AODV achieved a mean PDR of 159.203, which is 91.2% significantly higher than that of DSDV 73.298 whereby 42.02%. The t-value of 3.7742 and a low p-value of 0.00364 indicate that the result is statistically significant. Thus, we reject the null hypothesis and accept the alternative hypothesis (H_1), confirming that AODV significantly outperform DSDV in PDR for stationary networks [23].

In contrast, for MWSNs, the PDR values for AODV (79.327) and DSDV (78.045) are very close, with a mean difference of only 1.282 (Figure 5(b)). A high p-value of 0.812 and a t-value of 0.282 provide no basis to reject the null hypothesis, indicating no significant difference in PDR performance between AODV and DSDV in mobile scenarios.

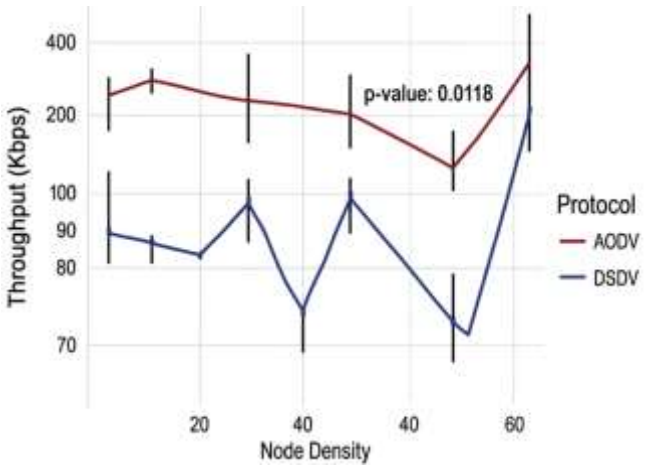


(a)

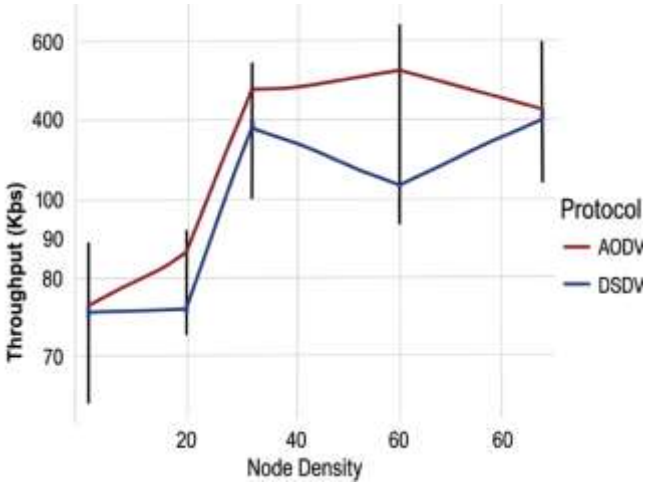


(b)

Figure 5. PDR for AODV vs DSDV on (a) SWSNs. (b)MWSNs.



(a)



(b)

Figure 6. Throughput for AODV vs DSDV on (a)SWSNs (b) MWSNs.

6.3 Throughput

In the SWSN scenario, the mean throughput (in kbps) for AODV was higher than DSDV, with a p-value of 0.0118 kbps, which is below the 0.05 significance level (Figure 6(a)). This leads to rejection of the null hypothesis, suggesting a statistically significant difference in throughput, with AODV outperforming DSDV in stationary networks.

However, in the MWSN scenario, the p-value is 0.289 kbps, which is greater than 0.05, indicating that the difference in throughput between AODV and DSDV is not statistically significant under mobile conditions (Figure 6(b)).

6.4 Power Consumption

Figure 7 shows p-values of 0.2 and 0.853 for SWSNs and MWSNs, both greater than 0.05. Therefore, we fail to reject the null hypothesis in these two scenarios, indicating no statistically significant difference in power consumption

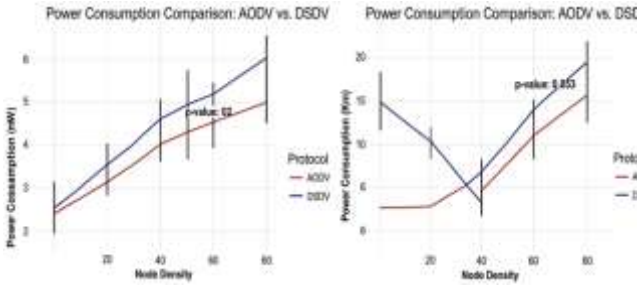


Figure 7. Power Consumption for AODV vs DSDV on SWSNs and MWSNs.

between AODV and DSDV in either stationary or mobile environments.

6.4.1 Performance in Stationary WSNs

The results indicate that in SWSNs, AODV significantly outperforms DSDV in terms of PDR and throughput, making it more suitable for scenarios where reliable data delivery and higher transmission rates are essential. However, while AODV demonstrated lower power consumption than DSDV, the difference was not statistically significant, and therefore no conclusive claims regarding power efficiency can be made. In terms of end-to-end delay, DSDV showed lower values due to its proactive nature, but the difference was not statistically significant.

6.4.2 Performance in Mobile WSNs

In In MWSNs, the performance differences between AODV and DSDV were not statistically significant across all metrics. Both protocols exhibited similar behavior in terms of PDR, delay, throughput, and power consumption, indicating comparable performance in dynamic mobile environments.

7 Conclusion

This study evaluated the performance of AODV and DSDV routing protocols in both stationary and mobile Wireless Sensor Networks (WSNs) by analysing four key performance metrics, namely end-to-end delay, throughput, packet delivery ratio (PDR), and power consumption, while varying the number of nodes. Performance comparisons were then made between the two protocols in both SWSNs and MWSNs using t-tests to determine statistical significance.

Table 4 summarizes the results and highlights the metrics where statistically significant differences were observed. Overall, the study concludes that AODV is better suited for stationary WSN environments where high packet delivery and throughput are priorities, while both AODV and

Table 4. Performance Comparison Based on T-Test Results.

Metrics	Scenario	Protocols	Significant Differences	Hypothesis
E2E Delay	SWSN	AODV DSDV	No	H_0
	MWSN	AODV DSDV	No	H_0
PDR	SWSN	AODV DSDV	Yes (p = 0.00364)	H_1
	MWSN	AODV DSDV	No (p = 0.812)	H_0
Throughput	SWSN	AODV DSDV	Yes (p = 0.0118)	H_1
	MWSN	AODV DSDV	No (p = 0.289)	H_0
Power consumption	SWSN	AODV DSDV	No	H_0
	MWSN	AODV DSDV	No	H_0

DSDV perform comparably in mobile scenarios. Future work may consider testing additional protocols and scenarios, including varied mobility patterns, energy models, and node densities, to further refine the understanding of routing performance in WSNs.

CONTRIBUTIONS OF CO-AUTHORS

Ramadhan A. Rai		Conceived the idea and drafted the manuscript
Ali I. Adnan	ORCID: 0000-0003-2891-4974	Provided methodological guidance, supervised the study, and critically reviewed the manuscript
Omar H. Kombo	ORCID: 0000-0001-93590916	Contributed to conceptual development, validated the findings, and revised the manuscript for intellectual content.

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