Assessing the Effectiveness of Routing Protocols for IoT Applications

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Abstract –*A routing protocol serves as a means to transmit application data, and it includes the necessary addressing details at the network or internet layer, enabling the forwarding of packets from one network to another. Routing protocols are systems designed to identify the most efficient route for transferring data from a single node to multiple nodes or a specific destination node within a network. A Wireless Sensor Network (WSN) is established across an extensive area with numerous wireless sensor nodes set up in an ad-hoc fashion to observe system, physical, or environmental conditions such as agriculture, environmental monitoring, healthcare, smart cities, industrial IoT, home automation, supply chain management, energy management, smart grids, transportation, retail, wearable devices, and smart appliances. These applications leverage IoT-connected sensors in WSNs to collect data and enhance efficiency, safety, and decision-making in diverse sectors. This study uses the Network Simulator tool (NS-2 simulator) to do performance analysis of different routing protocols, such as Adhoc On-demand Distance Vector (AODV), Adhoc On-demand Multipath Distance Vector (AOMDV), Destination Sequenced Distance Vector (DSDV), and Dynamic Source Routing (DSR) protocols for various scenarios. The throughput, residual energy, energy consumption, and packet delivery ratio are the four standard measures used for the comparison of the performance of the above protocols using different topologies. The outcome of this study shows that selecting a routing protocol should take into account the particular network topology, the total number of connected nodes, and the performance criteria needed, since various protocols perform better in different situations.*

Keywords*: Energy consumption, NS-2 Simulator, Packet Delivery Ratio, Residual Energy, Routing Protocols, Throughput, Topology, Wireless Sensor Network.*

Article History
Received 28 February 2026
Received in revised form 16 May 2026
Accepted 31 May 2026
Published online October 2026

I. Introduction

A wireless sensor network (WSN) is composed of self-governing sensors distributed throughout a space to observe various physical or environmental conditions like temperature, sound, vibration, pressure, and humidity [1]. WSNs Sensor nodes face limitations in both energy supply and bandwidth [2],[3],[4]. Coupled with the common practice of deploying a considerable quantity of sensors, these factors have presented numerous difficulties in the formulation and administration of WSNs. The development of an effective routing protocol for WSNs stands out as a significant challenge in this context. Sensor networks prioritize interactions with the environment rather than human interactions [5]. In terms of scale, sensor networks can exhibit significantly greater node counts and deployment densities compared to ad hoc networks. This discrepancy arises because sensor network nodes are integrated into the environment to detect and potentially respond to various phenomena. Routing protocols have a significant role of reliability data transmission in computer networks. The efficiency of the network depends on the routing protocol's proficiency, therefore, enhancing the routing protocol's efficiency, many researchers have been working on it. Research conducted by Vanthana and Prakash compared reactive (e.g., AODV, DSR) and proactive (e.g., DSDV) routing protocols using NS-2 [6]. Their research focused on metrics such as packet delivery ratio, end-to-end delay, packet loss, and average throughput. The results indicated that AODV performed better in the case of packet loss and DSDV outperformed others in the case of throughput. Previous literature showed varying results, which justify why this specific comparative topology study is necessary. Another research in [7], they assessed four performance metrics, namely control overhead, packet delivery ratio, end-to-end delay, and throughput, and conducted these evaluations across various parameters, including varying

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node quantities, different speeds (pause times) of nodes, and diverse network sizes. Throughout the investigation in [8]-[9], different classifications of routing protocols were employed to determine the optimal selection. Each trial yielded distinct outcomes based on the specific attributes and evaluation parameters involved. In the article [10]-[18], the authors examined the behavior and diverse performance metrics of Mobile Ad hoc Networks (MANETs) by employing distinct protocols (namely AODV, Optimized Link State Routing Protocol-OLSR, and Temporally Order Routing Algorithm-TORA). They conducted a comparative analysis of their performance metrics, including end-to-end delay, packet delivery fraction, and throughput, and conduct an in-depth investigation into the parameter performance of different routing protocols using the network simulator tool (NS-2) simulation platform. Through a systematic analysis and comparison of the behaviors of various routing protocols in different network scenarios, this research aims to offer valuable insights into the advantages and disadvantages of these protocols, assisting network designers in making educated choices. There exists a research gap in identifying energy-efficient routing protocols for IoT applications alongside the evaluation of other performance metrics. Therefore, this researh aim to assess the performance of various existing routing protocols named AODV, AOMDV, DSDV, and DSR across diverse network configurations and structures including energy efficiency.

II. Methodology

The approach used to assess the effectiveness of routing protocols—AODV, AOMDV, DSDV, and DSR across three different network topology types—hybrid, star, and ring—is shown in this section. The evaluation of the protocols was carried out through simulation methodologies, wherein the number of nodes was increased to assess their effect on network performance. Key metrics such as average throughput, packet delivery ratio, total residual energy, residual energy per node, and overall energy consumption efficiency were measured as shown in equations (1)-(5). The simulations were conducted using NS-2 software.

A. Performance parameters Calculation

Throughput Calculations:

(a) Average throughput in kbps = $\frac{\text{received packets}}{\text{stop time}-\text{start time}} * \frac{8}{1000}$. (1)

(b) Packet Delivery Ratio = $\frac{\text{received packets}}{\text{send packets}} * 100\%$. (2)

(c) Residual energy per node = Initial energy per node – energy consumption per node. (3)

(d) Total Residual Energy = Sum of residual energy per node. (4)

(e) Energy Consumption = (Initial energy* Number of nodes) - Total Residual Energy. (5)

B. Simulation Strategy

Here, the most recent NS-2 version 2.35 has been utilized to simulate the created system. A discrete event simulator designed for networking research is called Ns-2. It started off as a component of the REAL network simulator. We execute the simulation in (NS-2) and take as input a scenario file that details each node's precise motion, the precise packets that each node originates, and the precise moment at which each motion change or packet origination is to take place. Each run generates a thorough trace file that is saved on disc and examined by a number of scripts, especially one file named *.tr that keeps track of how many packets are successfully delivered, how long their pathways are, and other details on how each script runs inside. To create the visualizations, this data is further processed using MATLAB and an AWK file. A radio propagation model is the mobility model that is employed. 1900 x 1900 m field configurations with 5, 7, 21, 31, and 41 nodes are utilized. Table I presents selections for routing protocol node evaluation in various network densities to determine the scalability/performance characteristics of routing protocols. 5 and 7 nodes simulate sparse networks, while 21, 31, and 41 nodes represent moderately/full dense networks. The node count was selected to determine how routing protocols such as AODV, AOMDV, DSDV, and DSR react under increasing complexities/traffic loads/routing overheads/connectivity conditions in various topologies. Here, the source and destination of each packet with its speed is chosen by randomly. Simulations are run for 5 simulated seconds. Below in Fig. 1 to Fig. 5 is the specified layout of nodes used in the NS-2 simulation.

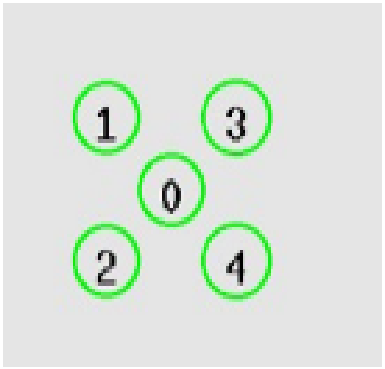


Fig.1. Connection among 5 nodes.

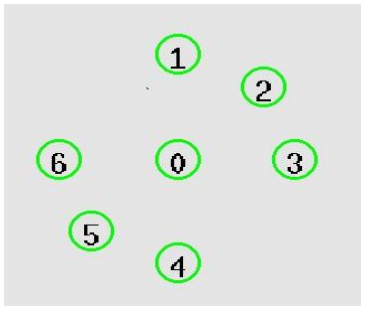


Fig. 2. Connection among 7 nodes.

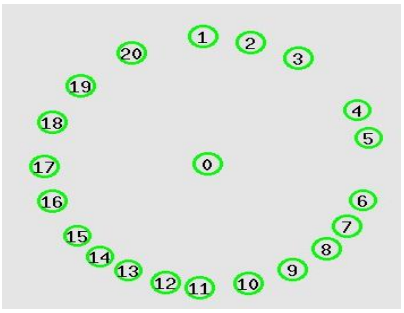


Fig. 3. Connection among 21 nodes

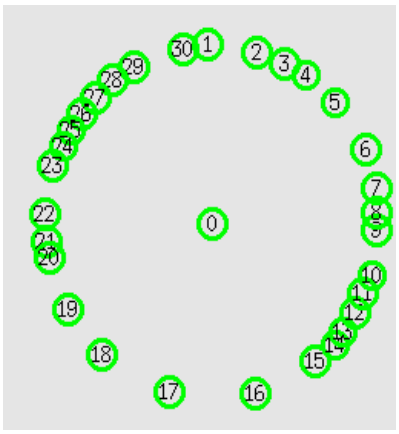


Fig. 4. Connection among 31 nodes.

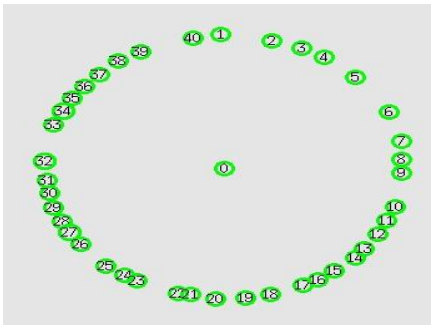


Fig. 5. Connection among 41 nodes.

TABLE I
PARAMETERS USED IN THE SIMULATION

Parameter	Value
Simulator	NS-2 [version-2.35]
Channel type	Channel/Wireless Channel
Radio Propagation Model	Propagation/Two-Ray Ground Wave
Network Interface type	Phy/Wirelessphy
MAC (Medium Access Control) Type	Mac/802_11
Interface Queue Type	Queue/Drop Tail [for AODV,AOMDV, and DSDV routing protocols]
Interface Queue Type	Queue/Drop Tail/PreQueue [for DSR routing protocol]
Link Layer Type	LL(Link Layer)
Antenna	Antenna/Omni Antenna
Maximum packet in ifq	50
Area (M*M)	1900*1900
Initial Energy	2000
Number of mobile nodes	5, 7, 21, 31, and 41
Source Type	TCP (Transmission Control Protocol), FTP (File Transfer Protocol)
Simulation Time	5 sec
Routing Protocols	AODV, AOMDV, DSR, and DSDV
Topologies	Hybrid, Star, and Ring

III. Results and Discussion

Different network topologies, such as Hybrid, Star, and Ring, are considered for this study. NS-2 is used as a network simulator tool, which provided raw data regarding network performance based on changing network conditions. The data gathered from simulation results was processed using MATLAB to create graphical representations that would enable a comparative analysis of network performance for each protocol. By studying these graphical representations, it is possible to determine how each protocol performs when network topology is changed, or network size is increased, and which protocol

performs better in terms of efficiency or reliability, etc. Such an analysis not only helps in identifying the advantages or disadvantages of each protocol but also assists in decision-making regarding which protocol should be used in a given network environment.

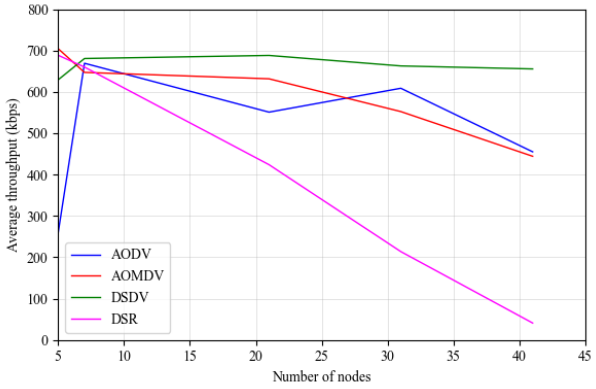


Fig. 6. Number of Nodes versus Average throughput (kbps) for Hybrid Topology of AODV, AOMDV, DSDV, and DSR routing protocols.

As depicted by the graph presented in Fig. 6, it is clear that the DSR protocol performs optimally with a certain number of nodes in the hybrid topology, especially concerning the average throughput parameter. As the number of nodes increases, there is a gradual decline in the overall system's throughput. It should be noted that the DSDV protocol performs better in terms of average throughput compared to the AODV and AOMDV routing protocols in the hybrid topology, as it achieved 662.62 kbps average throughput, whereas AODV, AOMDV, and DSR achieved 608.62, 552.23, and 213.67 kbps, respectively. It should be noted that the AODV protocol's suitability reduces when dealing with low numbers of nodes.

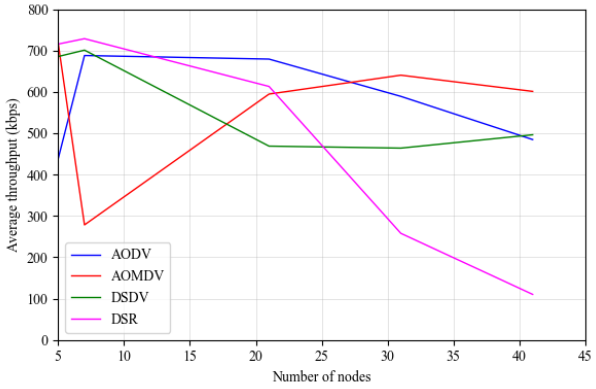


Fig. 7. Number of Nodes versus Average throughput (kbps) for Star Topology of AODV, AOMDV, DSDV, and DSR routing protocols.

The graph in Fig. 7 shows that when only a few nodes are connected, the AODV protocol tends to have lower average throughput than other protocols in a star topology. However, as the number of nodes increases, the average throughput of the AODV protocol surpasses that of the other protocols in a star topology network configuration. For example, AODV achieved 437.6 kbps, whereas the others achieved more at 5 connected nodes, but it achieved more average throughput by increasing the number of connected nodes, i.e., at 21 connected nodes, it achieved 679.17 kbps. In essence, while AODV's performance is initially weaker with fewer nodes, it becomes notably better than the alternatives when dealing with a larger number of nodes in this specific network setup, i.e., it achieved 640.26 kbps at 31 connected nodes. Furthermore, the DSR protocol seems to be better suited only for networks with a smaller number of connected nodes for a star topology.

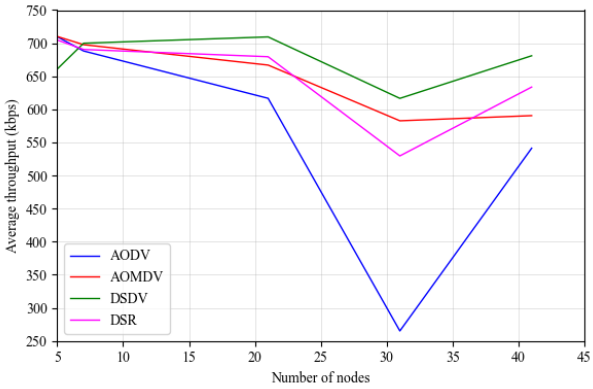


Fig. 8. Number of Nodes versus Average throughput (kbps) for Ring Topology of AODV, AOMDV, DSDV, and DSR routing protocols.

The graph in Fig. 8 illustrates that the DSDV protocol consistently provides superior average throughput performance. However, in the context of a ring topology and a significant number of connected nodes, the AODV protocol does not fare well in achieving higher average throughput compared to the others. For example, at 31 connected nodes, DSDV achieved 616.62 kbps, whereas AOMDV, DSR, and AODV achieved 582.74, 529.67, and 265.165, respectively. The reduction in values depicted in Fig. 8 is primarily attributable to rising network congestion, increasing routing overhead, packet collisions, and interference between nodes based on a larger number of connected nodes to the network. Due to the nature of the ring topology, data packets tend to traverse longer sequential paths; this results in an increase in both delay and packet loss probabilities. The operation of maintaining routes in the network becomes more frequent as the number of nodes reaches a specific density within the network. This increases the likelihood of temporary reduction in throughput and packet delivery ratio. All of these characteristics contribute to the overall observed performance reduction in the graphs.

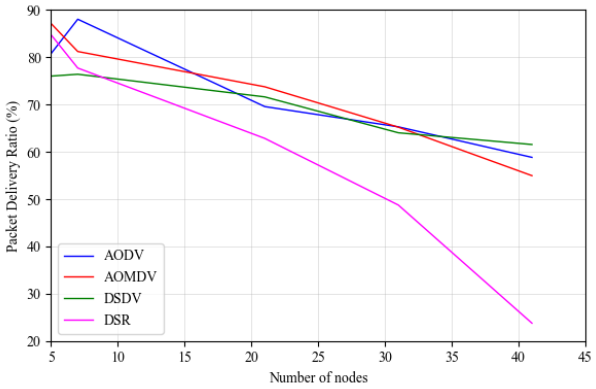


Fig. 9. Number of Nodes versus Packet Delivery Ratio for Hybrid Topology of AODV, AOMDV, DSDV, and DSR routing protocols.

From the data presented in Fig. 9, it appears that the DSR protocol is less appropriate for maintaining a high packet delivery ratio in a hybrid topology compared to others. On the other hand, the DSDV protocol appears to be better studied for this purpose. For example, as it achieved only 23.76% packet delivery ratio whereas DSDV, AODV, and AOMDV achieved 61.56%, 58.84%, and 54.97%, respectively at 41 connected nodes.

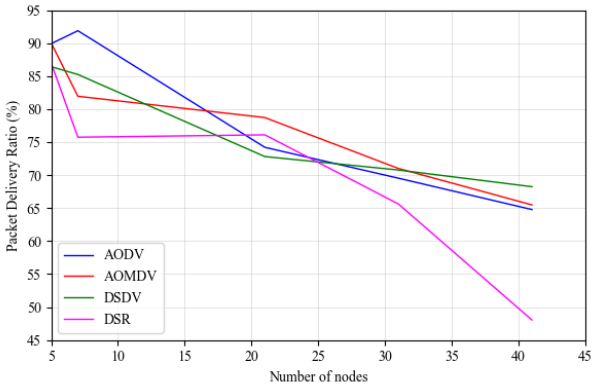


Fig. 10. Number of Nodes versus packet Delivery for Star Topology of AODV, AOMDV, DSDV, and DSR routing protocols.

The graph in Fig. 10 depicts that, in a star topology, the AODV protocol generally achieves a superior packet delivery ratio overall. Conversely, the DSR (Dynamic Source routing) protocol seems to be ill-suited for scenarios involving a substantial number of connected nodes, as it struggles to maintain a satisfactory packet delivery ratio under these conditions. For example, DSR gained 48.04% packet delivery ratio at the 41 connected nodes whereas DSDV, AOMDV, and DSDV gained 68.24%, 65.48%, 64.78%, respectively.

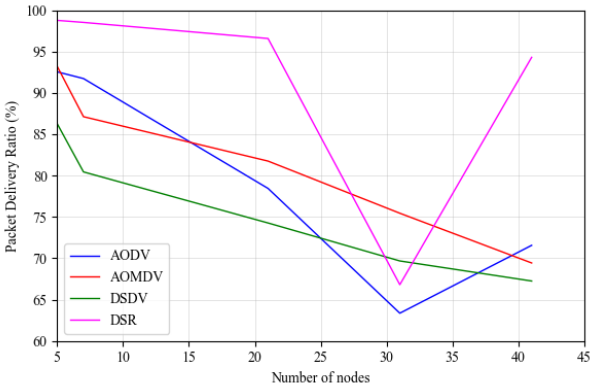


Fig. 11. Number of Nodes versus packet Delivery for Ring Topology of AODV, AOMDV, DSDV, and DSR routing protocols.

Based on the graph in Fig. 11, it's evident that the DSR protocol consistently demonstrates a superior packet delivery ratio compared to the other protocols in the context of ring topology at the smaller to medium number of connected nodes. For example, at the 7 number of connected nodes DSR gained 98.5% packet delivery ratio whereas AODV, AOMDV, and DSDV gained 91.7%, 87.1%, and 74.2%, respectively. The dip from 30 – 35 nodes is due primarily to increased routing overhead, increased packet collisions, increased congestion, and increased contention among nodes as the network becomes denser. At this point, the routing protocols have temporary instability due to the increased number of control packets being sent and the interference from all of the transmissions on the medium. This will affect the throughput and packet delivery performance until they stabilize again.

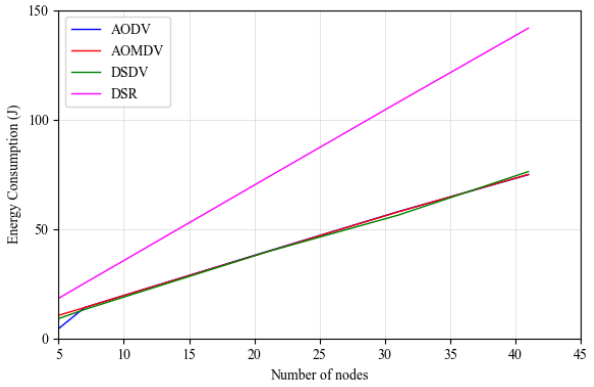


Fig. 12. Number of Nodes versus Energy Consumption for Hybrid Topology of AODV, AOMDV, DSDV, and DSR routing protocols.

Fig. 12 depicts how energy usage changes based on how many nodes there are in a hybrid topology and which four types of routing protocols (AODV, AOMDV, DSDV, & DSR) will be used to route these nodes. All routing protocols see an escalating trend of energy consumption

as the number of nodes increases. DSR consumes the most amount of total energy throughout the entire simulation with a steep rise from approximately 18.3J to nearly 141.68J as the number of nodes increases from 5 to 41, compared to AODV, AOMDV, & DSDV which have very similar performance with steady increases in energy consumed (between 5J & ~75J). As such, it can be concluded that while DSR is an inefficient use of energy when used across many nodes, AODV, AOMDV, & DSDV have lower levels of energy consumption and therefore maintain more consistent levels of energy consumption with increasing numbers of nodes.

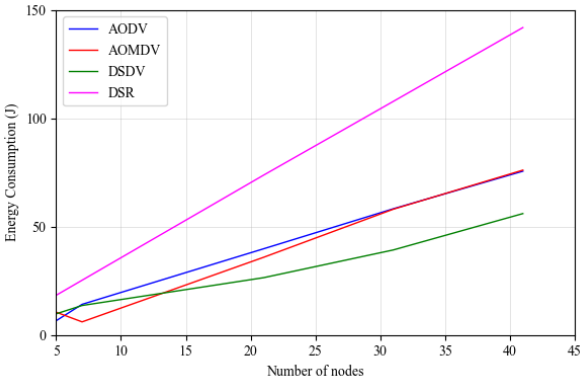


Fig. 13. Number of Nodes versus Energy Consumption for Star Topology of AODV, AOMDV, DSDV, and DSR routing protocols.

The four routing protocols, AODV, AOMDV, DSDV, and DSR, were compared using their energy consumption in a star topology with respect to the number of nodes shown in Fig. 13. All four protocols demonstrated an increase in energy consumption with an increase in the number of nodes. Energy consumption increased significantly for DSR, increasing from approximately 18.32 J to nearly 141.78 J when the number of nodes increased from 5 to 41. AODV and AOMDV exhibited moderate energy consumption and demonstrated a steady increase, reaching approximately 75 J with 41 nodes. On the other hand, the energy consumption of DSDV was consistently and continuously the lowest throughout the entire simulation, rising gradually from approximately 10 J to about 56 J. Therefore, under conditions where nodes were added to the star topology, DSDV was found to be the most energy-efficient of all the protocols, and DSR was determined to be the least energy-efficient routing protocol as the size of the network increased.

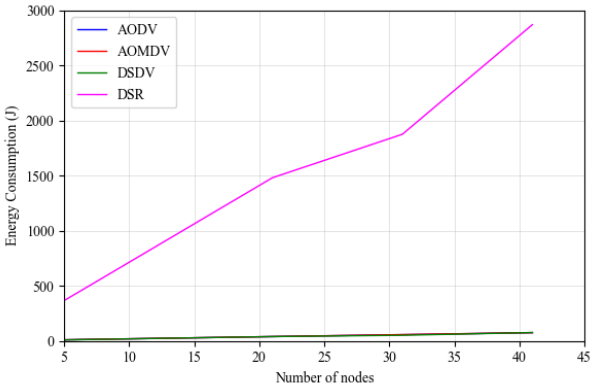


Fig. 14. Number of Nodes versus Energy Consumption for Ring Topology of AODV, AOMDV, DSDV, and DSR routing protocols.

In the scenarios of Fig. 14, where hybrid, star, and ring network topologies are considered, the energy consumption tends to be greater when utilizing the DSR protocol. It shows the highest energy consumption, increasing significantly from about 500 J to nearly 2868 J. This can be justified by the inherent nature of the protocol, which includes its capability for source routing. DSR appends the complete routing path into the header of every single data packet, which significantly inflates packet overhead size compared to AODV's hop-by-hop routing table lookups. These features lead to increased overhead and signalling operations, thus making devices consume more energy as opposed to other routing protocols. However, it is important to note that these are general trends that can change depending on various factors. Finally, this research establishes the best routing protocols available for a variety of different networking environments in Internet of Things (IoT)-based Wireless Sensor Networks (WSNs). The results of this research will allow for practical guidance in determining proper routing protocol selection by examining network topology, the number of nodes in the network and the energy and reliability requirements for each network type. The following are a few examples of how the selected routing protocol from this research would be utilized, based on simulations:

- DSR may be an ideal choice for smaller and/or ring based IoT networks that require the delivery of packets with a certain level of reliability
- AODV performs better in larger star topology than smaller star topology networks and when more nodes are added to an existing star topology network
- DSDV has been shown to provide stable throughput performance under many different scenarios

The results of this study can be applied in real world IoT implementations such as Smart Agriculture, Environmental Monitoring, Industrial Automation, Health

Care Monitoring, Smart Cities, and Transportation Systems where efficient routing directly impacts network lifetime, energy consumption, and communication reliability.

IV. Conclusion

Routing protocol performance is different for different topologies. In a hybrid topology, the DSR protocol shows optimal performance for a limited number of nodes, but its suitability reduces with a higher number of nodes. In a star topology, the AODV protocol shows lower average throughput with respect to fewer connected nodes, but its performance is superior to other routing protocols with an increasing number of nodes. DSR protocol is more suitable for networks with fewer connected nodes, whereas DSDV protocol shows superior performance with respect to average throughput. In ring topology, the DSR protocol performed better in terms of packet delivery ratio compared to other routing protocols. Nevertheless, the AODV protocol finds it challenging to sustain high levels of average throughput. Higher levels of energy consumption may be experienced when using the DSR protocol in hybrid, star, and ring topologies due to the dynamic nature of route discovery. Therefore, the choice of routing protocol should take into consideration the topology of the network, the number of connected nodes, and the performance parameters of the network since each protocol performs better in a particular situation.

Acknowledgements

The authors gratefully acknowledge to the department of EEE, GSTU to facilities the laboratory.

Conflict of Interest

The authors declare no conflict of interest in the publication process of the research article.

Author Contributions

Author 1: Data collection, analysis, writing – original draft preparation; Author 2: Supervision, draft review and editing, investigation; Author 3: Conceptualization, review; Author 4: Project administration, Analysis, writing – original draft preparation.

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