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Performance Evaluation of QoS-Aware Routing Protocols for IoT Wireless Networks

Durgesh Kumar Keshar[1*], Dr. Guddi Singh[2]and Devendra Kumar[3]

[1]PhD. Research Scholar, Department of CSE, Kalinga University, Raipur, Chhattisgarh

[2]Professor, Department of CSE, Kalinga University, Raipur, Chhattisgarh

[3]M.tech. Computer Science, Bilaspur, Chhattisgarh

Corresponding Author: **Durgesh Kumar Keshar[1*]**

[1]PhD. Research Scholar, Department of CSE, Kalinga University, Raipur, Chhattisgarh

Abstract: IoT wireless networks are a fundamental component of the Internet of Things ecosystem, offering extensive coverage and the capability to wireless connect a diverse array of devices. These networks span large geographic areas, such as smart cities, industrial facilities, and remote agricultural regions. Understanding the unique characteristics of QoS-aware routing protocols is essential for evaluating their performance in this context. Examining challenges such as intermittent connectivity, limited bandwidth, and energy constraints is crucial for understanding the complexity of delivering reliable Quality of Service (QoS) in IoT wireless networks. Routing protocols play a crucial role in guiding data transmission in networks, determining how data packets are routed from the source to the destination. The study employed an extensive simulation-based approach to evaluate the performance of quality of service (QoS)-aware routing protocols in Internet of Things (IoT) wireless networks. Using simulation environments in Network Simulator 2.35, we created various scenarios to replicate real-world IoT applications. These scenarios varied in terms of network topology, traffic patterns, and device constraints in order to comprehensively assess protocol performance. The assessments were conducted in two modules, with AODV demonstrating efficiency in scenarios involving low end-to-end delay, packet loss, and routing overhead. It excelled in achieving a high packet delivery ratio and throughput. This article provides a comprehensive analysis of the QoS awareness of protocols such as AODV, AOMDV, and DSDV, highlighting their suitability in different Internet of Things (IoT) scenarios. Additionally, it provides new perspectives on optimizing Quality of Service (QoS) in the constantly changing environment of wireless networks in the Internet of Things (IoT).

Keywords: *Network topology, IoT wireless networks, QoS-aware routing protocols, Routing protocols, Simulation-based evaluation*

1. Introduction

The Internet of Things is an evolving technology that enables the interconnection of various devices and objects through wireless networks. These networks can consist of numerous devices with diverse communication requirements. Therefore, it is necessary to implement QoS-aware routing protocols to effectively manage the network resources and enhance the overall performance. QoS-aware routing protocols aim to provide high-quality and reliable communication by considering various QoS metrics, such as throughput, latency, packet loss, and energy efficiency. In recent years, researchers and industry professionals have shown significant interest in QoS-aware routing protocols for IoT wireless networks.

One of the key challenges in IoT wireless networks is the limited resources, such as bandwidth, energy, and computational power. Due to resource constraints, it is crucial to evaluate the performance of Quality of Service

(QoS)-aware routing protocols to ensure efficient utilization of these resources. Researchers have proposed various quality of service (QoS)-aware routing protocols for IoT wireless networks to address the aforementioned challenges. These protocols focus on various aspects of Quality of Service (QoS), such as reliability, delay, bandwidth, and jitter. In a study conducted by Jaiswal et al., they proposed an optimal QoS-aware multi-path routing protocol for IoT-based wireless sensor networks. The protocol aimed to determine the optimal cost factor by measuring two factors: reliability and timeliness. [1]

The performance evaluation of QoS-aware routing protocols is important for determining their effectiveness in meeting the QoS requirements of IoT applications. Until now, most QoS efforts in wireless sensor networks have focused on protocol-level solutions or cross-layer interactions. These efforts have primarily focused on addressing a few Quality of Service (QoS) parameters, such as reliability and delay, while neglecting other important parameters, such as jitter and bandwidth. To address this limitation, researchers have been developing new routing protocols that take into account the characteristics of IoT systems. These protocols aim to satisfy application-specific QoS requirements while maximizing the utilization of network resources. [2]

One common approach to evaluating the performance of QoS-aware routing protocols for IoT wireless networks is through simulation and modeling techniques. These techniques allow researchers to assess the behavior and performance of routing protocols in various scenarios and network conditions. By utilizing simulation and modeling techniques, researchers can measure the effectiveness of routing protocols in terms of metrics such as throughput, latency, packet loss, and energy consumption. Furthermore, researchers have also utilized software-based modeling techniques to evaluate the design and performance of ad-hoc networking protocols in IoT wireless networks. This approach involves testing the functionality of the protocols with improved energy efficiency and routing capacity in different networking scenarios and WSN conditions.

The purpose of this study is to provide a comprehensive rationale for investigating quality-of-service (QoS)-aware routing protocols in the context of wireless networks in the Internet of Things (IoT). This research aims to elucidate the importance of QoS-aware routing protocols in improving the overall performance and efficiency of IoT wireless networks. The rationale for this study arises from the increasing significance of IoT wireless networks in diverse fields, such as healthcare, transportation, and smart cities. As the number of IoT devices continues to increase, the demand for efficient and reliable communication becomes crucial. QoS-aware routing protocols play a crucial role in ensuring the delivery of data packets with specific QoS requirements, such as low latency, high reliability, and minimal energy consumption. By investigating Quality of Service (QoS)-aware routing protocols, this study aims to tackle the current challenges and limitations in wireless networks for the Internet of Things (IoT). These challenges include network congestion, limited bandwidth, and the varying QoS requirements of different IoT applications. By implementing QoS-aware routing protocols, it is anticipated that the overall network performance will be improved, leading to an enhanced user experience and increased network efficiency. Furthermore, this study aims to contribute to the existing body of knowledge by evaluating and comparing various QoS-aware routing protocols for IoT wireless networks. By conducting a comprehensive analysis, the study will offer valuable insights into the strengths and weaknesses of different protocols. This will enable network administrators and researchers to make well-informed decisions when selecting and implementing protocols.

The remainder of this paper is organized as follows: Section 2 presents a literature survey on the relevant proposed research topics. Section 3 describes the proposed methodology for the research work, including the modules, routing protocols, and QoS parameters considered. Section 4 describes the analysis of the simulation experiments' results, and the paper is concluded in Section 5.

Contributions in this paper

- The central objective of this research endeavor is to conduct a comprehensive assessment of routing protocols that are specifically designed to prioritize Quality of Service (QoS) in the context of wireless networks for the Internet of Things (IoT).
- This study aims to provide comprehensive insights into the performance characteristics of these protocols, as well as their suitability for implementation in IoT applications.

2. Related Work

Routing protocols for IoT-based wireless networks in the context of quality of service (QoS) have been extensively studied. Various routing approaches have been categorized and compared based on parameters such as energy consumption, network lifetime, path length, packet delivery ratio, and network latency [3]. The comparison shows that Routing Protocol for Low Power and Lossy Networks (RPL), Efficient Tree-based Self-Organizing Protocol (ETSP), Collection Tree Protocol (CTP), and Fast Multi-Constrained Multicast Routing Algorithms (FAMOUS) are considered the best protocols in terms of performance metrics such as energy consumption, network lifetime, reliability, efficiency, and packet delivery ratio [4]. These protocols are tree-based and have the lowest time complexity, making them effective in solving routing problems in IoT networks [5]. Additionally, the use of ad hoc routing protocols such as AODV, OLSR, and GRP has shown significant improvements in network performance, including reduced delay, increased throughput, and decreased data dropped [6].

These papers collectively address the research question of simulating and analyzing the Quality of Service (QoS) of routing protocols for IoT-based wireless networks. The author in [7] proposes a routing protocol called REL (Routing by Energy and Link Quality) that selects routes based on link quality, residual energy, and hop count. The results show that REL (Reactive Energy Level) improves the network lifetime, service availability, and quality of service (QoS) of IoT applications. The author in [8] introduces two QoS provisioning-based routing protocols, O-ETSSEP and MSO-ETSSEP, that utilize multiple data sinks in WSN-based IoT. The protocols optimize Cluster Head (CH) selection and energy balancing, resulting in superior performance compared to existing protocols. The author in [9] provides an analysis and classification of routing protocols for IoT and WSN based on success criteria such as minimizing delay, reducing energy consumption, and maximizing data delivery ratio.

The author in [10] discusses thermal-aware routing protocols in wireless body area networks (WBANs) for Internet of Things (IoT)-based healthcare applications. The author in [11] analyzes the impact of transmission power on the quality of service of MANET routing protocols, including AODV, OLSR, DSDV, and DSR. The author in [12] provides a comprehensive survey of QoS support in IoT networks and communication protocols. This includes an analysis of QoS-aware architectures and methods for optimizing network resources. The author in [13] proposes a Markov chain model to analyze and evaluate the QoS parameters of medium access control (MAC) protocols in Internet of Things (IoT) applications.

3. Materials and Methods

The present study aims to investigate and evaluate the performance of Quality of Service (QoS)-aware routing protocols for wireless networks in the Internet of Things (IoT). In order to achieve this objective, a systematic and rigorous methodology was adopted. This section provides a detailed description of the methodology used in this research article.

Firstly, a comprehensive literature review was conducted to gain a thorough understanding of the existing quality of service (QoS)-aware routing protocols for Internet of Things (IoT) wireless networks. This involved an extensive search of scholarly databases, such as IEEE Xplore, ACM Digital Library, and ScienceDirect, using relevant keywords and filters. The selected articles were critically analyzed and synthesized to identify the most commonly used QoS-aware routing protocols in the field.

Based on the findings of the literature review, a set of evaluation criteria was established to assess the performance of the identified QoS-aware routing protocols. These criteria included metrics such as packet delivery ratio, end-to-end delay, network lifetime, energy efficiency, and scalability. The selection of these criteria was guided by their relevance to the QoS requirements of IoT applications and their significance in evaluating routing protocols.

To conduct the performance evaluation, a simulation-based approach was employed. The widely used network simulator, NS-2, was utilized to create a realistic IoT wireless network environment. The simulation scenarios were designed to replicate real-world IoT deployments, taking into account factors such as network topology, traffic patterns, and node mobility. Multiple experiments were conducted using various combinations of QoS-aware routing protocols and network parameters to ensure the reliability and validity of the results. The following figure (Figure 1) shows the general methodology outline for conducting the present research work.

Step 1: Develop a simulation scenario for the IoT network

In the first step, it is important to decide on the simulation scenario for an IoT-based wireless network. Since IoT applications are widely used in wireless networks and the nodes in IoT are distributed, a scenario is considered where the network is wireless and the nodes are randomly distributed.

Step 2: Two modules with two different scenarios are considered

In the second step, it is important to initiate the research work with a simulation tool. It is decided to start with a lightweight simulation using a small network in Module I, and then progress to a slightly deeper simulation with a larger network in Module II.

Step 3: Module I with a smaller number of nodes in an IoT-based wireless network.

In the third step, Module I is executed with a reduced number of nodes in an IoT-based network using the simulation tool NS-2. The objective is to identify the appropriate routing protocol for meeting the QoS requirements of the IoT application. This includes identifying the appropriate routing protocols based on the desired levels of reliability, availability, and latency. In the first module, three routing protocols, namely AODV, AOMDV, and DSDV, are compared. Their evaluation is based on three basic QoS parameters: Throughput, Packet Delivery Ratio, and End-to-End Delay. In the first module, the primary focus is to understand the workings of various routing protocols, how they function in wireless networks, and how they impact the QoS parameters. Since learning Network Simulator 2 (NS2) can be challenging and time-consuming, the study in module 1 focuses on a limited number of parameters and nodes to create wireless IoT networks.

Step 4: Module II with a larger number of nodes in an IoT-based wireless network.

In the fourth step, Module II is chosen to be executed with a larger number of nodes in an IoT-based network using the simulation tool NS-2. The objective is to identify the factors that can affect the quality of service (QoS) in the IoT network. This includes the number of devices connected to the network, the type of data being transferred, and the network infrastructure. In the second module, the AODV, DSDV, and AOMDV routing protocols are tested based on a scenario where the number of nodes varies from 25 to 200. In this module, the scalability factor of routing protocols is taken into consideration, focusing on their performance as the number of nodes increases in wireless IoT networks.

Step 5: Selection of Quality of Service (QoS) parameters and Routing Protocols.

In the fifth step, the routing protocols considered are AODV, AOMDV, and DSDV, as they are implemented in NS-2. Therefore, it is necessary to understand their performance in various wireless networks. Routing protocols are used to determine the optimal path for data to travel between nodes in a network. Wireless routing protocols are specifically designed to function in wireless networks, which possess distinct characteristics such as limited bandwidth, high error rates, and dynamic topology. There are three routing protocols that are considered in both Module I and Module II. There are three QoS parameters considered in Module I and five QoS parameters considered in Module II.

Step 6: Run Simulation and Analyze the Results.

In the sixth step, simulations are conducted for each module individually, and the performance of routing protocols is recorded. In Module I, two simulation scenarios are conducted for 50 and 100 nodes. In Module II, eight simulation scenarios are conducted for nodes ranging from 25 to 200. The obtained results are exported to MS Excel files, and appropriate graphs are formed for QoS parameters for both Modules I and II.

Step 7: Conclusion drawn from Module I and Module II.

After plotting the graph, it becomes easier to determine the performance of routing protocols based on the set parameters for the study. This step clarifies which protocols are well-suited for IoT-based wireless network applications and which can adapt dynamically as the number of nodes increases in the network.

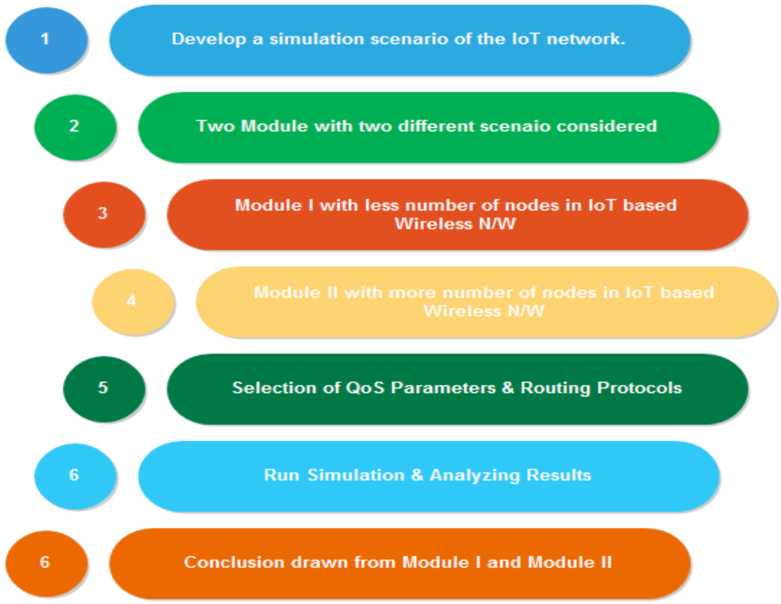


Figure 1: Methodology Adopted for Research Work

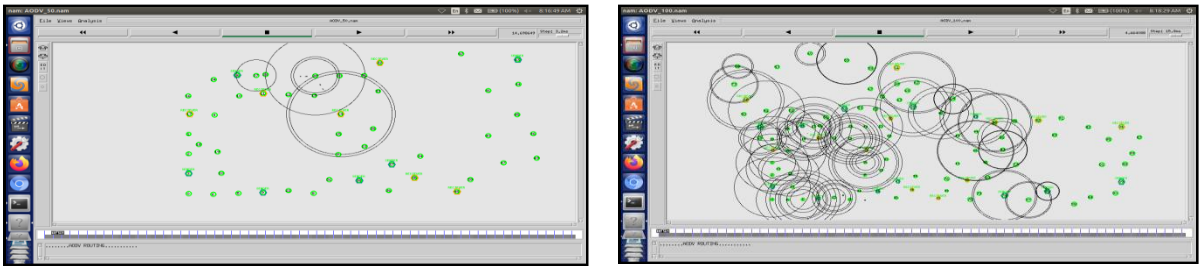
4. Results and Discussion

The simulation tool NS-2 (version 2.35) is used in Ubuntu OS 16.04 for both Modules I and Module II. Table 1 lists some of the simulation parameters used in the experiments. The simulation area is distributed over a 1000m x 1000m area, and the simulation time is set to be around 600 seconds.

Table 1: Simulation Parameters for Module I and Module II

SN	Simulation Parameters	Values
1	No of Nodes	Module I: 50 nodes and 100 nodes Module II:25, 50, 75, 100, 125, 150, 175 and 200 nodes
2	Routing Protocols	AODV, DSDV, AOMDV for Both Modules
3	Data Payload (UDP)	512 Bytes for Both Modules
4	Transmission Range of Node	250 meters
5	Propagation Model	Two Ray Ground
6	QoS Parameters	Module I: PDR, Throughput, Delay Module II: PDR,PLR, Throughput, Delay and RO
7	Simulation time & Area	6000 seconds and 1000m x 1000m

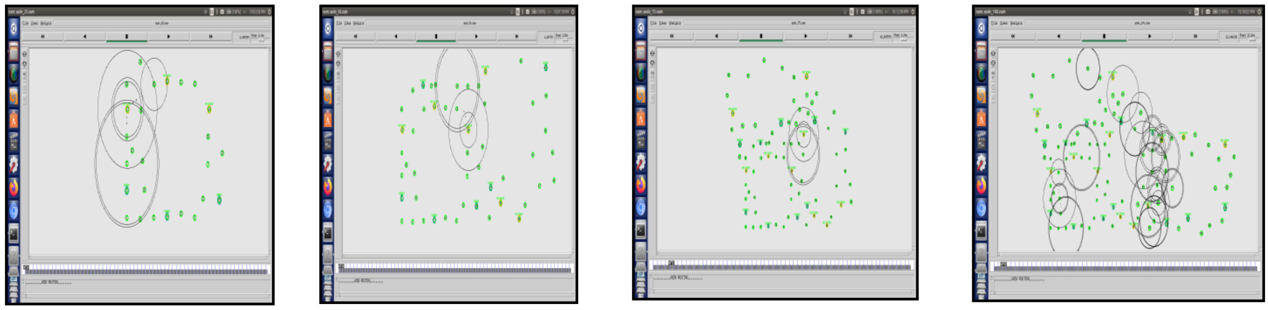
In Module I, there are two scenarios where the number of nodes is kept constant at 50 and 100 nodes. These scenarios are static, meaning that the nodes do not move around. There are some sender and receiver nodes for communication, which sets up an environment for IoT communication. The Module 1 is focused to check the performance of three routing protocols namely; AODV, AOMDV and DSDV routing protocols. Since NS 2 simulator took lot of time to setup for IoT based environment, so only few parameters are considered for the experiment. Figure 2 (a) shows the scenario of 50 nodes where sender communicates with the receiver node in wireless IoT network. The other nodes act as intermediate nodes to carry forward the packets after establishing path between sender and receiver nodes. Figure 2 (b) shows the scenario of 100 nodes in which some sender and receiver node pairs are increased. Whenever there is increase in sender and receiver nodes pairs in a wireless network then some routing overhead and exchange of packets increase. In this scenario, routing protocols performance have been watched over many nodes when deployed to IoT based wireless network.



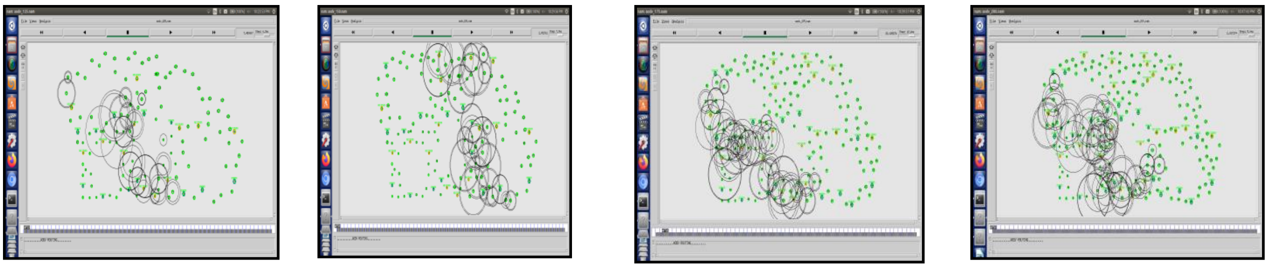
(a) 50 nodes *(b) 100 nodes*

Figure 2: Module I scenarios

In Module II, there are eight scenarios where the number of nodes is kept at 25, 50, 75, 100, 125, 150, 175, and 200 nodes, as shown in Figure 3 from (a) to (h). There are sender and receiver nodes for communication, which establish an environment for IoT communication. The Module II focuses on evaluating the performance of three routing protocols: AODV, AOMDV, and DSDV, in a scalable manner. Since setting up the NS 2 simulator for an IoT-based environment is time-consuming, additional parameters are being considered for the experiment in Module II, apart from Module I. All figures (a) to (h) depict a scenario with an increasing number of nodes, where certain sender and receiver node pairs are added. Whenever there is an increase in the number of sender and receiver node pairs in a wireless network, there is an increase in routing overhead and packet exchange. In these scenarios, the performance of routing protocols has been observed across multiple nodes when deployed in IoT-based wireless networks.



(a) 25 nodes *(b) 50 nodes* *(c) 75 nodes* *(d) 100 nodes*



(e) 125 nodes *(f) 150 nodes* *(g) 175 nodes* *(h) 200 nodes*

Figure 3: Module II scenarios

Regarding the three parameters considered in Module I, it can be concluded that AODV outperforms the other routing protocols, namely AOMDV and DSDV. Figure 4 shows the graph depicting the performance of routing protocols in Module I. Figure 4 (a) shows the graph of the throughput parameter for three routing protocols, measured in kbps. The results of the simulation show that AODV consistently achieves the highest throughput, followed by AOMDV, and then DSDV. Figure 4 (b) shows the graph of the packet delivery ratio parameter for

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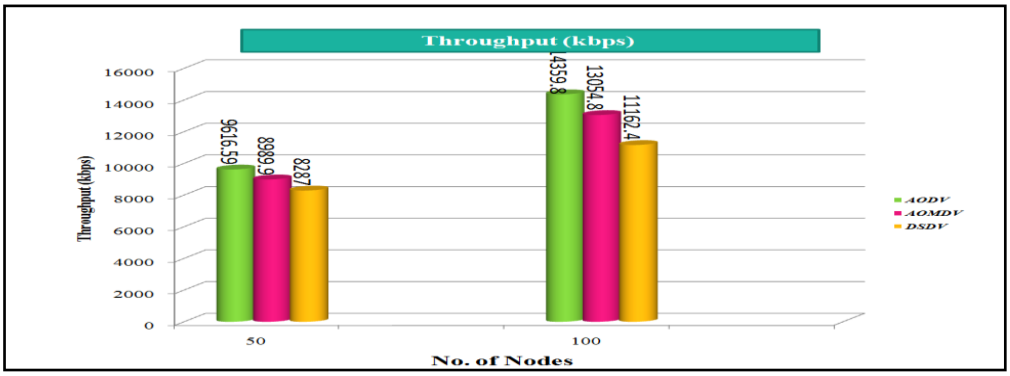
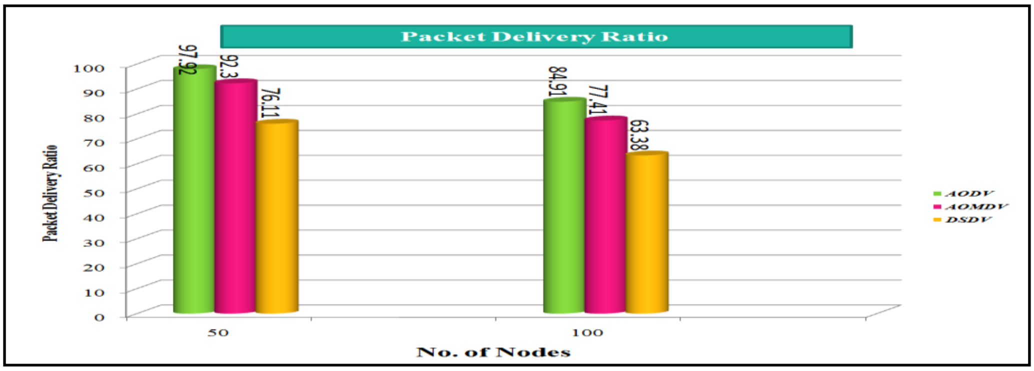
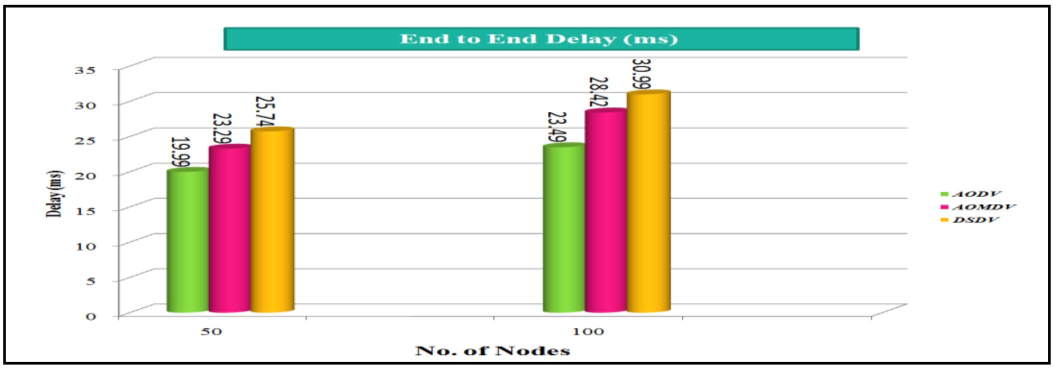
three routing protocols, measured in percentage. The simulation results indicate that AODV consistently achieves the highest packet delivery ratio, followed by AOMDV and then DSDV. Figure 4 (c) shows the graph of the end-to-end delay parameter for three routing protocols, measured in milliseconds. The results of the simulation show that AODV consistently achieves the lowest end-to-end delay, followed by AOMDV and then DSDV.



(a) Throughput



(b) Packet Delivery Ratio

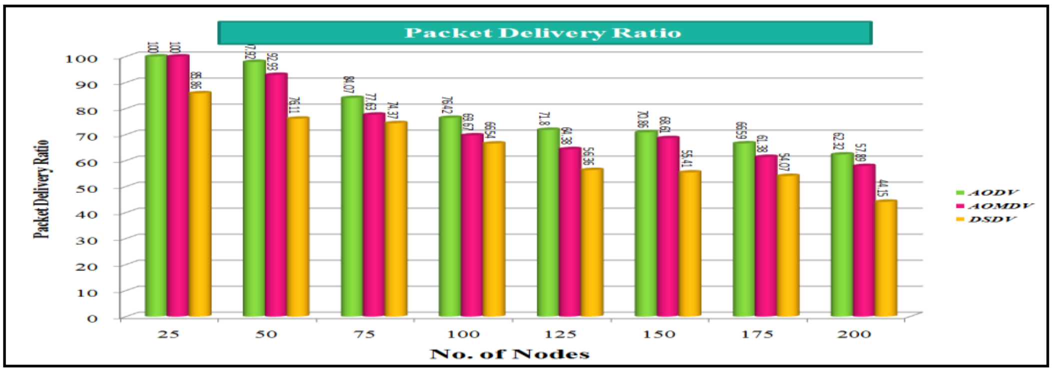


(c) End-to-End Delay

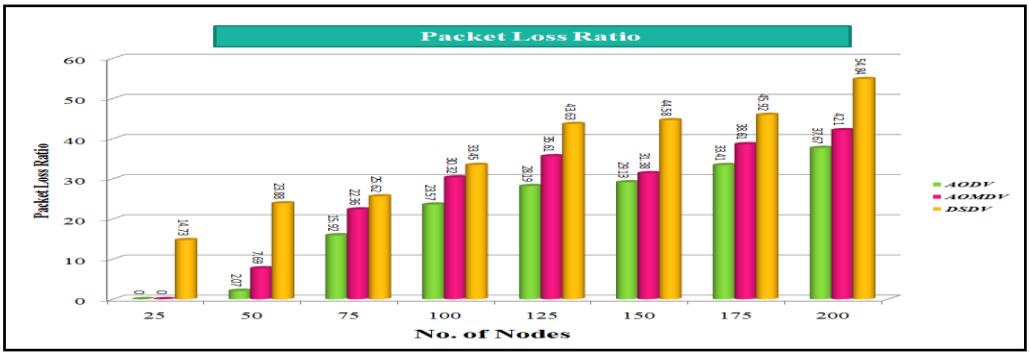
Figure 4: Module1- Graphs

Module II was conducted to compare the performance of three different routing protocols (AODV, AOMDV, and DSDV) in terms of throughput, packet delivery ratio, packet loss ratio, routing overhead, and delay. The simulation was conducted with varying numbers of nodes, ranging from 25 to 200. Figure 5 shows a total of five graphs that depict the parameters of three routing protocols. These graphs were generated using different numbers of nodes in a wireless IoT network. The graph in Figure 5(a) shows the packet delivery ratio for each routing protocol as the number of nodes increases. As the number of nodes increases, the packet delivery ratio decreases for all three routing protocols. However, the decrease is more pronounced for AODV than for AOMDV and DSDV. The graph in Figure 5(b) shows the packet loss ratio for each routing protocol as the number of nodes increases. As the number of nodes increases, the packet loss ratio increases for all three routing protocols. However, the increase is more pronounced for AODV than for AOMDV and DSDV.

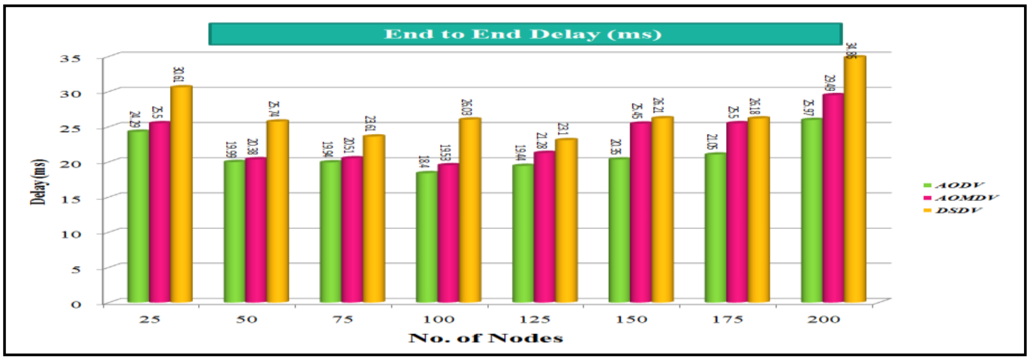
The graph in Figure 5(c) shows the average end-to-end delay for each routing protocol as the number of nodes increases. As the number of nodes increases, the end-to-end delay for all three routing protocols also increases. However, the increase is more pronounced for AODV than for AOMDV and DSDV. The graph in Figure 5 (d) shows the throughput for each routing protocol as the number of nodes increases. As the number of nodes increases, the throughput for all three routing protocols also increases. However, the increase is more pronounced for AODV than for AOMDV and DSDV. The graph in Figure 5 (e) shows the routing overhead for each routing protocol as the number of nodes increases. As the number of nodes increases, the routing overhead increases for all three routing protocols. However, the increase is more pronounced for AODV than for AOMDV and DSDV.



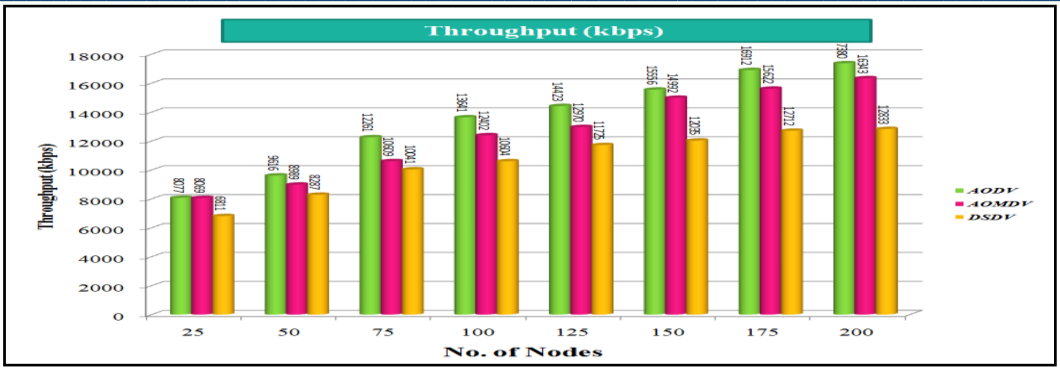
(a) Packet Delivery Ratio



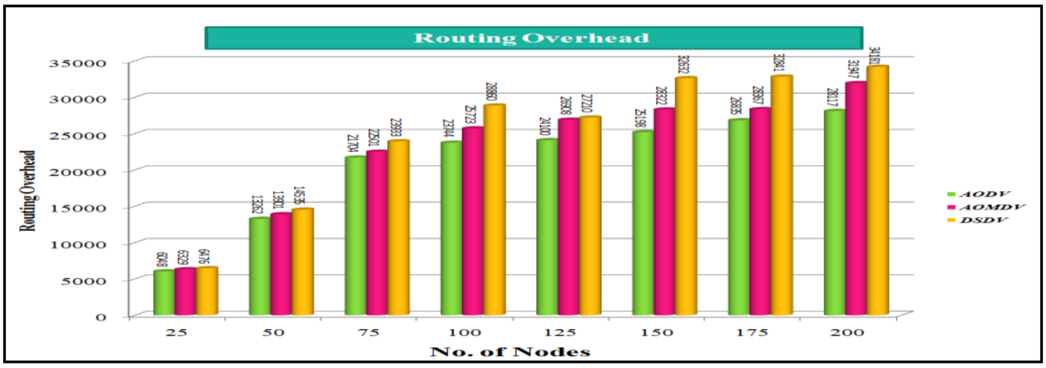
(b) Packet Loss Ratio



(c) End-to-End Delay



(d) Throughput



(e) Routing Overhead

Figure 5: Module2- Graphs

5. Conclusion

In this research work, two modules, Module I and Module II, have been discussed. Module I focuses on finding the most suitable routing protocol for IoT-based wireless networks. So, in the initial phase of the research work, three routing protocols have been considered, both of which are proactive and reactive in nature. AODV is a reactive type of routing, while DSDV and AOMDV are proactive types of routing. Since we chose Network Simulator 2 to conduct the simulation, which was initially challenging, we only tested three parameters for QoS purposes with a smaller number of nodes in Module I. Three Quality of Service (QoS) parameters, namely Packet Delivery Ratio, Throughput, and Average End-to-End Delay, were evaluated among three routing protocols in Module I. It was found that AODV is the better choice when compared to the other two routing protocols.

Module II focuses on finding the best scalable routing protocol for IoT-based networks, particularly when the number of nodes in the network increases. So, once again, the same three routing protocols are being considered. However, in Module II, the number of nodes varies from 25 to 200. Additionally, two more Quality of Service (QoS) parameters are evaluated, namely packet loss ratio and routing overhead. Here again in Module II, AODV routing is found to be a better choice when compared with the other two routing protocols.

Furthermore, it was found that the selection of a QoS-aware routing protocol had a significant impact on the overall network performance. The selection of an appropriate protocol is crucial to ensure efficient resource utilization and reliable data transmission in wireless networks for the Internet of Things (IoT). Additionally, the research highlighted the importance of considering the specific requirements and characteristics of Internet of Things (IoT) applications when selecting a quality of service (QoS)-aware routing protocol. Different applications may have distinct quality of service (QoS) requirements, and therefore, the protocol should be customized to meet these specific needs.

In terms of future work, there are several avenues for further research that can be explored. Firstly, evaluating additional QoS-aware routing protocols can provide a more comprehensive understanding of their performance in IoT wireless networks. This can help identify the most suitable protocol for specific application scenarios. Moreover, investigating the impact of various network parameters, such as network size, traffic load, and mobility patterns, on the performance of QoS-aware routing protocols can provide valuable insights. Understanding how these factors influence the performance of the protocol can help optimize network design and resource allocation.

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