A PROJECT REPORT

on

"IoT Application Scheduling problem using PSO in Cloud/Fog Computing"

Submitted to

KIIT Deemed to be University

In Partial Fulfillment of the Requirement for the Award of

BACHELOR'S DEGREE IN
COMPUTER SCIENCE & ENGG.

BY

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- SRUJANA MISHRA
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UNDER THE GUIDANCE OF

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CERTIFICATE

This is certify that the project entitled

"NAME OF PROJECT"

submitted by

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is a record of bonafide work carried out by them, in the partial fulfillment of the requirement for the award of Degree of Bachelor of Engineering (Computer Sci-ence & Engineering) at KIIT Deemed to be university, Bhubaneswar. This work is done during year 2024-2025, under our guidance.

Date: 04/04/24

PROF. PRASENJIT MAITI
Project Guide

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ABSTRACT

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This study explores how the number of fog nodes affects network delay in IoT systems, aiming to improve performance by optimizing fog computing deployment. We examine two IoT scenarios: a smart agriculture network with **100** IoT devices, used for tasks like automated irrigation and environmental monitoring, and a smart city network with **10,000** IoT devices, supporting applications such as traffic management and pollution monitoring. We test three cases where the number of fog nodes increases from 1 to 15, 1 to 20, and 1 to 30. The results show that adding more fog nodes initially reduces delay, as tasks are processed closer to the IoT devices. However, after a certain point, increasing fog nodes no longer improves delay because of extra communication overhead and resource competition. We also consider real-world factors like network congestion, varying workloads, and different device capabilities, which impact delay. These findings help in deciding the optimal number of fog nodes to minimize delay without wasting resources. This study provides useful insights for designing efficient, fast, and scalable IoT networks with improved service quality.

KEYWORDS:

Fog nodes, IoT devices, delay, network congestion, varying workloads, device capabilities, communication overhead, real-world conditions, estimation accuracy, dynamic factors, optimization.

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Chapter 1

Introduction

As the number of IoT devices continues to grow, they generate massive amounts of data that must be processed efficiently. Traditional cloud computing often struggles with high latency, making real-time processing difficult. Fog computing addresses this issue by bringing computational resources closer to the devices, reducing delay and improving performance. However, the efficiency of fog computing depends on the number and placement of fog nodes, which act as intermediaries between IoT devices and the cloud.

In this study, we analyze how the number of fog nodes affects the delay in an IoT network with 100 devices and 10000 devices . We test different setups, varying the number of fog nodes from 1 to 15 , 1 to 20 , 1 to 30 to identify the optimal configuration that minimizes delay and maximizes efficiency. To ensure reliable results, we conduct the analysis under controlled conditions using a random seed while also considering real-world factors that introduce variability.

Understanding the trade-offs between the number of fog nodes and network delay is crucial for designing scalable and efficient IoT systems. By leveraging statistical methods such as averaging results, we ensure the accuracy and stability of our findings. This research provides valuable insights into optimizing fog node deployment, ultimately contributing to the development of more responsive and efficient IoT networks

Chapter 2

Literature Review:

Fog computing decentralizes computational resources, reducing latency and enhancing efficiency in IoT networks. It extends cloud services to the network edge, improving bandwidth utilization and security. Researchers have emphasized optimal fog node placement and explored its benefits for real-time applications. IoT connects smart devices for autonomous data exchange, but challenges arise from massive data volumes, necessitating efficient processing techniques to manage network traffic and performance. Low-latency solutions are particularly crucial for applications like healthcare and autonomous systems.

Latency, influenced by network congestion and node distribution, is critical for IoT performance. Strategic fog node placement has been shown to reduce response times and improve network efficiency. Studies have examined the trade-offs between latency and bandwidth while analyzing fog networks' ability to handle dynamic workloads. Performance analysis often relies on random seed initialization for reproducibility, ensuring consistent results in simulations and experiments. Mean estimation techniques help stabilize outcomes by reducing variability in stochastic models.

Real-world IoT environments introduce uncertainties such as network congestion and device failures, requiring adaptive algorithms and dynamic scheduling models for resource optimization. This project builds on prior research by analyzing fog node deployment's impact on network delay, using statistical techniques to enhance reliability and performance. By incorporating real-world uncertainties, the study aims to provide practical insights into optimizing fog computing for IoT networks.

Chapter 3

Problem Statement

The rapid adoption of IoT devices across various domains has led to an exponential increase in data generation, creating a need for efficient data processing and management. While cloud computing is commonly used, it introduces high latency due to the long-distance communication between IoT devices and centralized cloud servers. Fog computing offers a solution by bringing computational resources closer to the devices, reducing latency and improving real-time processing.

However, the effectiveness of fog computing depends on the optimal number of fog nodes deployed within the network. If too few fog nodes are used, the system may still experience high delay due to limited processing capacity. On the other hand, deploying too many fog nodes can lead to resource inefficiencies and increased overhead without significant performance improvements.

This delay is a major issue for real-time applications where immediate decision-making is crucial, such as traffic management, remote healthcare monitoring, and precision farming. To overcome this, fog computing places smaller processing nodes closer to the devices. However, finding the right number of fog nodes is challenging. Too few fog nodes result in slow processing, while too many lead to wasted resources. This project aims to determine the optimal number of fog nodes to reduce delays and efficiently manage resources in IoT networks.

3.1 Project Planning:

The following steps will be followed to plan and execute the project development:

- ❖ Define the Problem Statement
- ❖ Clearly articulate the problem being addressed and the objectives of the project.
- ❖ Conduct a Literature Review
- ❖ Review existing research on fog computing, IoT, and latency optimization to identify gaps and opportunities.
- ❖ Collect Requirements
- ❖ Gather functional and non-functional requirements from stakeholders and relevant literature.
- ❖ Set up the necessary software and hardware tools for simulating the IoT network and fog nodes.
- ❖ Implement the simulation model using appropriate programming languages and tools in different scenarios.
- ❖ Execute simulations with varying numbers of fog nodes and collect data on delay.
- ❖ Analyze Results.
- ❖ Prepare a comprehensive report detailing the methodology, results, and insights gained from the project.

3.2 Project Analysis:

After collecting the requirements and conceptualizing the problem statement, the following steps will be taken to analyze the project:

- Identify Ambiguities:
- Review the problem statement and requirements to identify any ambiguities or inconsistencies.
- Validate Requirements
- Ensure that the requirements are complete, consistent, and feasible.
- Assess Risks
- Identify potential risks and challenges that may arise during the project and develop mitigation strategies.
- Refine the Problem Statement:
- Based on the analysis, refine the problem statement to ensure clarity and focus.

3.3 System Design:

3.3.1 System Architecture :

Three-layer architecture:

1. IoT Device Layer – Sensors and devices that collect data.

2. Fog Computing Layer – Intermediate processing units (fog nodes) that reduce latency by handling data closer to IoT devices.

3. Cloud Layer – Centralized storage and processing for long-term analytic

3.3.2 Hardware and Software Components :

Software Tools:
Simulation software (e.g., Python) for modeling the IoT network and fog nodes.
Statistical tools for data analysis and visualization.

Hardware Requirements:

IoT Devices: Sensors, actuators, and communication modules
Fog Nodes: Edge servers or computing units handling intermediate processing.
A computer with sufficient processing power and memory to run simulations.
Internet connectivity for accessing relevant literature and tools.
Communication Technologies**:** Wi-Fi, 5G, or LPWAN used for data transfer between layers.

Chapter 4

Implementation and Result

4.1 Methodology

The implementation of the project involves several steps to ensure a structured approach to solving the problem of optimizing fog node deployment in an IoT network. The methodology consists of the following phases:

Problem Definition

- **Objective:**
  - Identify how the number of fog nodes affects network delay in an IoT environment.

Data Collection and Device Distribution

- **Simulation Setup:**
  - Simulate two IoT network scenarios: one with 100 devices and another with 10,000 devices.
- **Device Distribution:**
  - Used the Poisson distribution to find how many devices are likely to be present in a given area , randomly distributed the IoT devices over the network area, ensuring a realistic and variable spread..

Cluster Formation and Fog Node Placement

- **Algorithm Selection:**
  - Apply K-means clustering to group the IoT devices into clusters.
- **Clustering Process:**
  - The K-means algorithm is used to partition the devices into a specified number of clusters (e.g., 15, 20, or 30 clusters).
  - The centroid of each cluster, which represents the average position of all devices in the cluster, is identified.

- **Fog Node Placement:**
    - Place a fog node at the centroid of each cluster, ensuring that the nodes are positioned where they can optimally manage and process data from nearby devices.

Data Processing and Statistical Analysis

- **Data Aggregation:**
    - Calculate performance metrics such as mean delay , efficiency across the network for each configuration.
- **Statistical Methods:**
    - Use statistical methods to interpret and stabilize the results, allowing for a clear comparison between different deployment scenarios.

Result Analysis

- **Performance Evaluation:**
    - Assess the delay reduction and computational efficiency achieved with different numbers of fog nodes.
- **Graphical Representation:**
    - Plot graphs of network delay as a function of the number of fog nodes to visualize the performance trends.
- **Optimal Configuration Identification:**
    - Identify the point at which adding more fog nodes does not result in significant delay improvements.

4.2 Testing

- **Objective:**
  Assess how the delay in an IoT network changes with the number of fog nodes deployed.
- **Test Condition:**
  - The number of fog nodes is varied while the IoT device distribution remains constant.
  - Two test cases are used: one with 100 IoT devices and another with 10,000 IoT devices.
  - Within these test cases, the number of devices used in the clustering (or distribution analysis) may be set at 15, 20, or 30 devices to find the delay behavior.
- **System Behavior:**
  - As the number of fog nodes increases, the system measures the network delay.
  - Initially, increasing fog nodes helps reduce the delay due to more localized processing.
  - Beyond an optimal number of fog nodes, additional nodes do not significantly reduce delay, and the performance plateaus.
- **Expected Result:**
  - A graph showing network delay as a function of the number of fog nodes.
  - The graph is expected to depict a decrease in delay up to a certain point (optimal configuration), after which the delay levels off.
  - Comparing the two test cases (100 vs. 10,000 IoT devices) can reveal how scalability impacts network delay.

4.3 Result Analysis:

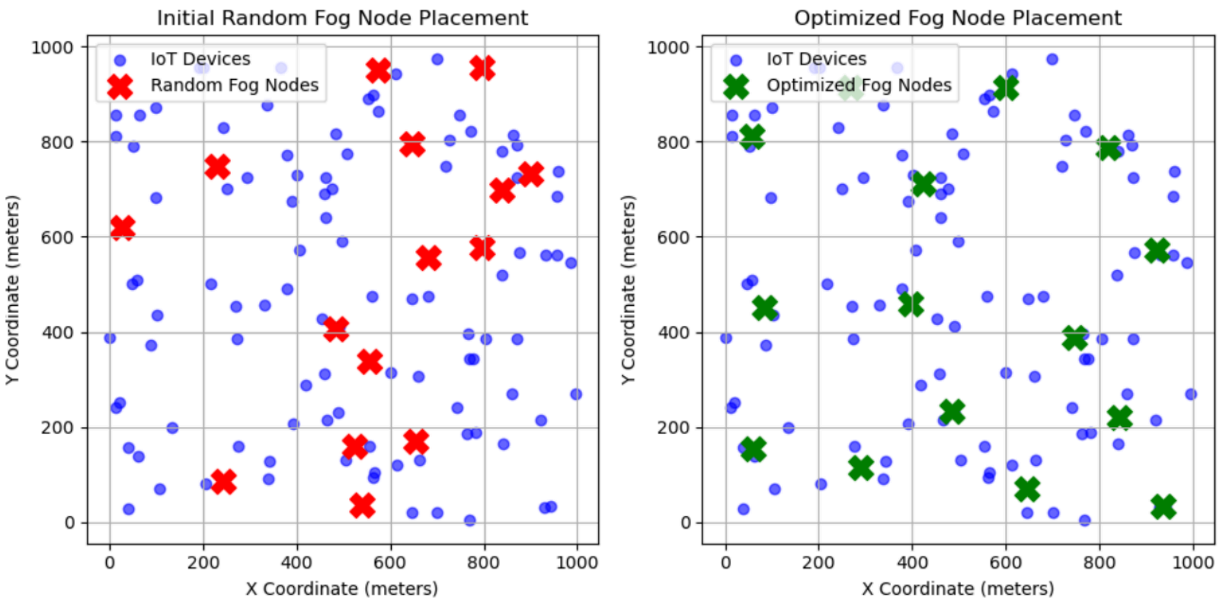
Below is an analysis of how delay changes with an increasing number of fog nodes:
Observations:
- As the number of fog nodes increases, the delay initially decreases.
- Beyond a certain point (approximately 12, for (case 1), 16 for (case 2), 25 for (case 3) nodes), delay stabilizes.
- This suggests an optimal range for deploying fog nodes.

1. Poisson distribution result :-

```
Estimated number of IoT devices required for 1 km²: 94
```

```
Mean number of IoT devices: 99.57
Standard deviation: 10.46
Minimum devices: 67, Maximum devices: 132
```

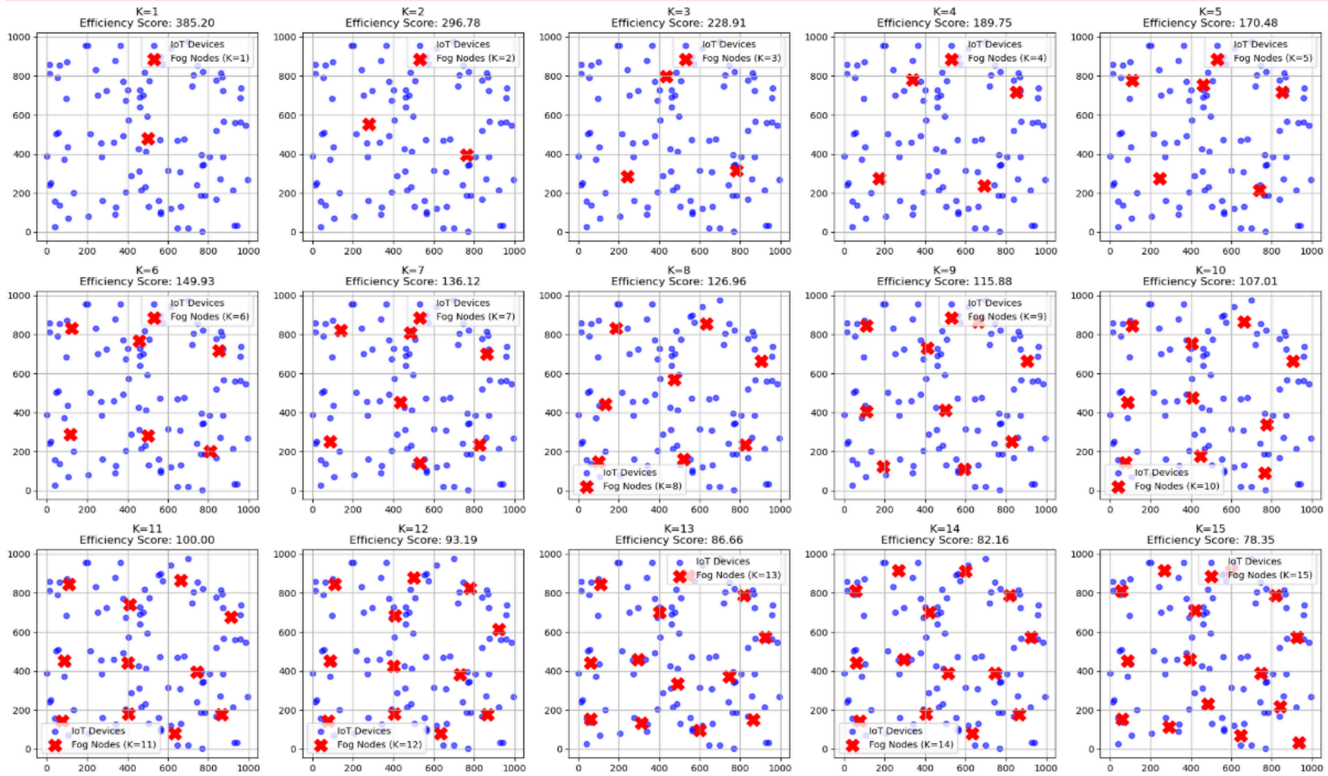
2. k-means optimization result :-




```
📍 Initial Random Fog Node Positions:
[[899 733]
 [484 406]
 [230 748]
 [654 170]
 [540  35]
 [524 159]
 [838 698]
 [242  85]
 [795 577]
 [681 556]
 [573 952]
 [645 795]
 [ 27 619]
 [555 339]
 [797 957]]

✅ Optimized Fog Node Positions:
[[395.375      459.875     ]
 [818.44444444 786.66666667]
 [645.57142857  70.71428571]
 [290.75       114.75      ]
 [267.6        915.2       ]
 [747.         388.875     ]
 [ 59.42857143 155.        ]
 [422.         712.08333333]
 [924.         573.5       ]
 [485.375      232.125     ]
 [ 85.33333333 451.66666667]
 [935.5         33.       ]
 [ 56.83333333 811.66666667]
 [600.4        913.6       ]
 [843.28571429 219.57142857]]
```

3. Efficiency (low efficiency score means that fog nodes are closer to IoT devices

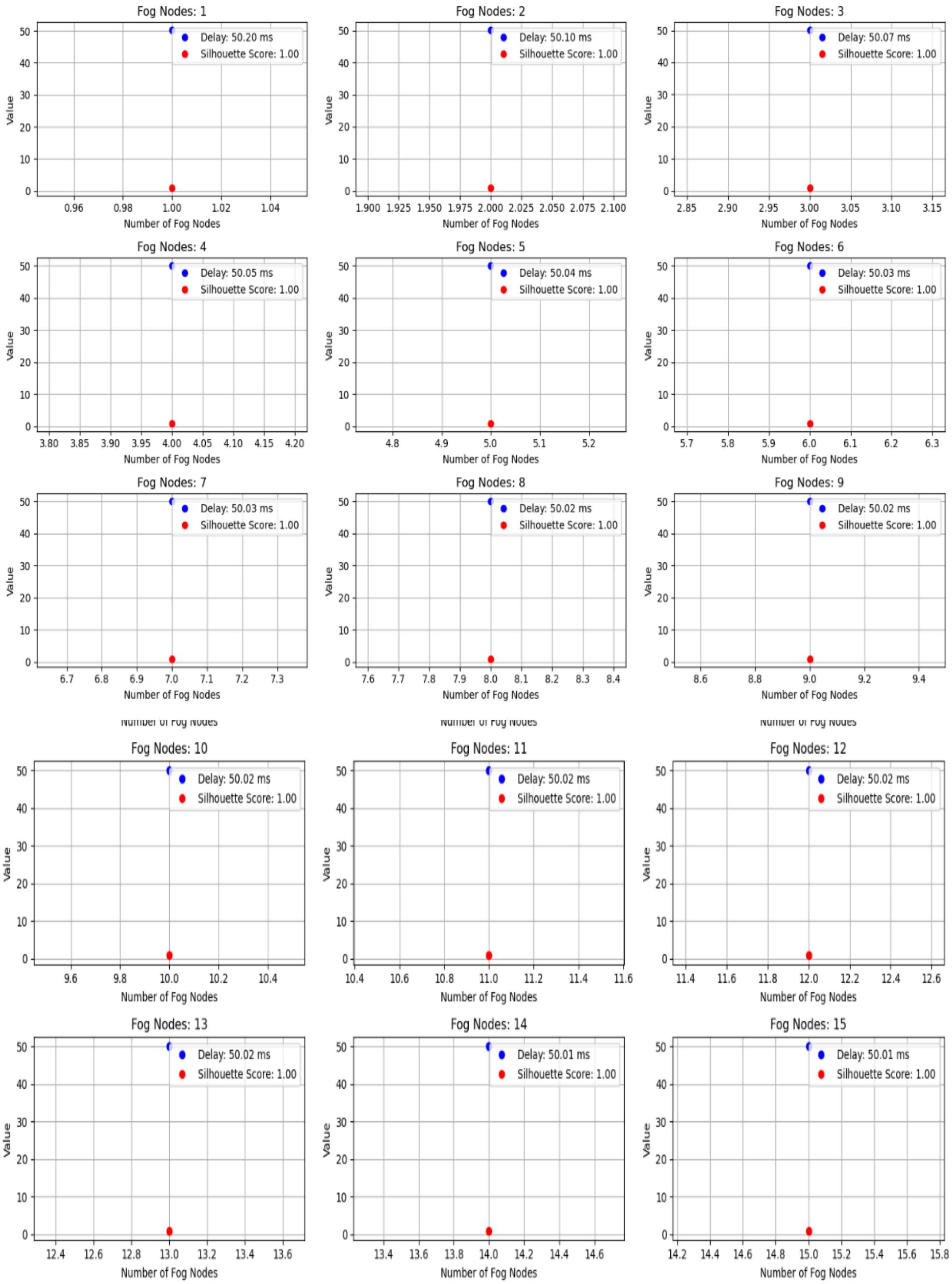


K=1 | Efficiency Score: 385.20
K=2 | Efficiency Score: 296.78
K=3 | Efficiency Score: 228.91
K=4 | Efficiency Score: 189.75
K=5 | Efficiency Score: 170.48
K=6 | Efficiency Score: 149.93
K=7 | Efficiency Score: 136.12
K=8 | Efficiency Score: 126.96
K=9 | Efficiency Score: 115.88
K=10 | Efficiency Score: 107.01
K=11 | Efficiency Score: 100.00
K=12 | Efficiency Score: 93.19
K=13 | Efficiency Score: 86.66
K=14 | Efficiency Score: 82.16
K=15 | Efficiency Score: 78.35

AGRICULTURAL SCENARIO

CASE 1 :-

FOG NODES(1 TO 15)
IOT DEVICES 100
AREA OF THE PLOT :- 1KM SQUARE


Fog Nodes: 1
Delay: 50.20 ms
Silhouette Score: 1.00
Fog Nodes: 2
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Fog Nodes: 3
Delay: 50.07 ms
Silhouette Score: 1.00
Fog Nodes: 4
Delay: 50.05 ms
Silhouette Score: 1.00
Fog Nodes: 5
Delay: 50.04 ms
Silhouette Score: 1.00
Fog Nodes: 6
Delay: 50.03 ms
Silhouette Score: 1.00
Fog Nodes: 7
Delay: 50.03 ms
Silhouette Score: 1.00
Fog Nodes: 8
Delay: 50.02 ms
Silhouette Score: 1.00
Fog Nodes: 9
Delay: 50.02 ms
Silhouette Score: 1.00
Fog Nodes: 10
Delay: 50.02 ms
Silhouette Score: 1.00
Fog Nodes: 11
Delay: 50.02 ms
Silhouette Score: 1.00
Fog Nodes: 12
Delay: 50.02 ms
Silhouette Score: 1.00
Fog Nodes: 13
Delay: 50.02 ms
Silhouette Score: 1.00
Fog Nodes: 14
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Fog Nodes: 15
Delay: 50.01 ms
Silhouette Score: 1.00
Value
Number of Fog Nodes

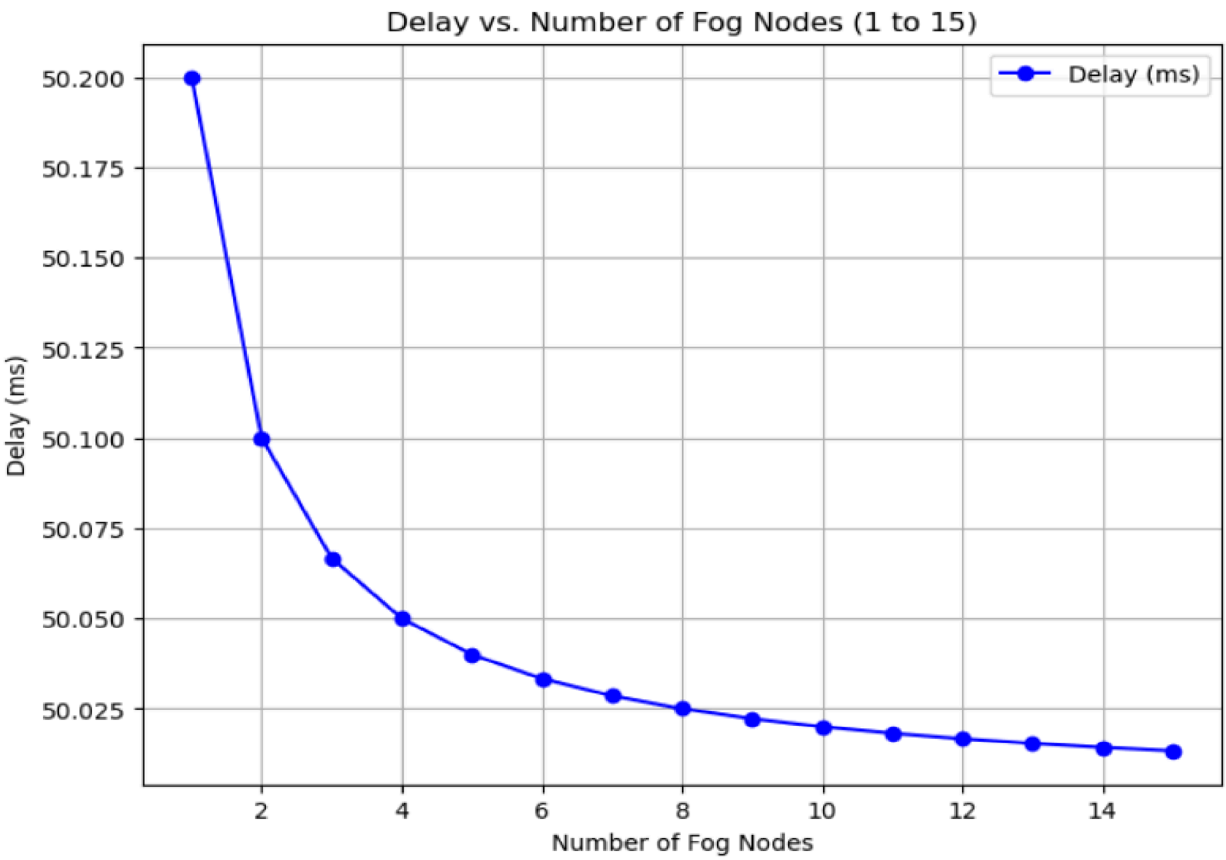


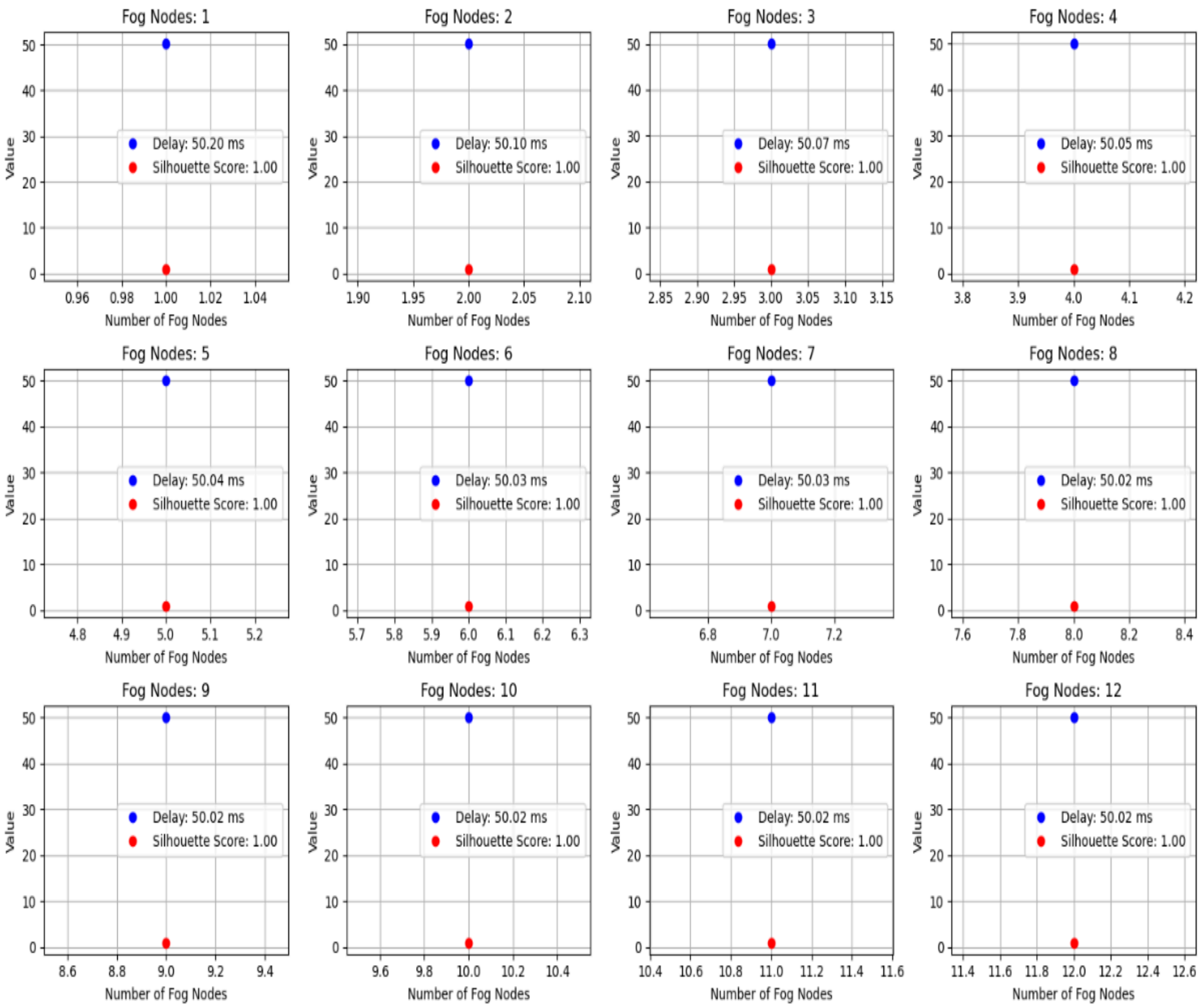
fig 4.1

percentage changes in delay as the number of fog nodes increases up to 15:

- From 1 to 3 nodes: -0.27%
- From 3 to 5 nodes: -0.05%
- From 5 to 7 nodes: -0.02%
- From 7 to 9 nodes: -0.01%
- From 9 to 11 nodes: -0.008%
- From 11 to 13 nodes: -0.006%
- From 13 to 15 nodes: -0.004%

CASE 2 :-

FOG NODES(1 TO 20)
IOT DEVICES 100
AREA OF THE PLOT :- 1KM SQUARE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Delay: 50.07 ms
Silhouette Score: 1.00
Fog Nodes: 4
Delay: 50.05 ms
Silhouette Score: 1.00
Fog Nodes: 5
Delay: 50.04 ms
Silhouette Score: 1.00
Fog Nodes: 6
Delay: 50.03 ms
Silhouette Score: 1.00
Fog Nodes: 7
Delay: 50.03 ms
Silhouette Score: 1.00
Fog Nodes: 8
Delay: 50.02 ms
Silhouette Score: 1.00
Fog Nodes: 9
Delay: 50.02 ms
Silhouette Score: 1.00
Fog Nodes: 10
Delay: 50.02 ms
Silhouette Score: 1.00
Fog Nodes: 11
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Fog Nodes: 12
Delay: 50.02 ms
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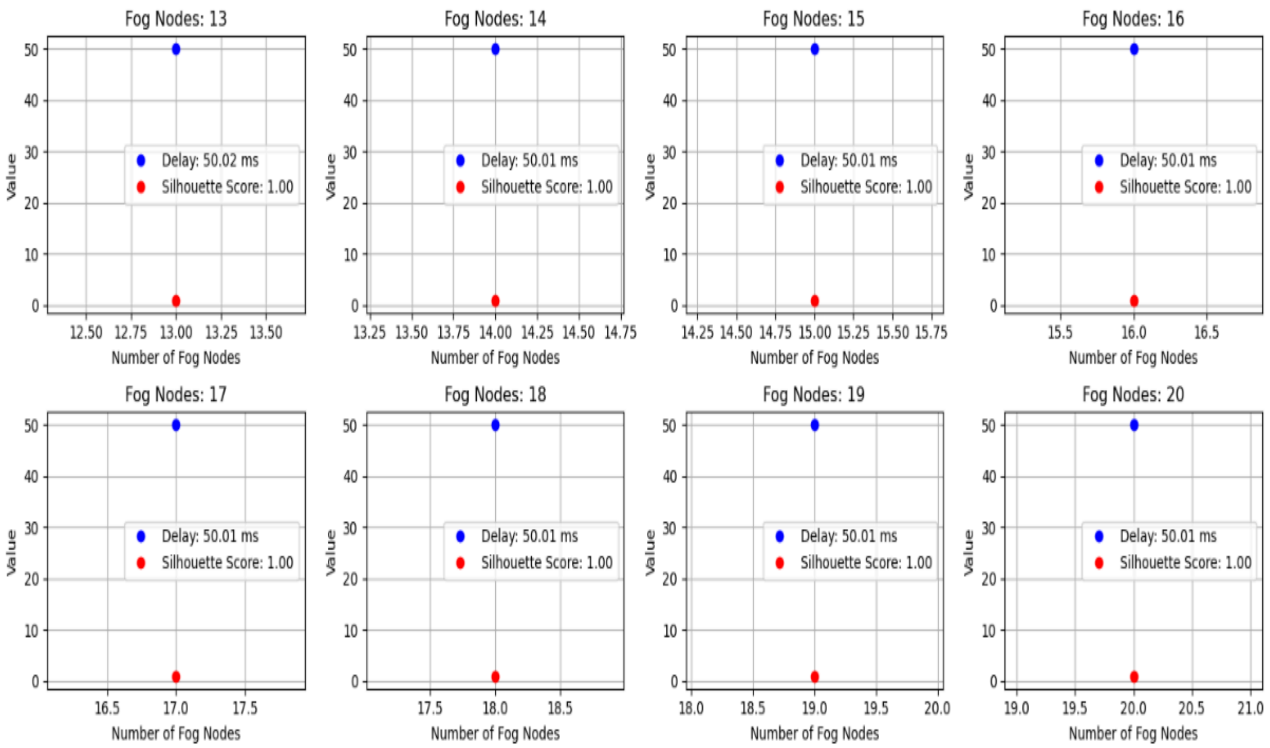
Value
Number of Fog Nodes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Fog Nodes: 15
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Fog Nodes: 16
Delay: 50.01 ms
Silhouette Score: 1.00
Fog Nodes: 17
Delay: 50.01 ms
Silhouette Score: 1.00
Fog Nodes: 18
Delay: 50.01 ms
Silhouette Score: 1.00
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Value
Number of Fog Nodes

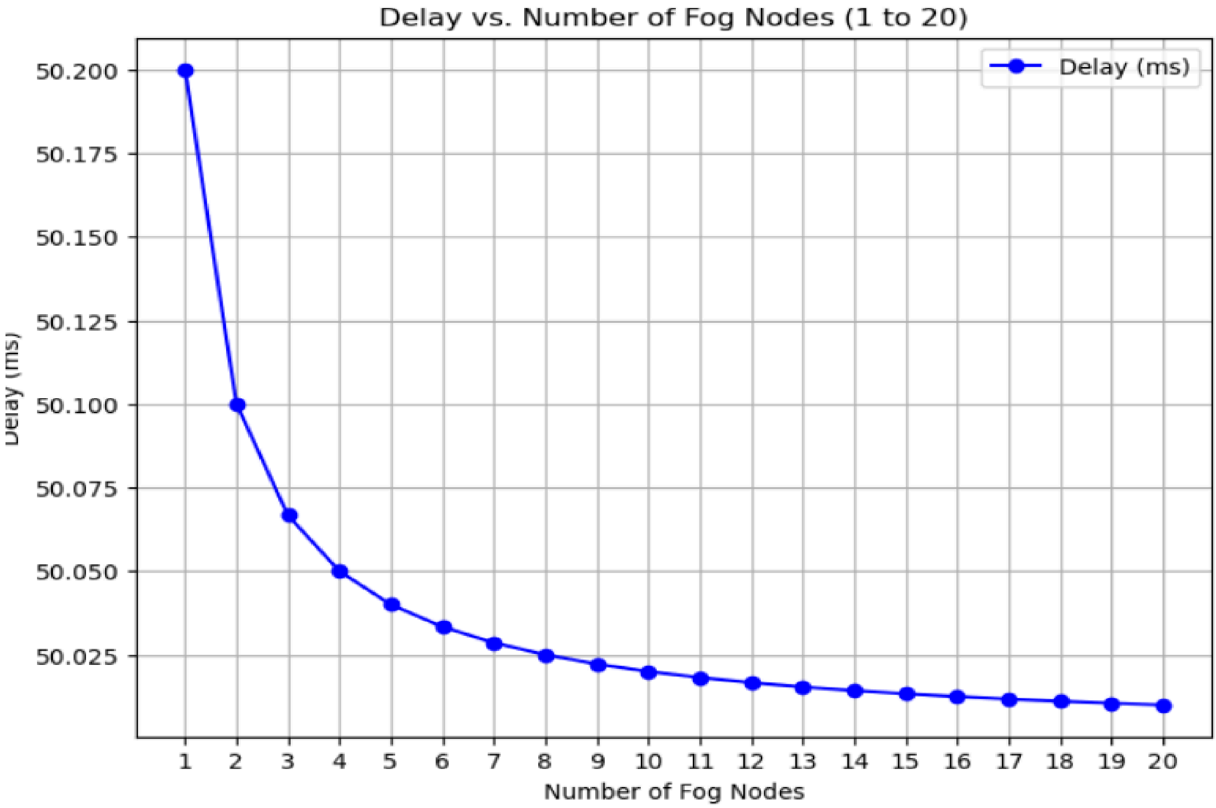


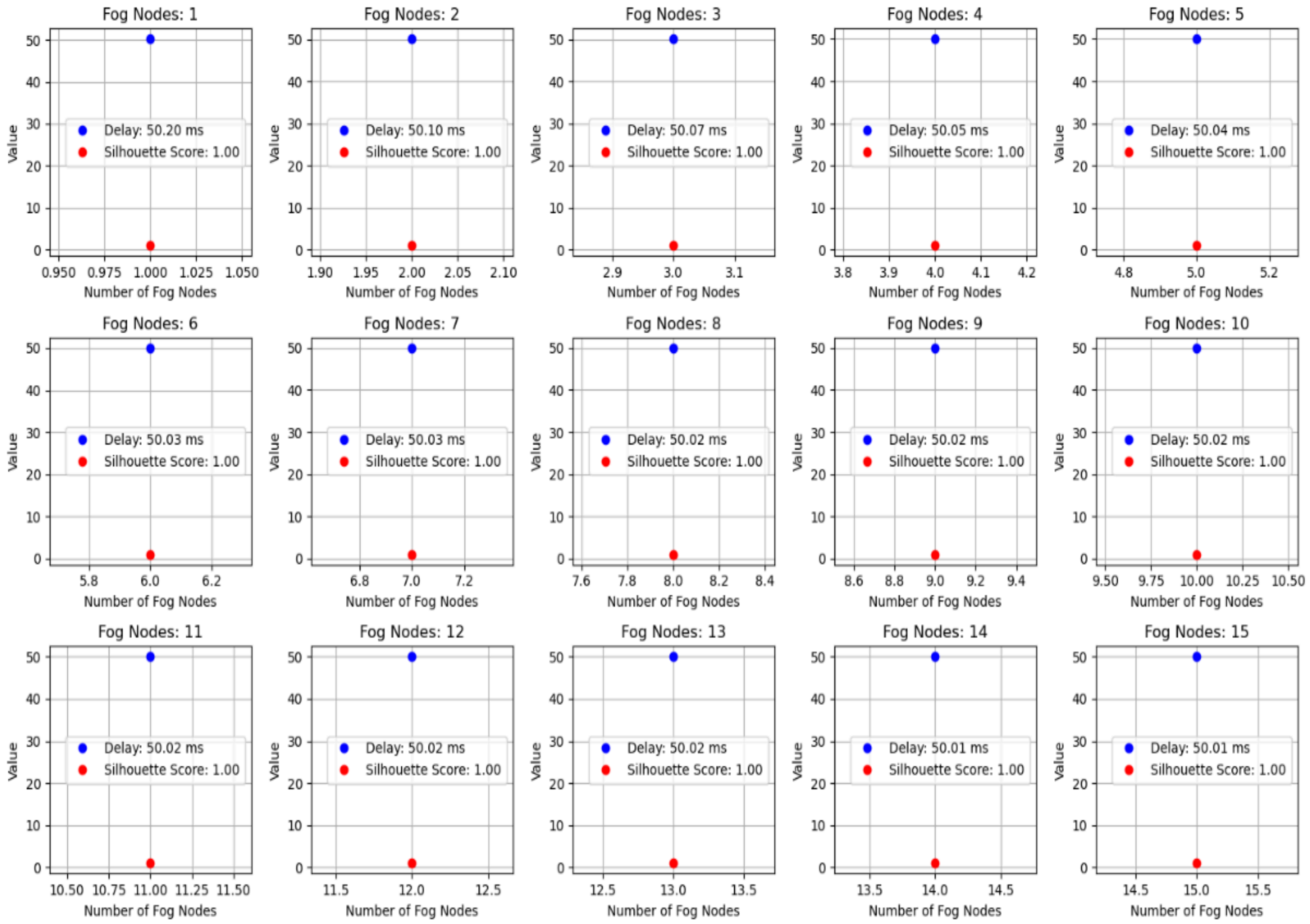
fig - 4.2

percentage changes in delay as the number of fog nodes increases from 1 to 20:

- From 1 to 3 nodes: -0.27%
- From 3 to 5 nodes: -0.05%
- From 5 to 7 nodes: -0.02%
- From 7 to 9 nodes: -0.01%
- From 9 to 11 nodes: -0.008%
- From 11 to 13 nodes: -0.006%
- From 13 to 15 nodes: -0.004%
- From 15 to 17 nodes: -0.003%
- From 17 to 20 nodes: -0.002%

CASE 3 :-

FOG NODES(1 TO 30)
IOT DEVICES 100
AREA OF THE PLOT :- 1KM SQUARE



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Delay: 50.20 ms
Silhouette Score: 1.00
Fog Nodes: 2
Delay: 50.10 ms
Silhouette Score: 1.00
Fog Nodes: 3
Delay: 50.07 ms
Silhouette Score: 1.00
Fog Nodes: 4
Delay: 50.05 ms
Silhouette Score: 1.00
Fog Nodes: 5
Delay: 50.04 ms
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Fog Nodes: 7
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Fog Nodes: 8
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Fog Nodes: 9
Delay: 50.02 ms
Silhouette Score: 1.00
Fog Nodes: 10
Delay: 50.02 ms
Silhouette Score: 1.00
Fog Nodes: 11
Delay: 50.02 ms
Silhouette Score: 1.00
Fog Nodes: 12
Delay: 50.02 ms
Silhouette Score: 1.00
Fog Nodes: 13
Delay: 50.02 ms
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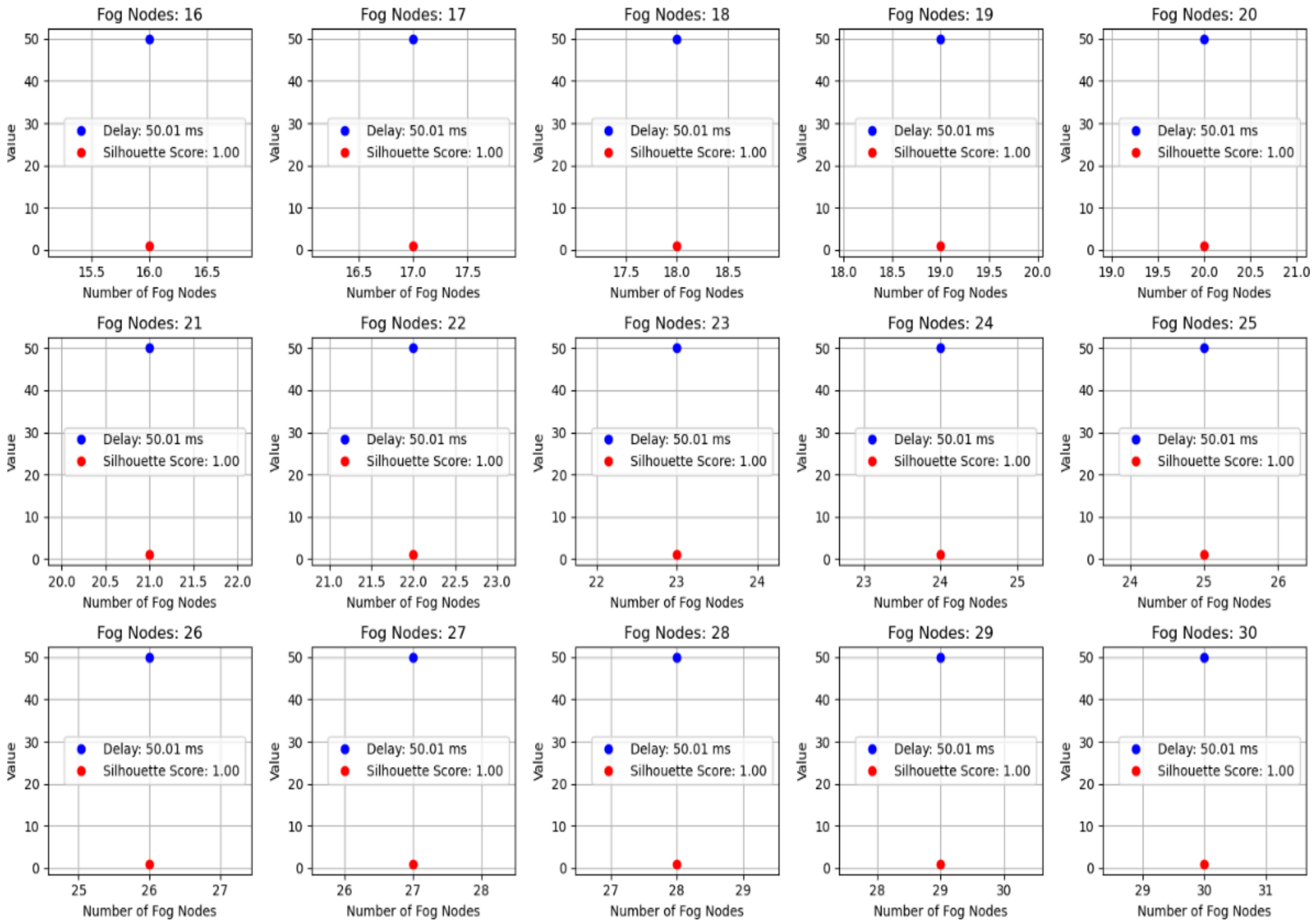
Value
Number of Fog Nodes



Fog Nodes: 16
Fog Nodes: 17
Fog Nodes: 18
Fog Nodes: 19
Fog Nodes: 20
Fog Nodes: 21
Fog Nodes: 22
Fog Nodes: 23
Fog Nodes: 24
Fog Nodes: 25
Fog Nodes: 26
Fog Nodes: 27
Fog Nodes: 28
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Fog Nodes: 30
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Value
Number of Fog Nodes

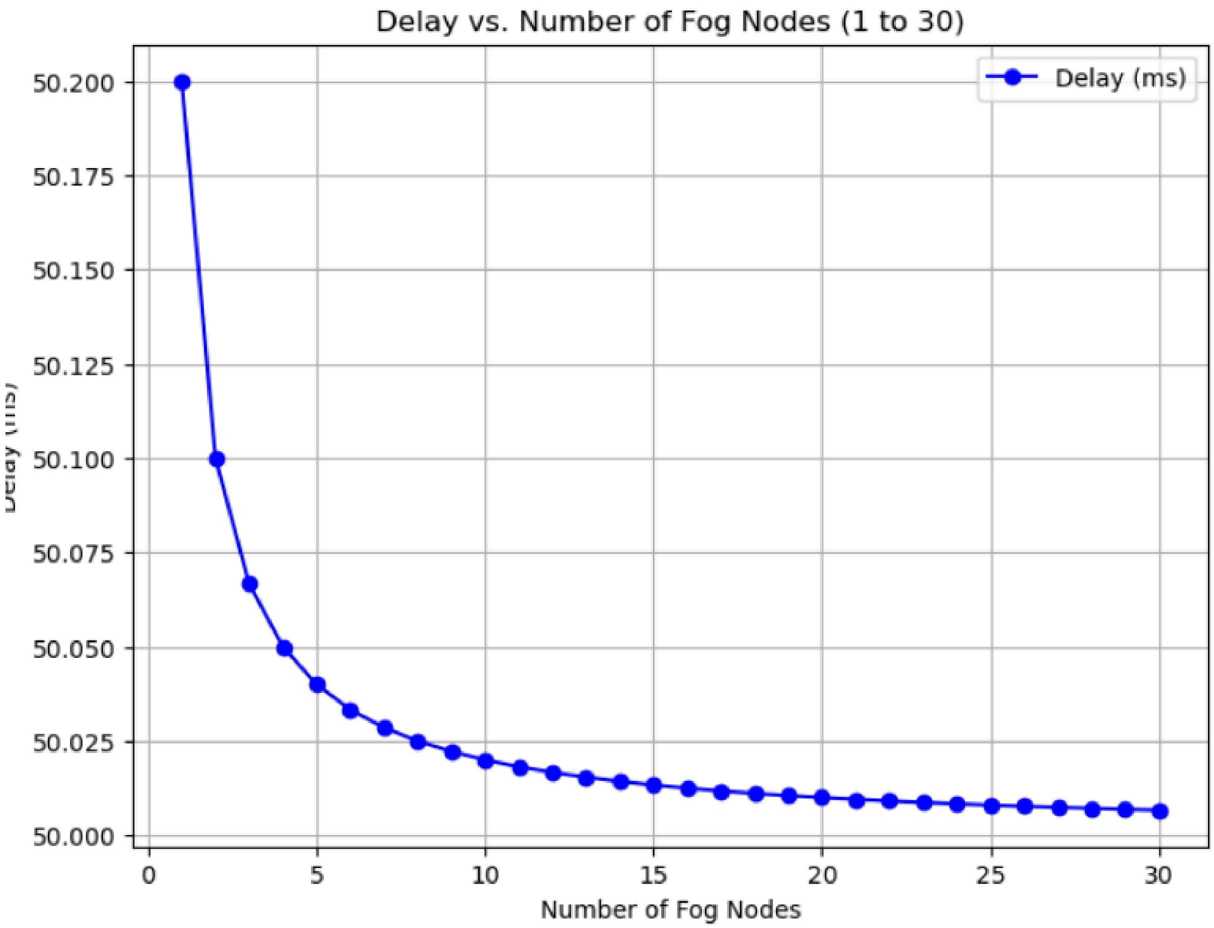


fig - 4.3

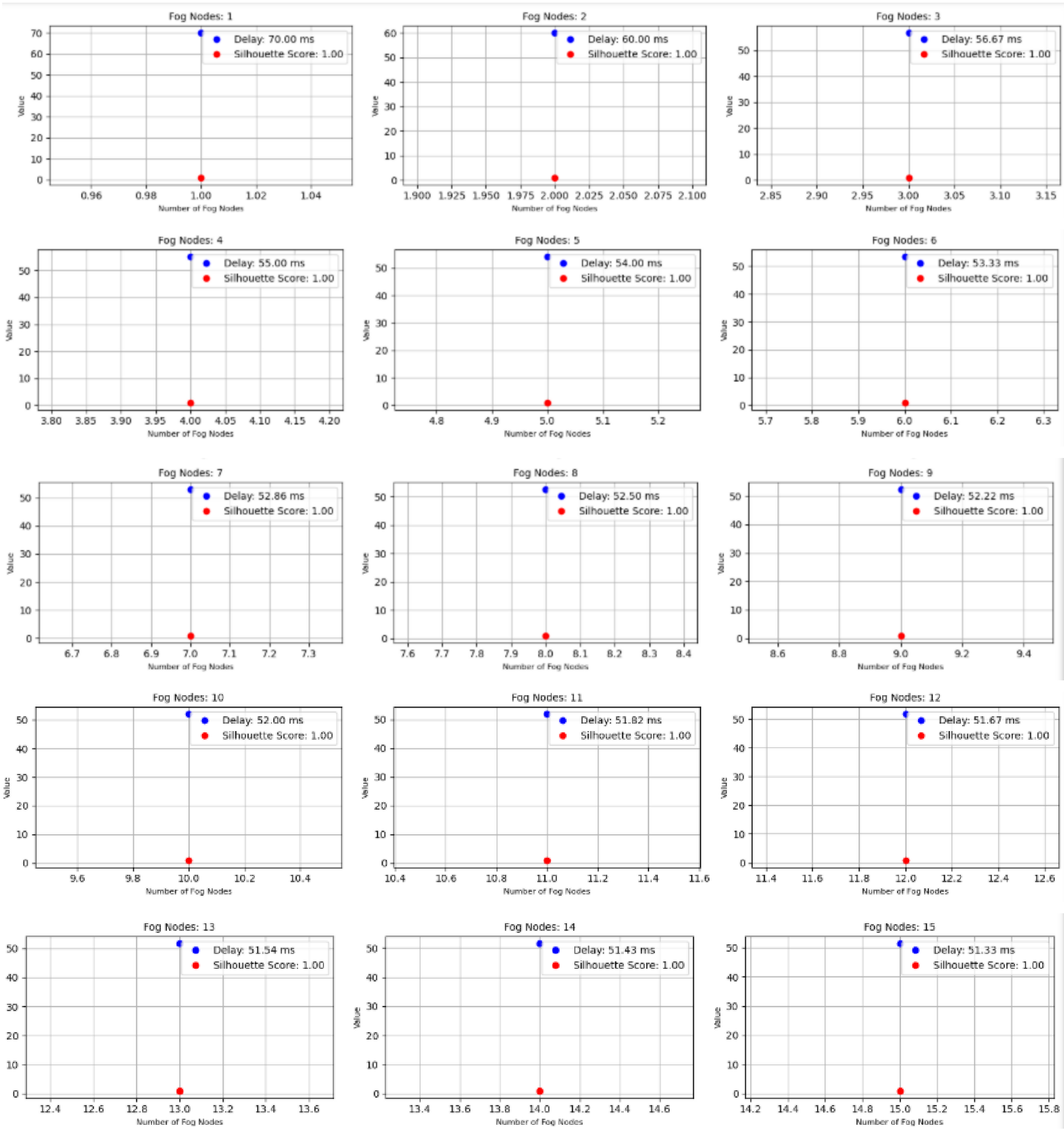
- From 1 to 3 nodes: -0.27%
- From 3 to 5 nodes: -0.05%
- From 5 to 7 nodes: -0.02%
- From 7 to 9 nodes: -0.01%
- From 9 to 11 nodes: -0.008%
- From 11 to 13 nodes: -0.006%
- From 13 to 15 nodes: -0.004%
- From 15 to 17 nodes: -0.003%
- From 17 to 20 nodes: -0.002%
- From 20 to 23 nodes: - 0.0018%
- From 23 to 26 nodes: - 0.0016%
- From 26 to 30 nodes: - 0.0015%

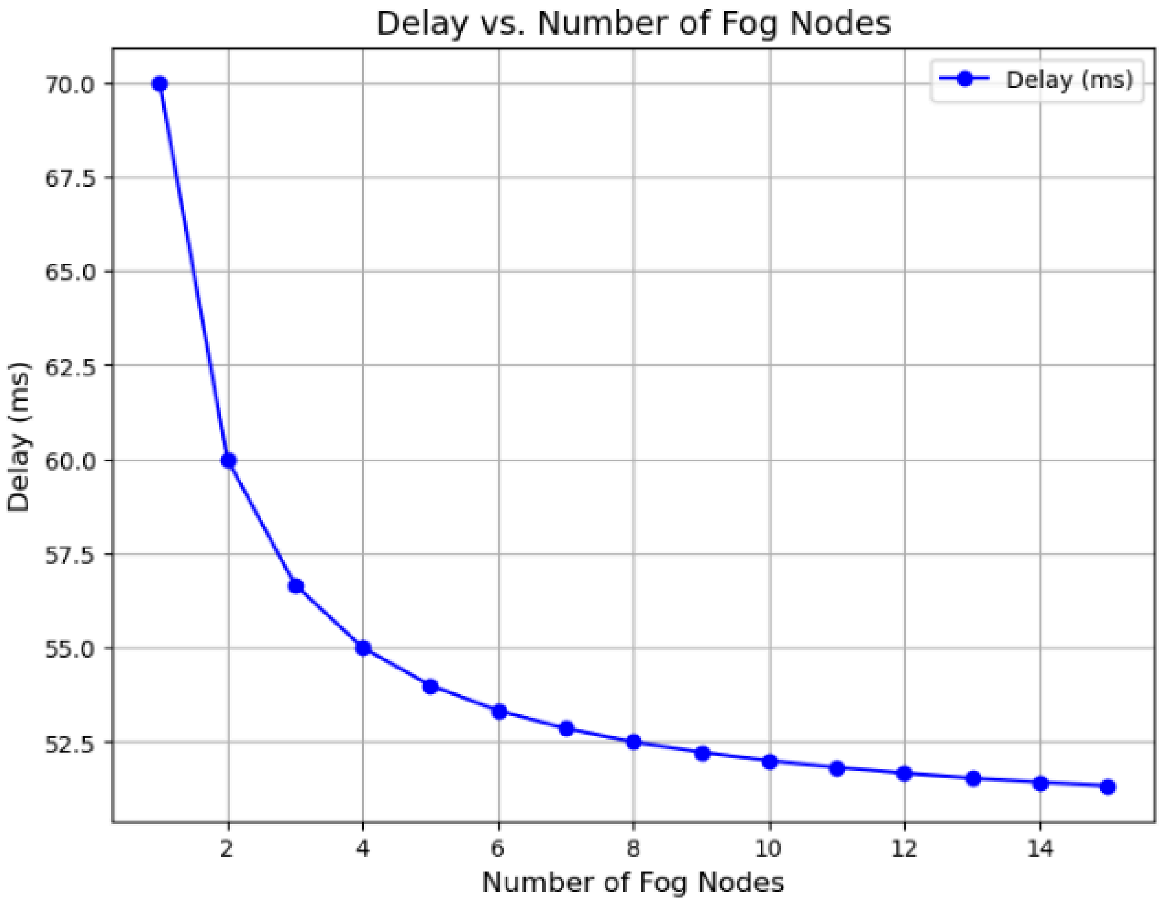
This confirms that while adding fog nodes reduces delay, the rate of improvement decreases significantly. After a certain point, additional fog nodes provide minimal benefit.

SMART CITY SCENARIO

CASE 1 :-

FOG NODES(1 TO 15)
IOT DEVICES 10000
AREA OF THE PLOT :- 1KM SQUARE





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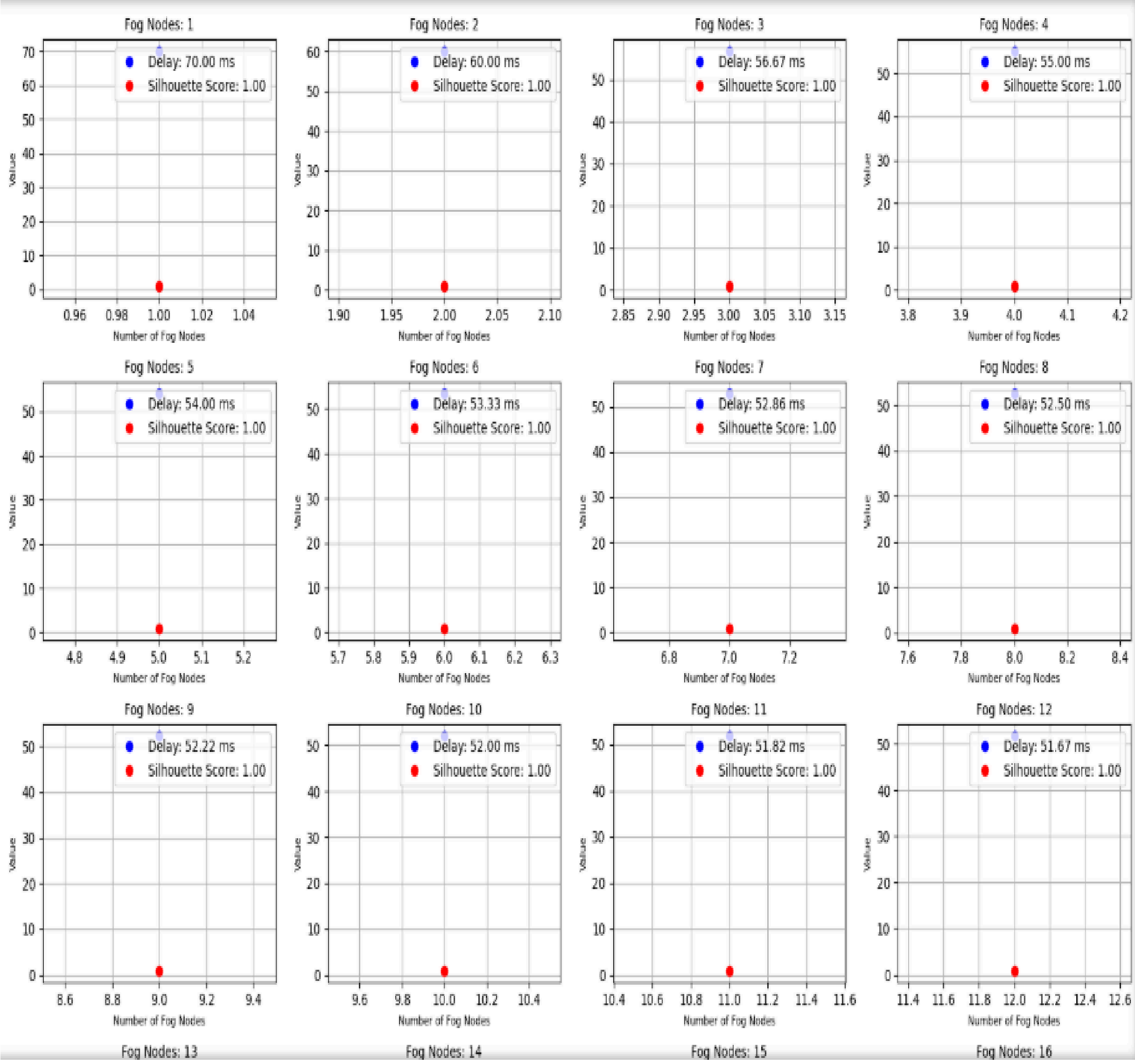
CASE 2 :-

FOG NODES(1 TO 20)
IOT DEVICES 10000
AREA OF THE PLOT :- 1KM SQUARE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Fog Nodes: 4
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Fog Nodes: 5
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Fog Nodes: 6
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Fog Nodes: 7
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Fog Nodes: 8
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Fog Nodes: 9
Delay: 52.22 ms
Silhouette Score: 1.00
Fog Nodes: 10
Delay: 52.00 ms
Silhouette Score: 1.00
Fog Nodes: 11
Delay: 51.82 ms
Silhouette Score: 1.00
Fog Nodes: 12
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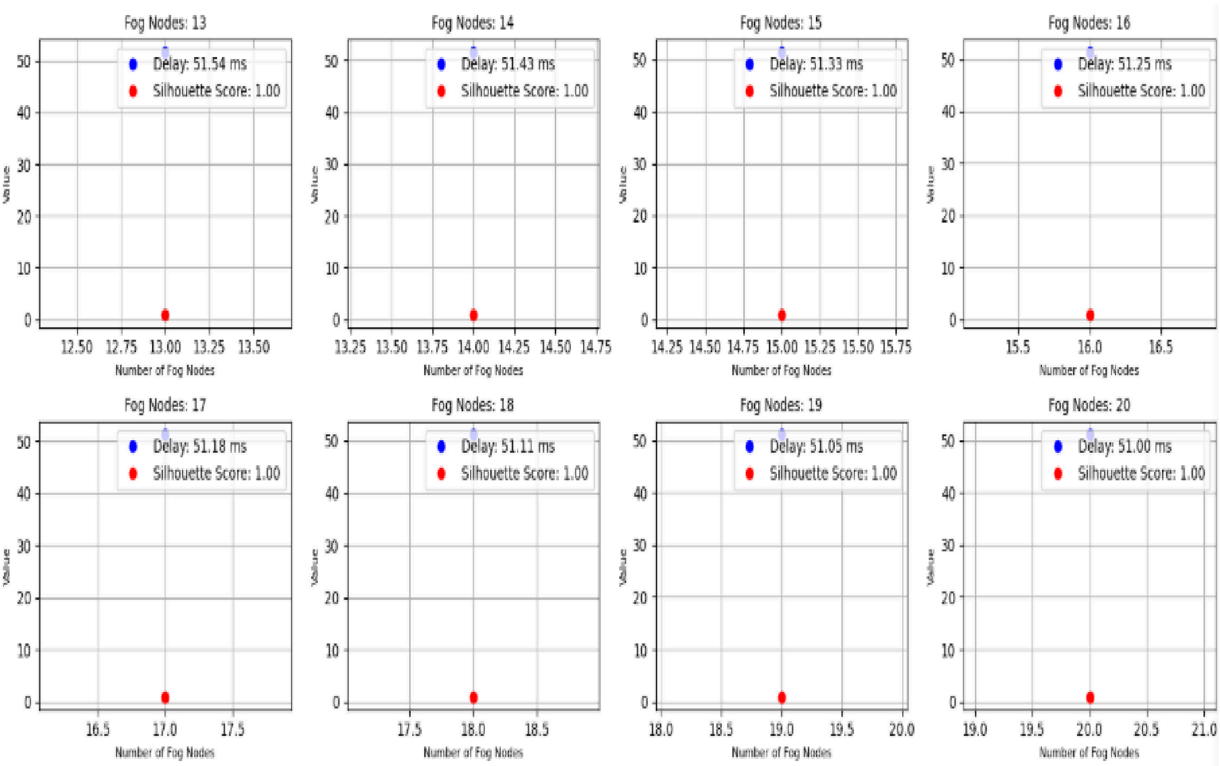
Fog Nodes: 15
Fog Nodes: 16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Fog Nodes: 16
Delay: 51.25 ms
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Fog Nodes: 17
Delay: 51.18 ms
Silhouette Score: 1.00
Fog Nodes: 18
Delay: 51.11 ms
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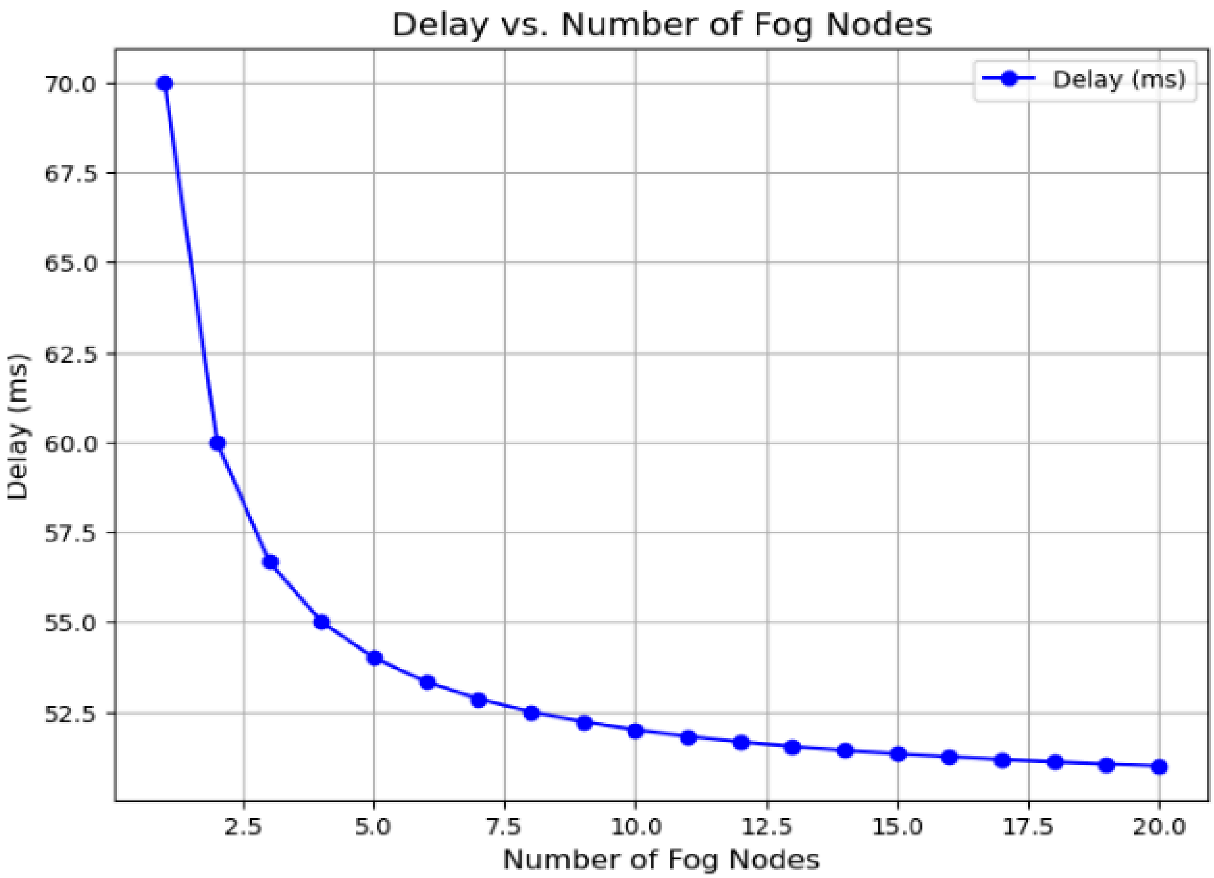
Number of Fog Nodes



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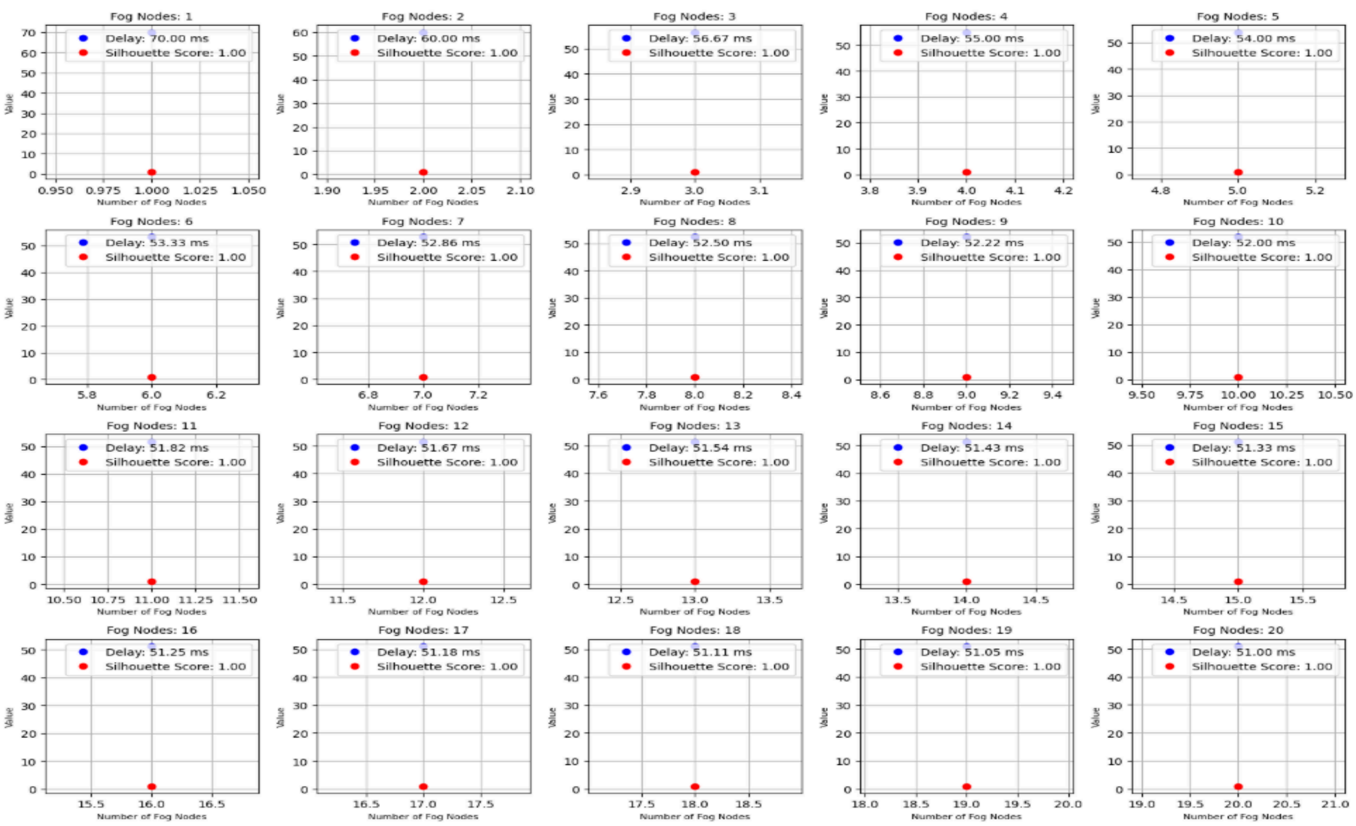
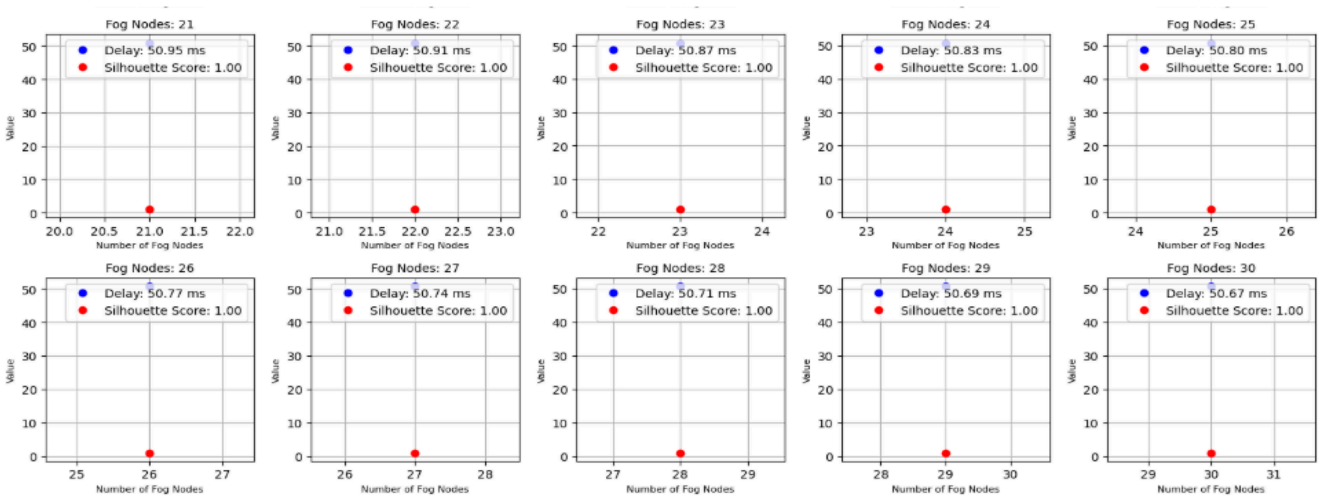
CASE 3 :-

FOG NODES(1 TO 30)
IOT DEVICES 10000
AREA OF THE PLOT :- 1KM SQUARE





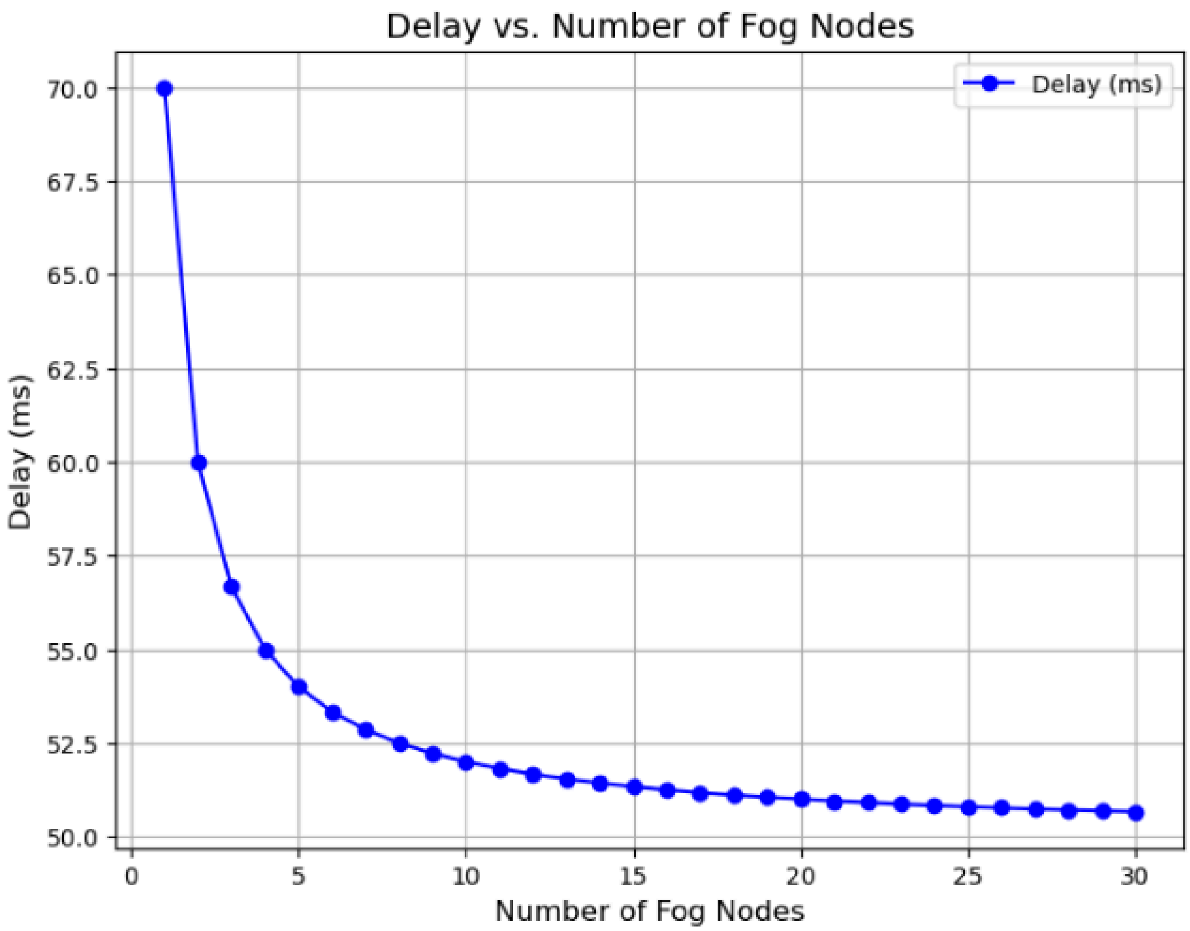


fig - 4.6

In our study, we analyzed two IoT scenarios:

1. **Agriculture Scenario** – A network with 100 IoT devices used for precision farming, automated irrigation, and environmental monitoring.

2. **Smart City Scenario** – A large-scale network with 10,000 IoT devices used for traffic management, pollution monitoring, and public safety applications.

For both scenarios, we tested the impact of different numbers of fog nodes under three cases:

- **Case 1:** 1 to 15 fog nodes
- **Case 2:** 1 to 20 fog nodes
- **Case 3:** 1 to 30 fog nodes

This resulted in a total of **six observations**, three for each scenario.

4.4 Key Findings from Observations

- Increasing the number of fog nodes initially reduces network delay**.** This is because more fog nodes mean tasks are processed closer to the IoT devices, reducing the time taken for data transmission and processing.
- However, after a certain point, the reduction in delay becomes minimal. This happens because once a sufficient number of fog nodes are available, adding more does not significantly improve efficiency.
- The delay continues to decrease slightly but becomes nearly flat. This means that although the graph shows a downward trend, the improvements become marginal after a specific number of fog nodes.
- Beyond a certain threshold, adding extra fog nodes does not provide any noticeable benefit. Instead, it may lead to unnecessary resource allocation, increased management complexity, and additional overhead without improving performance.

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Chapter 5: Conclusion and Future Scope

5.1 Conclusion

This project demonstrates that deploying additional fog nodes substantially reduces network delay up to an optimal point, after which further additions provide minimal benefits. In the test scenario, the delay starts around 50 ms with one fog node and drops significantly as more nodes are introduced, stabilizing near 10–15 nodes. By strategically placing fog nodes using K-means clustering, the system balances performance gains and resource utilization, emphasizing the importance of identifying an optimal fog node configuration for scalable and efficient IoT networks.

5.2 Future Scope

This study provides valuable insights into optimizing fog computing for IoT networks, but there are several areas for future improvements and extensions.

1. Scalability and Large-Scale Deployment
2. Adaptive and Intelligent Fog Node Allocation
3. Energy Efficiency and Sustainability
4. Real-World Implementation and Testing
5. Security Improvements
6. Hybrid Fog-Cloud Systems

References:-

1. IEEE Standard for Fog Computing Architecture. IEEE 1934-2018.
2. Bonomi, F., Milito, R., Zhu, J., & Addepalli, S. (2012). Fog computing and its role in the internet of things.
3. Mahmud, R., Kotagiri, R., & Buyya, R. (2018). Fog computing: A taxonomy, survey, and future directions.

INDIVIDUAL CONTRIBUTION REPORT

"IoT Application Scheduling problem using PSO in Cloud/Fog Computing".

NAME **CONTRIBUTION**

AYUSH NAYAK :- Tested two different scenarios (like agriculture and smart city). obtained graph outputs of the delay vs no of fog nodes. Tested different scenarios of increasing fog nodes from (1-15), (1-20),(1-30) . calculated and mentioned percentage of change in delay during increase of fog nodes .

SRUJANA MISHRA :- I estimated the number of IoT devices required using Poisson distribution to analyze demand patterns effectively. Additionally, I identified the optimal placement of fog nodes to enhance network efficiency and reduce latency. To evaluate performance, I calculated the efficiency score of fog nodes for 15 different cases, ranging from 1 to 15 fog nodes, ensuring a comprehensive understanding of system behavior under varying conditions.

Full Signature of Supervisor: Full signature of the student:
AYUSH NAYAK

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