SMART FOG – A COLLABORATIVE APPROACH TO SHARE COMPUTATIONAL POWER OF FOG DEVICES FOR FOG COMPUTING IN SMART CITY IoT NETWORK

स्मार्ट फ़ॉग - स्मार्ट सिटी आईओटी नेटवर्क में फ़ॉग कंप्यूटिंग के लिए फ़ॉग उपकरणों की कम्प्यूटेशनल शक्ति साझा करने के लिए एक सहयोगात्मक दृष्टिकोण

A Thesis

Submitted for the Award of Ph.D. degree

by

NALAWADE SURAJ RAJARAM

नलवडे सूरज राजाराम

Under the Supervision of

Dr. ASHOK KUMAR JETAWAT

Professor
Pacific Academy of Higher Education
& Research University, Udaipur

FACULTY OF COMPUTER ENGINEERING
PACIFIC ACADEMY OF HIGHER EDUCATION AND RESEARCH UNIVERSITY UDAIPUR
2024

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I, **NALAWADE SURAJ RAJARAM** S/o **Mr. NALAWADE RAJARAM ANNA** resident of 4624, Suryoday Niwas, Adarsh Colony, Near Modern High School, Rahimatpur Road, Koregaon. Satara Maharashtra, hereby declare that the work incorporated in the present thesis entitled **"SMART FOG – A COLLABORATIVE APPROACH TO SHARE COMPUTATIONAL POWER OF FOG DEVICES FOR FOG COMPUTING IN SMART CITY IoT NETWORK" ("स्मार्ट फ़ॉग - स्मार्ट सिटी आईओटी नेटवर्क में फ़ॉग कंप्यूटिंग के लिए फ़ॉग उपकरणों की कम्प्यूटेशनल शक्ति साझा करने के लिए एक सहयोगात्मक दृष्टिकोण")** is my own work and is original. This work (in part or in full) has not been submitted to any University for the award of a Degree or a Diploma. I have properly acknowledged the material collected from secondary sources wherever required. I solely own the responsibility for the originality of the entire content.

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PACIFIC ACADEMY OF HIGHER EDUCATION & RESEARCH UNIVERSITY, UDAIPUR

Dr. ASHOK KUMAR JETAWAT
Professor

CERTIFICATE

It gives me immense pleasure in certifying that the thesis entitled **"SMART FOG – A COLLABORATIVE APPROACH TO SHARE COMPUTATIONAL POWER OF FOG DEVICES FOR FOG COMPUTING IN SMART CITY IoT NETWORK" ("स्मार्ट फ़ॉग - स्मार्ट सिटी आईओटी नेटवर्क में फ़ॉग कंप्यूटिंग के लिए फ़ॉग उपकरणों की कम्प्यूटेशनल शक्ति साझा करने के लिए एक सहयोगात्मक दृष्टिकोण")** submitted by **NALAWADE SURAJ RAJARAM** is based on the research work carried out under my guidance. he has completed the following requirements as per Ph.D. regulations of the University.

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Professor
Pacific Academy of Higher Education & Research University.

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ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest regards and gratitude to my eminent and esteemed supervisor and guide **Dr. Ashok Kumar Jetawat**, Professor, Department of Computer Engineering, Pacific Academy of Higher Education and Research University, Udaipur, Rajasthan, for giving me inspiration, guidance, valuable suggestions, opinions and correction for the betterment of my research work. I will always be grateful to him. He was always available for help at any point in time. His guidance helped me in the time of research work and writing of my thesis.

As I reflect on this milestone, I am reminded of the profound significance of the support network which surrounds us. To **Dr. Jayshree Jain** madam, I extend my deepest gratitude for her unwavering support and understanding throughout this journey. In this journey, I have witnessed the impact of her support, whether it was through guiding me at different stages of my research work or offering words of encouragement when the path seemed daunting. Her contribution, perhaps less visible, has been just as vital in shaping my academic growth.

I am thankful to the University authorities, especially **Dr. HEMANT KOTHARI**, Dean, Pacific Academy of Higher Education and Research University, Udaipur, Rajasthan, and **Shri Ramesh Agrawal** who guided me at different stages of research work and others in PAHER for their support and encouragement. Without their precious support, it would not be possible to conduct this research, and Ms. **Kusum Madam** and **Dr. Surya** Pacific University Udaipur for helping me in creating the Plagiarism report.

A special note of gratitude to my father, **Shri Rajaram Anna Nalawade**, My mother, **Smt. Sangita Rajaram Nalawade**, whose blessings, love, and support have always aided me in my research endeavors. My lovely wife, **Smt. Ashwini Suraj Nalawade**, my smart son, **Mr. Advait Suraj Nalawade**, and my brother, **Mr. Uday Rajaram Nalawade**, Dr. Manisha Songire (Nalawade) Mrs. Survena Yadav, Mr. Vinod Yadav, who has always stood by me, I express my gratitude for their love, support, and encouragement.

I am thankful to my grandfather, **Shri Namdev Shivram Deokar**, whose blessings, love, and inspiration always added to my research work.

I would like to thank **Prof. Dasharath Sagare Sir** - Founder President, YSPM's Yashoda Technical Campus, Satara; **Prof. Ajinkya D. Sagare Sir** - Vice President, **Mr. Ganesh K. Survase** Sir - Registrar, **Mr. R. D. Mohite** - Associate Director, YSPM's Yashoda Technical Campus, Satara, **Dr. R. J. Dias** working at Government College of Pharmacy, Karad, Late **Dr. A. B. Mahatme**, Ex Principal, YSPM's Yashoda Technical Campus, Sataras.

I pay all my heartfelt gratitude to my friend Mr. Navnath Pandurang Jadhav working at MAHLE Holding India Pvt Ltd, Pune, Dr. Madhuri Navanath Jadhav Professor at Pune, Mr. Amol Baburao Nalawade, Mphasis Limited, Pune, Mr. Abhijeet Avinash Salunkhe, Branch Manager at Janata Sahakari Bank, Satara, Mrs. Nikita Abhijeet Salunkhe, my colleague Prof. Hakke Dasganu G. Working at Yashoda Technical Campus, Satara, and Pacific University, Udaipur for helping me directly or indirectly making this research work a success.

Thank you to everyone who has directly or indirectly helped me on this beautiful voyage.

NALAWADE SURAJ RAJARAM

PREFACE

Smart cities have emerged as a solution to enhance services and quality of life for residents and visitors. These cities have made significant progress in optimizing resource utilization, promoting environmental protection, improving infrastructure operations and maintenance, and strengthening safety and security measures. Achieving these improvements requires the implementation of new and existing technologies, as well as the application of optimization techniques. Among the technologies supporting smart city applications, the Internet of Things, FOG computing, and cloud computing play vital roles. Integrating these three technologies into a single system, known as the integrated IoT-Fog-Cloud system, offers a sophisticated platform for developing and managing various smart city applications. By leveraging the strengths of IoT gadgets, FOG nodes, and cloud services, this platform enables applications to deliver optimal functionality and performance. The integrated system opens up numerous opportunities for enhancing applications across sectors such as energy, transportation, healthcare, and more. This research work focuses on designing an improvised SMART FOG system, which the key emphasis of the study.

Outline of the Thesis:

The entire research work is divided into six chapters as discussed. The chapterization contains the overview of the proposed SMART FOG protocol-based technique, implementation challenges, task allocation, scheduling techniques, fault tolerance mechanisms, literature review of different authors, result analysis/testing, performance evaluation, and conclusion.

- **Chapter - 1 Introduction:** Serves as a foundation for the research work by highlighting the need for the study. It accomplishes this by referencing various articles and analyzing surveys to establish a solid base for the proposed research. To clarify the background concepts of fog computing, different terminologies related to fog computing are defined and explained. This ensures that readers have a clear understanding of the key terms and concepts associated with the research topic. The chapter also provides an overview of the proposed SMART FOG protocol-based technique. It explains the core features and functionality of the technique, highlighting how it differs from existing approaches. Additionally, a comparative study is conducted to compare the proposed technique with other relevant methods in the field. This comparison helps to establish the unique benefits and advantages of the SMART FOG protocol-based technique. By encompassing these elements, the first chapter sets the stage for the research work, presenting the need for the study, providing a solid base through article references and survey analysis, clarifying fog computing concepts, and introducing the proposed SMART FOG protocol-based technique along with its comparative study.

- **Chapter -2 Literature Review:** Focuses on reviewing past studies conducted in the research area. It involves examining a broad range of previously completed research projects and providing a comprehensive background of other relevant research works. These sources of literature include journals, articles, research papers, and reputable platforms such as the OpenFog Consortium, IEEE conferences and journals, Springer publications, and online fog computing articles and resources. By conducting this review, the chapter aims to gather existing knowledge, identify gaps in the research field, and build upon the work that has already been done. It provides a critical analysis and synthesis of the literature, highlighting key findings, methodologies, and advancements in fog computing and related domains. The review of the literature serves several purposes. Firstly, it helps to establish the current state of the research area, providing a context for the proposed study. Secondly, it helps the researcher identify research gaps or areas that require further exploration. By examining the existing literature, the chapter also highlights the strengths and weaknesses of previous approaches, leading to insights and inspiration for the proposed research. The sources of literature mentioned, such as the OpenFog Consortium, IEEE, Springer, and online fog computing articles and resources, represent reputable and authoritative platforms in the field. By consulting these sources, the chapter ensures a comprehensive and reliable review of the existing literature, contributing to the overall credibility and validity of the research project.

- **Chapter -3 Research Methodology:** This is dedicated to describing the methodology used in the research project. It primarily focuses on the architecture of the proposed system, including the use of block diagrams to visualize the system's structure. The chapter provides a detailed explanation of the different layers within the architecture, highlighting their functions and interactions. In addition to the system architecture, the chapter also explores the various technologies employed in the implementation of the proposed system. It delves into the specifics of these technologies, discussing their relevance and suitability for the project. The methodology chapter also outlines the research methods employed in the study. It mentions the use of questionnaires or surveys to gather data and insights from relevant stakeholders or experts in the field. These methods help in understanding the requirements, challenges, and expectations associated with the proposed system. By gathering feedback through questionnaires, the research project can align its objectives with the needs of the intended users or beneficiaries. Furthermore, the chapter addresses any gaps or open challenges that were identified during the literature review. It highlights how these gaps are addressed or resolved through the proposed research. The focus is on designing and developing the proposed system to bridge these gaps and overcome challenges identified in previous studies.

- **Chapter - 4 SMART FOG-based Technique:** Focuses on the implementation of the proposed system. The chapter discusses the total work done in the system and outlines the next steps and milestones to be achieved. It also addresses the challenges encountered during the selection of communication protocols and security measures for each layer of communication. The sharing of computational power between IoT devices and fog devices is identified as a challenging aspect, and an improvised method is proposed to enable this sharing. The proposed SMART FOG protocol-based technique aims to execute tasks in the fog environment to avoid latency issues associated with sending requests to cloud centers.

- **Chapter – 5 Allocation and Scheduling of Computational Power:** The focus is on the allocation and scheduling of computational resources shared with IoT devices. The chapter explores different techniques of resource allocation and scheduling, identifying the most efficient ones suitable for fog computing. The current work is tested according to the proposed system, and the results are evaluated to meet the objectives of the research. The evaluation specifically assesses the impact of the proposed work on latency issues in the existing system. Testing and evaluation are crucial for validating the hypothesis, which centers around implementing the SMART FOG protocol-based technique to create a fog environment that shares computational power with IoT devices.

- **Chapter – 6 Conclusion and Future Work:** Provides a summary of the research work and its outcomes in comparison to the expected results defined during the design phase. A detailed analysis is conducted to project future possibilities and enhancements to the system resulting from the study. The chapter also highlights key challenges and issues that warrant further investigation for future development. This chapter serves as a conclusion to the research, summarizing its findings and suggesting avenues for future research and improvement.

In conclusion, based on the evaluation of various accuracy parameters, it can be inferred that the MLP classifier and Logistic Regression are the most suitable classification algorithms for resource allocation and task offloading in a SMART FOG environment. These classifiers consistently outperform the others and demonstrate their effectiveness in achieving accurate and reliable results.

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This chapter describes the research activity and its outcomes versus the predicted results as thought throughout the design phase. A complete analysis is being carried out to estimate future possibilities and enhancement to the system gained as a consequence of the suggested study. The study also discusses the important challenges/issues that could be investigated further to move it ahead.

6.1 Findings and Conclusions

By comparing the results of using the FCFS task scheduling algorithm in a Fog and cloud context, it appears that FCFS in the Fog environment better optimizes latency, total network utilization, and energy consumption. In contrast to cloud environments, latency, quality of service, and cost are all improved by using the fuzzy series parallel preprocessing resource scheduling algorithm in a Fog setting.

Latency and power consumption can be minimized by using the Shortest Job First Heuristic approach to schedule work. Much like the preemptive task priority network, the resource allocation technique greatly improves both QoS and efficiency.

Rule-based fuzzy network often known as fuzzy logic, is a resource scheduling technique that optimizes both latency and energy usage. In a similar vein, the QoS may be significantly optimized with the Fault, Configuration, Accounting, Performance, and Security methods.

6.2 Summarization of Hypotheses Testing Results

The comparison between fog-based and cloud-based systems based on execution time ($H_0$1) demonstrates that using smart fog-based systems results in a significant decrease in execution time when compared to cloud-based systems. With values of 9872, 3008, 7866, 5417, 4533, 4024, and 8703, respectively, there is a significant reduction in execution time in the Fog systems 8:10, 9:9, 7:10, 6:10, 6:6, 4:10, and 2:6. It is therefore abundantly evident that the Fog layer is crucial to cutting down on execution time.

The comparison of Fog-based and Cloud-based systems based on latency ($H_0$2) reveals that there is a significant reduction in latency with the usage of Smart Fog-based systems as opposed to Cloud-based systems. There is a significant reduction in latency value in the Fog system 10:5, 4:4, 2:5, 2:4, 2:3, 2:2, 1:5, 1:4, 1:3, 1:2, and 1:1, such as 453.52, 198.92, 190.69, 198.13, 199.71, 201.36, 191.91, 197.73, 199.41, 201.16, and 194.08. As a result, the fog layer plays a crucial role in latency reduction.

The evaluation between Fog-based and Cloud-based systems based on energy consumption reveals a significant reduction in energy consumption when using Smart Fog-based systems against Cloud-based systems ($H_0 3$). There is a significant reduction in energy consumption in the fog systems 10:5, 5:5, 4:5, 4:4, 3:5, 2:5, 2:4, 2:3, 2:2, 1:5, 1:4,1:3, 1:2 and 1:1. Hence, based on the performance measure energy used, it is apparent that there is a considerable difference between the SMART FOG protocol-based system and the cloud-based system.

The analysis of Fog fog-based systems and Cloud cloud-based systems based on cost of execution reveals that there is a significant cost of execution decrease with the usage of Smart Fog-based systems as compared to Cloud-based systems ($H_0 4$). There is a significant cost reduction in the Fog system 10:5, 6:10, 5:5, 4:5, 4:4, 3:10, 3:5, 2:9, 2:8, 2:6, 2:5, 2:4, 2:3, 2:2, 1:5, 1:4, 1:3, 1:2, and 1:1. Hence, based on the performance measure cost of execution, it is evident that there is a considerable difference between the SMART FOG protocol-based system and the cloud-based system.

The comparison between Fog-based system and Cloud cloud-based system based on total network usage reveals that there is a significant decrease in total network usage when using a Smart Fog-based system against Cloud-based systems ($H_0 5$).In the fog system, there is a significant reduction in overall network utilization such as 813124, 100000, 100000, 889585, 100000, 717690, 600582.6, 100000, 560311.2, 200000, 100000, 376389.8, 300487.8, 226130, 151466.2, 187988.4, 150136.4, 112806.6, 75270.6, and 38142.7. Hence, based on the performance measure of total network use, it is apparent that there is a considerable difference between the SMART FOG protocol-based system and the cloud-based system.

The analysis of Fog-based and Cloud-based systems based on computational power consumed reveals a significant reduction in computational power consumed when using Smart Fog-based systems against Cloud-based systems ($H_0 6$). There is a significant reduction in computational power consumed by Fog systems in all cases when compared to cloud-based systems, implying that there is a significant difference between SMART FOG protocol-based systems and cloud-based systems based on the performance measure computational power consumed by Fog devices in comparison to Cloud devices. For statistical validation of our findings, various null hypotheses were tested and the outcomes of these tests are as follows:

Table 6.1: Chi-Square (χ^2) Test for Awareness Level

Sr. No.	Hypothesis	Result @ 5 % Level
$H_0 1$	There is no significant difference between SMART FOG protocol-based system and cloud-based system based on the performance measure execution time.	Rejected
$H_a 2$	There is a significant difference between SMART FOG protocol-based System and cloud-based systems based on the performance measure latency.	Accepted
$H_0 3$	There is no significant difference between SMART FOG protocol-based system and cloud-based system based on the performance measure energy consumed.	Rejected
$H_a 4$	There is significant difference between SMART FOG protocol-based system and cloud-based system based on the performance measure cost of execution.	Accepted
$H_0 5$	There is no significant difference between SMART FOG protocol-based system and cloud-based system based on the performance measure of total network usage.	Rejected
$H_a 6$	There is a significant difference between SMART FOG protocol-based system and cloud-based system based on the performance measure computational power consumed.	Accepted

Table 6.1, can be concluded that the hypothesis “SMART FOG protocol-based technique to create Fog Computing environment will share computational power to IoT devices with low computational power and other aspects” is being accepted which suggests that SMART FOG protocol-based technique reduces computational power consumption for the Fog devices and share computational power with IoT devices by lower the total consumption.

Finally, the hypothesis "$H_a 1$: SMART FOG protocol-based technique to create Fog Computing environment will share computational power to IoT devices with low computational power and other aspects" is accepted, implying that the SMART FOG protocol-based technique reduces computational power consumption for Fog devices and shares computational power with IoT devices by lowering total consumption.

6.3 Use of Machine Learning Techniques for Task Scheduling

It was discovered that when the K-Star classifier was employed for task scheduling, it properly identified around 91% of the cases, which was much higher than the other classification approaches tested, such as IBK, Logistic Regression, and AdaBoostM1. Similarly, the accuracy, recall, and F-measure values of 0.92, 0.91, and 0.90 were greater in comparison to IBK, Logistic Regression, and AdaBoostM1; also, the mean absolute error value was 0.05, and the FP rate value was 0.04.

In logistic regression, the correctly categorized examples were about 88%, which was much higher than the other classification approaches investigated, such as IBK and AdaBoostM1. Similarly, the accuracy, recall, and F-measure values of 0.88, 0.88, and 0.87 were greater in comparison to IBK and AdaBoostM1, as was the mean absolute error value of 0.05 and the FP rate value of 0.04.

Overall K-star is the best classification algorithm that can be used for task scheduling followed by Logistic Regression as in the majority of observations at different configuration settings the Accuracy, Precision, Recall, F-Measure, etc. are higher in case of algorithms mentioned above.

6.4 Classification Algorithms in Task Offloading and Resource Allocation

The results confirm that the MLP classifier has the best overall accuracy value 0.83, followed by the Logistic Regression value 0.80. The other classification methods had an overall accuracy of roughly 0.75 in the case of the J48 classifier, 0.60, 0.61, and 0.48 in the case of Bagging, IBK, and K-Star, respectively. MLP and Logistic Regression were discovered to be the best acceptable classifiers based on performance measure total accuracy. Comparing classifiers based on overall Kappa statistics used for task offloading and resource allocation in SMART FOG environment, MLP and Logistic Regression have higher overall Kappa statistics values of 0.67 and 0.6, respectively, indicating that they are superior classifiers.

MLP classifier has the best precision at 0.85, followed by Logistic Regression at 0.83. J48 had 0.79 Precision, Bagging 0.48, IBK 0.76, and K-Star 0.49. MLP and Logistic Regression were the most precise classifiers.

MLP classifier has the greatest recall overall with 0.84, followed by Logistic Regression with 0.80. Bagging, IBK, and K-Star had Recalls of 0.61, 0.62, and 0.49, respectively, while J48 had 0.75. MLP and Logistic Regression were the best classifiers for total Recall.

MLP classifier has the lowest mean absolute error value of 0.17, followed by Logistic Regression with 0.23. J48, Bagging, IBK, and K-Star had mean absolute error values of 0.27, 0.58, 0.39, and 0.45, respectively. MLP and Logistic Regression were the best classifiers based on performance metric mean absolute error value.

In conclusion, after examining each classification algorithm based on a variety of accuracy parameters, one can conclude that MLP and Logistic Regression are the classification algorithms that are best suited for resource allocation and task offloading.

6.5 Future Scope

In this section, the key issues, future difficulties, and future research prospects for task scheduling in fog computing are discussed.

Resource Utilization of Fog Node

The fog devices have limited storage, processing, and energy capabilities due to their lack of resources. They receive dynamic workloads from applications that are sensitive to latency as well as apps that are tolerant of delay. As a result, the difficult aspect is to schedule the unpredictability of the arrival of activities on these fog nodes to make the best possible use of the available resources.

Optimal Resource Allocation

IoT devices produce a large number of tasks, which have to be appropriately distributed between fog nodes to achieve a quicker reaction time. This is especially important for applications that are sensitive to latency. Since fog computing makes it possible for fog nodes and Internet of Things devices to move about freely, the resources that are reachable at any given time may be inaccessible at other times. Because of this, the process of allocating resources is a difficult endeavor. The problems that need to be addressed are long latency for real-time applications, a lack of generalization, and rapid adaptation of the algorithms that are currently available.

Parallel Scheduling

In the method known as parallel processing, one operation is broken down into several smaller tasks, all of which are then carried out at the same time. Another unresolved problem that requires attention is the division of activities into subtasks that can decrease delays through the use of distributed computing.

Privacy

Several different fog applications, such as smart healthcare, send a significant amount of personally identifiable information to fog nodes. As a result, protecting the confidentiality of such data is of the utmost importance to users. Even while some researchers use methods that protect users' privacy on fog nodes, there is yet no authentication solution that can be considered satisfactory. Because the fog nodes are more susceptible to possible dangers, authenticating users can be a difficult and time-consuming process.

Security

Fog nodes are vulnerable to attacks. As a result, developing a safety algorithm that is not only lightweight but also has a fast speed and is trustworthy is still a tough issue. At the moment, only a small number of academics are focusing their attention on the security concerns associated with fog computing; nonetheless, there are still several outstanding challenges, such as dynamic authentication, access controls, external threats, and intrusion detection.

Context-aware Service Provisioning

The context is made up of the many runtime elements that have the potential to influence the applications. The currently available approaches to context-aware service provisioning are less flexible and scalable, and they are unable to manage a significant number of Internet of Things applications. Because of this, more approaches to context-aware service delivery should be researched so that the aforementioned restrictions may be solved.

Energy Consumption

Energy-aware computing in fog is still an open question that has to be answered since fog devices are limited in their ability to use energy due to their usage of low-power batteries. Several academics are concentrating their efforts on energy optimization, but several problems still need to be addressed, including improper utilization of bandwidth during data transfer, energy waste, and battery-draining concerns.

1.6 Limitations

Fog computing faces several limitations, including high latency compared to edge computing, increased complexity in network management, potential security vulnerabilities, and limited scalability. It can also suffer from resource constraints due to dependency on intermediate devices and challenges in data processing efficiency. Additionally, ensuring consistent connectivity and handling diverse data types can pose significant difficulties in fog computing environments.

1. Scope and Generalizability: The study may have focused on specific IoT architectures, protocols, and technologies, which might limit its generalizability to other IoT scenarios or environments.

2. Real-world Implementation Challenges: The study might not have addressed the practical challenges associated with implementing the SMART FOG protocol-based technique, such as hardware compatibility, software integration, security considerations, and deployment complexities.

3. Benchmarking and Comparison: The study might lack comprehensive benchmarking or comparison with existing IoT architectures, protocols, or alternative solutions. Comparative analysis would provide a better understanding of the advantages and limitations of the proposed SMART FOG approach.

4. Limited Testing Scenarios: The evaluation of the SMART FOG technique might have been conducted under specific testing scenarios or simulated environments, which may not fully capture the complexities and dynamics of real-world IoT deployments.

5. Time Constraints: The study might have faced time limitations, which could impact the depth of analysis, experimentation, and validation of the proposed techniques.

6. Lack of Real-world Deployment Validation: The proposed SMART FOG technique might not have been validated in real-world IoT deployments or scenarios, which may limit the assessment of its practical applicability and performance.

In conclusion, fog computing's limitations include potential latency issues, increased network complexity, and security vulnerabilities. It also faces scalability challenges, resource constraints from intermediary devices, and inefficiencies in data processing.

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APPENDIX

Appendix: List of Publications and Conferences Attended

1) Suraj Rajaram Nalawade, Dr. Ashok Kumar Jetawat, "Use of Clustering Machine Learning Algorithms in Fog Computing for Task Scheduling and Resource Allocation" has been published in European Chemical Bulletin (ISSN: 2063-5346), Volume 11, Issue 8, 2022 Date of Publication: - August 2022.

2) Suraj Rajaram Nalawade, Dr. Ashok Kumar Jetawat, "A Comparative Study of Various Classification Machine Learning Algorithms in Fog Computing: Task Scheduling" has been published in Industrial Engineering Journal (ISSN 0970-2555), Volume: 52, Issue 5, No. UGC Care Approved, Group I, Peer Reviewed Journal 4, May: 2023.

3) "The Survey on Fog Computing and its Applications" International Virtual Conference on "Emerging Era of Applications of Computer, 15th -16th of January 2022 Organized by Pacific University Udaipur.

4) National Seminar on "Implementation of Academic Bank of Credit (ABC) in Higher Education Institutes" on 21st March 2023 Organized by Avinashilingam Institute for Home Science and Higher Education for Women University Udaipur.

5) IP Awareness Training Program under "National Intellectual Property Awareness Mission" Organized by Intellectual Property Office, India on 18, January 2023.