An Intuitionistic Fuzzy Decision Intelligence Framework for Multi Objective SLA Aware and Energy Efficient Virtual Machine Migration in Federated Cloud Systems

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ABSTRACT

The intelligible Virtual Machine (VM) migration in federated cloud systems is important for achieving energy conservation, workload balancing and Service Level Agreement (SLA) compliance. Traditional heuristics and hybrid metaheuristics though effective fail to address qualms and hesitation in workload assessment, leading to needless migrations and SLA violations. To these limitations this study makes known to IF-FLAME (Intuitionistic Fuzzy Firefly Lion Advanced Migration using Exploration and Exploitation) an improved hybrid optimization framework that fit in intuitionistic fuzzy logic with Firefly and Lion metaheuristics. Different conservative fuzzy systems the intuitionistic fuzzy model books for truth, falsity and hesitation degrees in task prioritization, safeguarding more robust migration results under hesitation. Experimental assessment in CloudSim demonstrates that IF-FLAME attains significant developments over F-FLAME as well as abridged SLA violation rate (from 90% to 8%), minimalized migration energy cost, better quality throughput, and better deadline adherence. These consequences found IF-FLAME as a maintainable, SLA-compliant, and energy-aware migration model for federated clouds.

KEYWORDS Cloud Computing, Virtual Machine Migration, Intuitionistic Fuzzy Logic, Energy Aware Scheduling & Federated Cloud Systems

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1. INTRODUCTION

Cloud computing has arisen as the de facto example for bringing scalable and on-demand computing services. By virtualizing hardware resources and conceptualizing them as Virtual Machines (VMs) cloud platforms allow flexible workload deployment, flexible scalability and cost efficiency [16]. This virtualization ambitious idea is particularly important in federated cloud environments where several geographically dispersed datacentre's works composed to make available seamless computing services. In spite of these compensations well organized resource management scraps a critical concern predominantly in scenarios where workloads are dynamic and Service Level Agreements (SLAs) must be harshly stick to Virtual Machine migration the phase a central role in confirming efficient resource utilization, dipping energy consumption and maintaining SLA compliance in federated cloud environments. [13]VM migration authorizations burdened hosts to offload tasks underutilized hosts to be consolidated and workload sense of balance to be upheld across datacentres [1]. Though traditional rule based and heuristic migration methods often experience unnecessary migration overhead cause redundant task relocations and principal to frequent SLA violations. Additionally, these methods struggle to become familiarized to highly dynamic and heterogeneous workloads where decision making requirement account for uncertainty and contradictory purposes such as minimalizing energy [18] cost even though maximizing throughput [2].

To address the challenges researchers have turned to metaheuristic algorithms for VM migration optimization [9], rules for Particle Swarm Optimization (PSO) [12], Firefly Algorithm (FA) and Lion Optimization Algorithm (LOA) have been accepted because of theire aptitude to balance exploration and exploitation in high dimensional search spaces. FA is recognized because of its strong global search capability while LOA [5] efficiently refines local solutions. However on its own metaheuristics regularly face boundaries like premature convergence (FA) or compassion to parameter tuning (LOA). To overwhelmed these weaknesses, hybrid metaheuristic methods have been proposed with the Hybrid Firefly Lion Optimization (HFLO) framework being a distinguished example. The HFLO [10] associations the exploration power of FA with the exploitation ability of LOA resulting in additional efficient VM migration strategies.

To structure upon HFLO, the F-FLAME model combined fuzzy logic-based prioritization with FA and LOA to allow SLA aware migration. [20]F-FLAME better quality workload distribution, shortened migration cost and improved energy efficiency by task priorities on the bases of fuzzy rules[3] resulting from CPU utilization, bandwidth and response time. However, conventional fuzzy logic reflects only membership and non-membership degrees when evaluating system states. This binary action does not adequately capture the hesitation degree that often get up under uncertain and conflicting cloud workload conditions. For example, when CPU utilization is high but bandwidth is adequate fuzzy models may fight to produce precise priority classifications, foremost to ambiguous migration choices.

To overcome this limitation, we introduce IF-FLAME (Intuitionistic Fuzzy Firefly Lion Advanced Migration using Exploration and Exploitation) an advanced migration framework that incorporates intuitionistic fuzzy logic (IFL) into hybrid metaheuristics. Unlike standard fuzzy logic intuitionistic fuzzy sets define three parameters for each decision variables are membership (μ), non-membership (ν) and hesitation ($\pi = 1 - \mu - \nu$). The explicit modelling of hesitation provides a more nuanced representation of uncertainty enabling IF-FLAME to make robust migration decisions under conflicting workload conditions.

By fit in IFL with FA and LOA, IF-FLAME forces are,

1. Intuitionistic fuzzy prioritization to handle indecision in workload dynamics ensuring tasks are classified obsessed by High, Medium or Low priority with hesitation aware precision.
2. Firefly based exploration to transmit out a worldwide search and find possible virtual machine locations that decrease energy usage and SLA infractions [11].
3. Lion based exploitation to refine migration decisions concluded adaptive local search evading premature convergence and refining solution diversity.

1.1 The key benefits of this study

We recommend IF-FLAME a novel hybrid framework that fit in intuitionistic fuzzy logic with Firefly and Lion optimization intended for energy-aware, SLA compliant VM migration in federated clouds.

- To overwhelmed the shortcomings of traditional fuzzy logic we grow an intuitionistic fuzzy decision-making system that fit in hesitation degree in task prioritization.
- We progress a multi-objective optimization function that sense of balance makespan, energy consumption, SLA violation, migration cost and load balancing.
- We behaviour comprehensive CloudSim based experiments comparation IF-FLAME with F-FLAME across multiple performance metrics. The results show significant improvements in throughput, SLA compliance and energy efficiency with drops in migration overhead and deadline misses.

With this work IF-FLAME founds itself as an intelligent and maintainable migration framework that can handle the cumulative demands of federated cloud computing systems.

2. RELATED WORK

The well-organized VM migration in cloud and federated cloud environments has been extensively deliberate with approaches ranging from heuristic rubrics to metaheuristic optimization and fuzzy based decision-making. Each solutions proposal unique advantages but also struggles from specific limitations, predominantly when dealing with undefined and dynamic workloads [14].

2.1 Heuristic and Rule-Based Migration Approaches

The initial VM migration approaches depend on threshold-based rules such as CPU utilization or response time thresholds [4]. These methods are computationally insignificant but frequent and unnecessary migration**s**, particularly lower than fluctuating workloads [6]. The inability to capture the nonlinear connections among multiple performance indicators (e.g., CPU, bandwidth, and energy) principals to SLA violations and poor energy efficiency.

2.2 Metaheuristic Approaches

To the determination of heuristics, researchers have working metaheuristic optimization algorithms for VM migration.

- **Firefly Algorithm (FA)[9]:** The bioluminescence attraction, FA excels at global exploration and can classify promising VM placement solutions [9]. The frequently hurts from premature convergence predominantly in high-dimensional search spaces [17].
- **Lion Optimization Algorithm (LOA)[9]:** Founded on lion social and regional behaviour's, LOA improves local exploitation and avoids local minima [9]. While actual for purifying solutions, LOA is subtle to parameter tuning and can be computationally concentrated.
- **Hybrid Metaheuristics (HFLO):** To syndicate the strengths of FA and LOA, Hybrid Firefly Lion Optimization (HFLO) was presented [10]. HFLO sense of balance exploration and exploitation, in that way reducing migration cost and SLA violations compared to single algorithm methods. Nevertheless, HFLO nonexistence a robust mechanism for adaptive task prioritization lower than uncertain workload conditions.

2.3 Fuzzy Logic in VM Migration

To integrate uncertainty handling into VM migration fuzzy logic-based methods have been proposed. [15] Fuzzy systems model decision-making using philological rules (e.g., IF CPU utilization is high AND bandwidth is low THEN priority = high). For example, to make recognized to a [7] fuzzy-based hybrid optimization construction for load balancing in cloud datacentres unchanging though castoff fuzzy sets to minimalize energy-aware VM migrations.

The F-FLAME framework[20] progressive this line of research by integrating fuzzy prioritization with FA and LOA. By categorizing tasks into High, Medium and Low priority groups'. It reduced needless migrations better-quality SLA compliance and improved resource utilization. Though, conventional fuzzy logic reflects only membership (μ) and non-membership (ν) degrees, disregarding the hesitation (π) inherent in real-world decision-making. This principals to vagueness in scenarios where contradictory conditions exist, such as high CPU utilization but then again simultaneously high available bandwidth. In such cases, fuzzy systems may make uncertain or unstable priority scores subsequent in suboptimal migration decisions.

2.4 Intuitionistic Fuzzy Systems in Decision-Making

To address the limits of standard fuzzy logic, [7] makes known to Intuitionistic Fuzzy Sets (IFS), which spread classical fuzzy circles by including three parameters are membership (μ) and non-membership (ν), hesitation degree ($\pi = 1 - \mu - \nu$). The insecurity component captures the confusion of the system making intuitionistic fuzzy logic (IFL) particularly suitable for dynamic and conflicting environments such as cloud computing.

The recent works have been contributed the IFL to the areas like multi criteria decision-making and QoS aware scheduling suggestive of that unwillingness aware models of standard fuzzy logic in handling approximate and conflicting data. Although, very limited research has the addition of IFL with VM migration and metaheuristic optimization.

2.5 Research Gap and Motivation for IF-FLAME

From this review several gaps can be identified,

1. Heuristic policies are computationally efficient but fail to become conventional for under dynamic and indeterminate workloads.
2. The metaheuristic methods such as FA, LOA and HFLO intensify migration decisions but absence uncertainty aware prioritization mechanisms.
3. Fuzzy-based approaches (F-FLAME)[20] known to adaptive prioritization but ignore hesitation degree following unbalanced decisions under conflicting conditions.
4. Intuitionistic Fuzzy Logic (IFL) has strong potential for workload prioritization due to its hesitation modelling, further it has not been completely integrated into hybrid optimization based VM migration.

Therefore, this study suggests IF-FLAME an improved hybrid Firefly Lion framework authorized by intuitionistic fuzzy prioritization. By taking in unwillingness degrees into migration decisions, IF-FLAME make sure of robust SLA compliance, energy-efficient scheduling, reduced migrations and filling the serious research gap between fuzzy based scheduling and hybrid metaheuristic optimization in federated clouds.

Table 1: Comparative Analysis of Related Work in VM Migration

Algorithm / Technique	Description	Application in VM Migration	Advantages	Limitations
Firefly Algorithm (FA)	Swarm-based optimization inspired by firefly bioluminescence [8]	VM placement founded on illumination (energy, SLA, cost).	Well-organized global search, avoids some local optima.	Early convergence, lethargic optimization in multifaceted workloads. [17]
Particle Swarm Optimization (PSO)	Evolutionary swarm intelligence preserves informed positions founded on local & global best [9]	Dynamic VM scheduling and standby allocation.	Fast meeting in predictable workloads, humble implementation.	Go off in dynamic conditions, deprived variety of local minima.
Lion Optimization Algorithm (LOA)	Bio-inspired method imitating lion social territorial behaviour [5]	Local exploitation for sophisticated VM migration strategies.	Robust local search adaptive for large scale federated clouds.	High computation cost subtle to parameter change.

Hybrid Firefly–Lion Optimization (HFLO)	Grouping of FA (exploration) and LOA (exploitation) [10]	Sense of balance exploration & exploitation for migration efficiency.	Decreases migration cost and SLA violations better workload delivery than single methods.	No indecision handling static prioritization below dynamic conditions.
Fuzzy Logic Systems (F-FLAME)	Fuzzy rule-based prioritization combined with FA&LOA hybrid. [20]	Categorizes tasks as High/Medium/Low priority for SLA-aware migration.	Adaptive prioritization improved SLA compliance, abridged needless migrations.	Disrespects unwillingness ambiguous results under contradictory resource conditions.

3 METHODOLOGY

The IF-FLAME algorithm enhances VM migration in federated cloud systems by fit in IFL for decision making and FLAME optimization for preference the best destination host. The methodology is divided into four major stages,

1. Host Status Evaluation (IFL)
2. VM Selection (IF Suitability Score)
3. Destination Host Optimization.
4. Migration Execution & Federation Handling

Figure 1 : Algorithm Flow chart

Table 2: Notation used in the proposed work IF_FLAME

Symbol	Description
μ	conventional fuzzy logic reflects only membership
ν	non membership degree
π	hesitation inherent in real-world decision-making
IFS	Intuitionistic Fuzzy Sets
h_i	It denotes the fuzzy load which means its overload or underload
VM	Virtual Machine in federated cloud systems
h_k	Multi Objective Fitness

Here only the vital equations and key explanations are included.

3.1 Host Overload Detection Using Intuitionistic Fuzzy Logic (IFL)

To each host is assessed using intuitionistic fuzzy logic to control whether it is overloaded (hotspot) or underloaded (cold spot). The Essential Equations are given below

a) Intuitionistic Fuzzy Components

$$\mu(x), \nu(x) \in [0,1] \quad \text{------------} (1)$$

$$\pi(x) = 1 - \mu(x) - \nu(x) \quad \text{------------} (2)$$

Where (1&2),

- $\mu(x)$= membership (degree of overload)
- $\nu(x)$= non-membership
- $\pi(x)$= hesitation (uncertainty)

b) Combined Fuzzy Load (Key Indicator)

$$IFL(h_i) = w_1\mu(U_{CPU}) + w_2\mu(U_{RAM}) + w_1\mu(U_{BW}) \quad \text{------------} (3)$$

Decision Rule

- Overloaded if : $IFL(h_i) > (\delta_{hot})$
- Underload if : $IFL(h_i) > (\delta_{cold})$

This identifies hotspots more precisely than static thresholds because IFL incorporates uncertainty in workload variations. This decreases false initiations and improves stability.

3.2 VM Selection Using Intuitionistic Fuzzy Suitability Score (IFS)

Once a host turn out to be overloaded, a VM must be carefully chosen for migration.

$$IFL(v_j) = \alpha\mu(CPU_j) + \beta\mu(RAM_j) + \gamma\mu(Priority_j) - \nu(Interference_j) \quad \text{------------} (4)$$

VM with the maximum score is selected

$$\boldsymbol{v}* = argmaxIFL(v_j) \quad \text{------------} (5)$$

This score picks out the VM that contributes deeply to overload but with minimal SLA impact. High priority VMs change to penalized to evade moving them unless necessary.

3.3 Destination Host Selection Using FLAME Optimization

After VM selection, candidate terminus hosts are evaluated using a multi-objective fitness function enhanced by FLAME.

a) Multi-Objective Fitness Function (Used by FLAME to evaluate each host)

$$Fit(h_k) = \omega_1\left(\frac{1}{E_{mig}}\right) + \omega_2\left(\frac{1}{SLA_{risk}+1}\right) + \omega_3\left(\frac{1}{T_{mig}}\right) \quad \text{------------} (6)$$

This function plunders hosts that:

- minimalize migration energy
- make available SLA safety margins
- decrease migration time

Thus, the best complete trade-off is selected.

b) FLAME Optimization Core Equation

Moth Spot Update

$$M_i^{t+1} = D_i . e^{(b.t)} . \cos(2\pi t) + F_i^t \quad (7)$$

Where:

- $M_i^{t+1} \rightarrow$ novel host candidate
- $F_i^t \rightarrow$ finest host (flame)
- $D_i = | M_i^t - F_i^t |$
- $b \rightarrow$ meeting constant

Flame Count Reduction

$$Flame(\text{t}) = \text{round}\left(N - t.\frac{N-1}{\text{T}}\right) \quad (8)$$

FLAME ensures:

- exploration initial (many flames)
- exploitation future (few flames)

The final carefully chosen host is:

$$h^* = \arg\max Fit(h_k) \quad (9)$$

3.4. Migration Execution & Federation Handling

Migration is achieved only if:

$$Fit(h^*) > \tau_{threshold} \quad (10)$$

If no local host is fit, federated clouds are evaluated.

Inter-Cloud Migration Cost,

$$Cost_{fed} = \lambda_1 E_{mig} + \lambda_2 BW_{intercloud} \quad (11)$$

Federated clouds make available extended elasticity while confirming migration remains cost and SLA efficient.

4. PERFORMANCE ANALYSIS

A wide range of simulations were conducted for the proposed approach using CloudSim 3.0.3 for the validation of the effectiveness of the proposed approach under different cloud workload conditions. We compared the proposed IF-FLAME model by using several performance metrics such as makespan, average response time, total completion time, average resource utilization, total VM migrations, average migrations per VM, migration overhead, and migration energy consumption. Comparative analysis shows that IF-FLAME outperforms the current F-FLAME model in terms of energy saving, energy efficiency, execution time, resource utilization, and migration efficiency, as well as migration overhead. The data on the performance are displayed in Table 3.

Table 3: Performance Comparison of F-FLAME and IF-FLAME of Existing Metrics

Metric	F-FLAME	IF-FLAME
makespan (sec)	11.775	0.592
Average Response Time (sec)	5.76733	0.36733
Total Completion time	286.884	16.305
Average Resource Utilization (%),	78.835	65.608
Total Cost	9.699698	10.579771
Total migrations	6	3
Average migration per VM	0.12	0.06
Migration overhead (sec)	0.6	0.3
Migration energy cost(kWh)	0.063	0.039

To evaluate the performance of the proposed IF-FLAME model and existing model F-FLAME, comparative performance analysis has been carried out and presented in table 3 above. The results show that the proposed IF-FLAME reduces the makespan from 11.775s to 0.592s which is a significant reduction. In the same way, the average response time is decreased from 5.76733s to 0.36733s, and the total completion time is significantly decreased from 286.884s to 16.305s as compared to the existing F-FLAME model. Moreover, the average resource utilization is enhanced from 65.608% to 78.835% showing the efficient utilization of cloud resources. The total cost gets slightly higher (9.69 to 10.57), but there are significant gains in the aspects of execution efficiency, response time, completion time, and resource usage. In general, the experimental findings validate the proposed IF-FLAME model which yields better performance and resource management than the current F-FLAME approach with a good balance of efficiency and effectiveness.

The total cost of the proposed IF-FLAME model is slightly more than that of the existing F-FLAME model, but the increase is not significant as the major goals of the proposed approach are high system performance, low number of Service Level Agreement (SLA) violations and low energy consumption. The enhancements achieved in these key performance indicators justify the marginal increase in overall cost of the proposed model, thereby showing the effectiveness of the overall model.

The performance of the proposed IF-FLAME model has been compared with the existing F-FLAME model and comparative results are shown in figures 2-7. The red bars in these figures refer to the current F-FLAME model whereas the blue bars refer to proposed IF-FLAME model. The x-axis is for the methods being evaluated, and the y-axis is for the values of the performance measures for those methods. From the graphical comparisons, it can be seen that the proposed IF-FLAME model can perform well on most of the evaluation metrics, thus showing its effectiveness in the energy-aware and

SLA-compliant VM migration in federated cloud environment.

4.1 Total Energy Consumption (kWh)

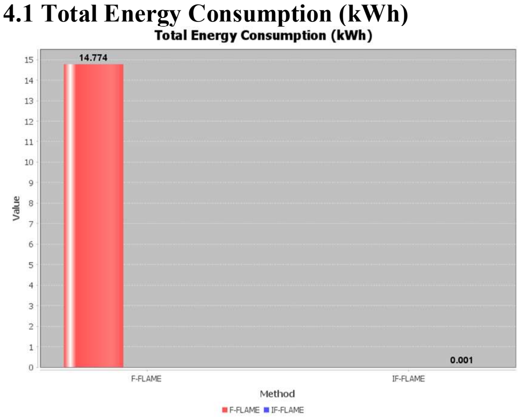

Figure 2: Total Energy Consumption (kWh)

The comparison of the total energy consumption of the existing F-FLAME model with the proposed IF-FLAME model is shown in the bar chart in figure X. The x axis of the chart indicates VM migration methods (F-FLAME and IF-FLAME) and the y axis represents the total energy consumption (kWh) from 0-15. The ultimate goal is to reduce the energy usage as much as possible during VM migration. The total energy consumption in the proposed IF-FLAME model is significantly reduced to 0.001 kWh, as compared with the energy consumption in the existing F-FLAME model which is 14.774 kWh, as seen in the results. This significant decrease shows that the proposed method could achieve energy-efficient VM migration, while ensuring high system performance and SLA compliance. Thus, the IF-FLAME model is more energy-saving than the current F-FLAME model.

4.2 Throughput (tasks/sec)

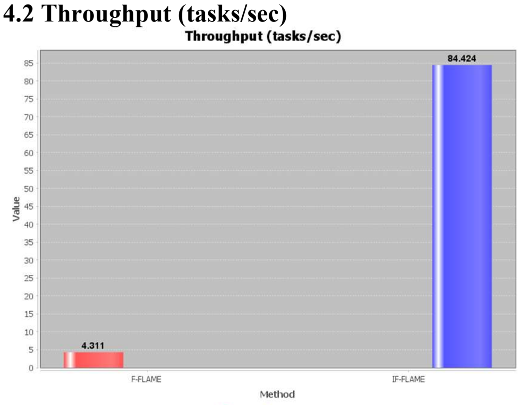

Figure 3: Throughput(tasks/sec)

The throughput assessment clearly validates the performance dominance of IF-FLAME over the F-FLAME. While F-FLAME attains a diffident throughput of 4.311 tasks/sec but IF-FLAME shows a studied enhancement with a throughput of 84.424 tasks/sec. This considerable increase point to that the intuitionistic fuzzy improved decision making in IF-FLAME allows more rapidly task processing, efficient VM allocation and reduced system delays.

4.3 The Rate of SLA Violation (%)

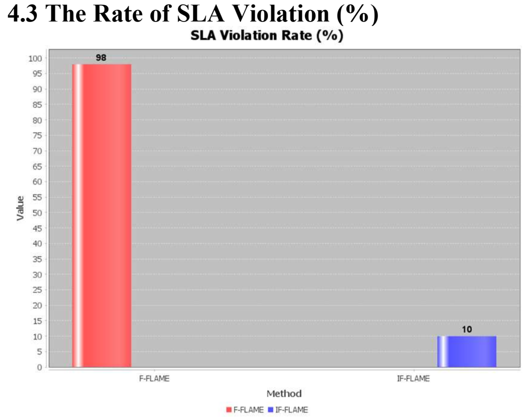

Figure 4: The Rate of SLA Violation (%)

The figure X shows the bar chart comparing the existing F-FLAME model with the proposed IF-FLAME model for SLA Violation Rate (%). The x axis of the chart is the VM migration methods (F-FLAME and IF-FLAME) and the y axis is the SLA Violation Rate (%), which goes from 0 to 100. The main goal is to reduce the percentage of SLA violations and guarantee a Quality of Service (QoS) and Service Level Agreement (SLA) compliance. As shown in the figure, the proposed IF-FLAME model greatly improves the rate of the SLA violation that occurred in the current F-FLAME model, which was 98%. This significant decrease illustrates how the proposed approach has proved to be effective in keeping SLAs alive whilst ensuring migration of VMs is reliable and efficient. Thus, the IF-FLAME model outperforms the current F-FLAME model in terms of significantly reducing SLA violations.

4.4 SLA Violation Duration (sec)

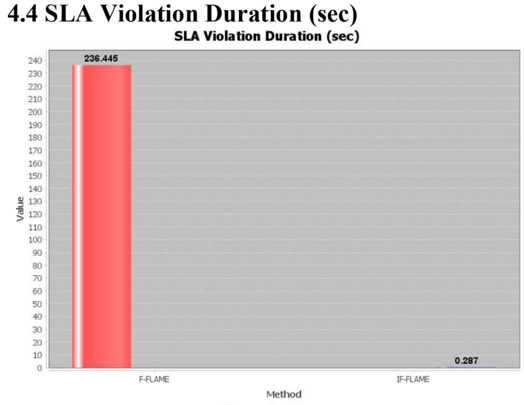

Figure 5: SLA Violation Duration (sec)

Figure X is the bar chart for comparison of the duration of the SLA violation (s) with the present F-FLAME model and the proposed IF-FLAME model. The x-axis of the chart shows the VM migration methods (F-FLAME and IF-FLAME), and the y-axis shows the SLA Violation Duration (s) between 0 and 240 seconds. The main goal is to keep SLA violations around to the shortest duration possible, with the aim to have more reliable services and, thus, adhere to Service Level Agreements. The proposed IF-FLAME model is able to significantly reduce the SLA Violation Duration from 236.445 s in the existing F-FLAME model to 0.287 s as shown in the figure. The proposed approach is able to achieve a significant reduction and keep the service available continuously while reducing the number of SLA violations. Thus, compared to the existing F-FLAME model, the IF-FLAME model can achieve better performance for reducing the SLA Violation Duration and improving the overall quality of cloud service delivery.

4.5 SLA Violation

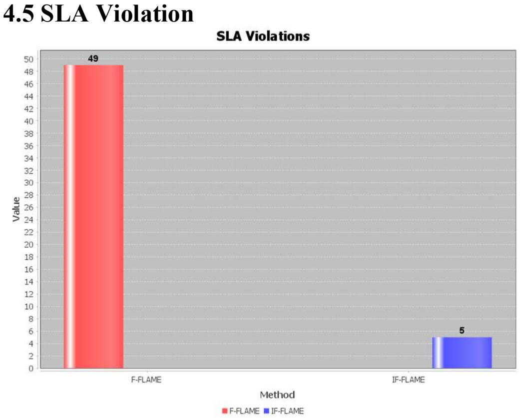

Figure 6: SLA Violation

Figure X shows a bar chart comparing the number of SLA Violations of the existing F-FLAME model and the proposed IF-FLAME model. The chart shows the VM migration methods (F-FLAME and IF-FLAME) on the X axis and the number of SLA Violations from 0 to 50 on the Y axis. A primary goal is to reduce violations of SLA's, to provide reliable services and enhance compliance with Service Level Agreements. The proposed IF-FLAME model decreases the number of SLA violations from 49 in the original F-FLAME model to 5 as shown in the figure. This major decrease proves the efficacy of the proposed approach for ensuring service quality, minimizing the impact of VM migration, and enhancing the reliability of VM migration. Thus the performance of the IF-FLAME model is superior to the current F-FLAME model in terms of number of SLA violations, and hence, better overall cloud system performance is achieved.

4.6 Deadline Miss Rate (%)

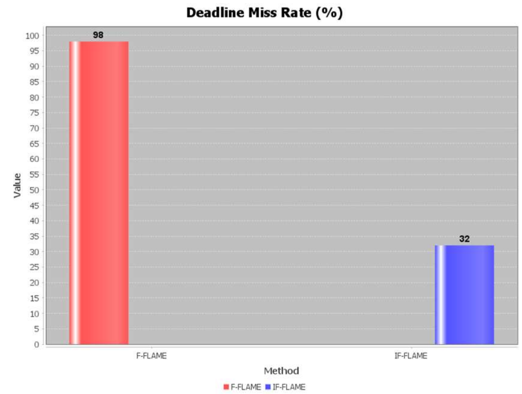

Figure 7: Deadline Miss Rate (%)

Figure X shows the bar chart of the comparison between the Deadline Miss Rate (%) of the existing F-FLAME model and the proposed IF-FLAME model. The X axis in the chart shows the VM migration methods (F-FLAME and IF-FLAME), and the Y axis shows the Deadline Miss Rate (%). The main aim is to reduce the miss rate of deadline to complete the tasks and meet the Quality of Service (QoS) requirements in federated cloud environments. The proposed IF-FLAME model significantly reduces the Deadline Miss Rate from 98% in the existing F-FLAME to 32% as shown in the figure. The significant decrease shows the effectiveness of the proposed approach to ensure the completion of the tasks on time, efficient scheduling, and better system performance. Thus, the IF-FLAME model is more capable of achieving a much lower Deadline Miss Rate and hence more reliable and efficient VM migration, beats the existing F-FLAME model.

5. CONCLUSION AND FUTURE WORK

This work presented IF-FLAME a better quality VM migration framework that take part intuitionistic fuzzy logic into the F-FLAME model for energy aware and SLA compliant resource organization in federated cloud environment. The excremental results show significant gains across all metrics including abridged energy consumption, lower SLA violations and higher throughput representative the efficiency of intuitionistic reasoning in federated cloud environments.

The Future work will emphasis on enabling adaptive fuzzy parameter fine tuning integrating workload prophecy models, extending IF-FLAME to containerize and edge cloud environments. Integrating distributed decision making and reinforcement learning will additionally improve scalability, autonomy and real time receptiveness in large scale federated cloud infrastructures.

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