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An Overview of Task Scheduling Approaches in Fog Computing Environment

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***Abstract*— Evolution of IoT devices and smart environments are certainly pushing the demand of fog computing paradigm. Fog layer brings the computation and processing nearer to the IoT devices. It can reduce the latency and requests could be served quickly. Fog layer offers fog nodes and servers that are often resource constrained, hence the need of effective resource management arises. Effective scheduling of the tasks generated through IoT layer is the key factor in achieving optimized resource management. This paper has tried to represent various effective task scheduling approaches evolved in the recent time. A differentiating summary of various task-scheduling approaches based on various parameters and their performance is presented. It is followed by the description of performance metrics used for validating the proposed schemes and various research directions for potential researchers.**

***Keywords*— IoT, Fog Computing, Latency, Energy consumption**

I. INTRODUCTION

Over the past few years, IoT (Internet of Things) devices have evolved tremendously with constant increase in distributed applications as per current requirements [1]. IoT smart applications can produce huge amount of data with the help of sensors and actuators and due to the dynamic and ever changing IoT requests, it is difficult for traditional cloud environment to handle the situation. IoT devices require fast response because of their critical nature, but as most of the applications are dependent on the cloud environment, delay can be observed, which can hamper the efficiency of overall distributed computing [2]. To solve the above stated problems, cisco company introduced a new approach, called fog computing [1]. For catering the service requests of IoT devices, Fog computing has emerged to be the distributed computing environment which has attracted the concern of researchers from all communities.

Fog computing offers processing, networking and storage capabilities in order to move cloud-like services closer to IoT devices with an objective of reducing latency, energy consumption, and overall costs [1]. Fog computing enables location awareness, support for user accessibility, low latency, high scalability, and automation in operations that cloud-computing systems could not support. Effective resource management is one of the major challenges as fog computing environment is often lacking enough number of resources unlike cloud computing [2]. Effective task scheduling is one of the key contributors for achieving optimum resource management. Fig. 1 is also highlighting task-scheduling mechanism in fog environment.

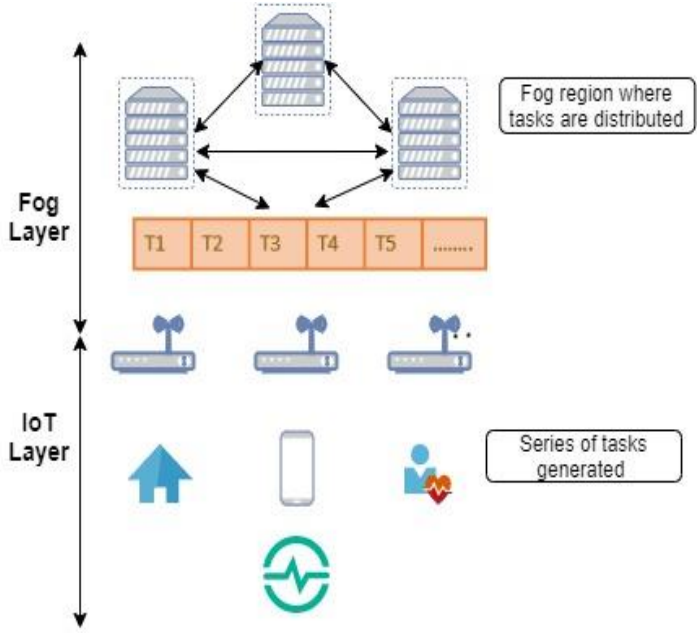

Fig. 1: Task scheduling in fog computing

A. Implementation of Task scheduling schemes in various application domains

Task scheduling strategies are crucial with respect to the time sensitive IoT applications. Healthcare domain [12] is critical and with the advancements of wearable devices, it becomes necessary to avoid the service delays. Delivering quick responses and predicting the criticality of task are the desired outcomes from the fog networks. Various other domains like: Smart City, Smart Grid, Smart Industry and Linked Vehicles (or Self driven Vehicles) [2] are prospering and they all work with time bound strategies. In order to cater the needs of listed

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application domains, development of efficient resource and task scheduling strategies is quite obvious.

B. Types of task scheduling schemes

Task scheduling schemes are divided into two types based on the architecture implementation, i.e., Centralized and De-centralized [1]. Under centralized architecture, a single central scheduler is responsible for distributing load among various fog nodes, whereas in de-centralized, each fog node has its own scheduler for scheduling tasks. We can also categorize the scheduling approach on the basis of task nature, i.e., Static and Dynamic [1]. Static scheduling algorithms works with an approach where task details are already available with the schedulers before the task actually arrives at the fog environment. Dynamic scheduling approach works with the identification of task related parameters when the task actually arrives at the fog scheduler. Most of the existing literature surveys are focused on elaborating task scheduling approaches on the basis of architecture and task nature.

C. Research motivation

Meta-heuristic optimization techniques are implemented over variety of engineering applications. Most of the techniques are nature-inspired and they have shown their effectiveness to a greater extent. As most of the existing surveys on task scheduling approaches are architecture centric, there is a need to exploring meta-heuristic based and techniques other than nature inspired optimizations. This review paper is written with these objectives where various limitations and overall analysis is presented in the following sections.

II. LITERATURE REVIEW

Over the past few years, considerable amount of work is performed on optimizing task scheduling in fog computing environment. IoT requests are pushed to the fog layer for obtaining quick reply. So, as per the current trends the need of balanced workload is one of the major factor in fog environment. Considering the dynamic nature of fog nodes, optimizations and frequent improvements in the overall system is need of the hour. The following part is representing the abstract view of contributions performed over the years for easing task scheduling in fog computing. After going through proper analysis, task-scheduling approaches could be divided into two categories: Nature-inspired optimization-based task scheduling approaches and techniques other than nature-inspired optimizations.

A. Task scheduling approaches assisted with nature-inspired optimization techniques

Gill et al. [10] presented an approach for resource management which could be implemented in smart environments. The proposed approach is implemented through particle swarm optimization technique. Results are validated through a real time smart home case study and compared with two techniques from state of the art such as: Fog-computing paradigm for wireless sensor networks which is dependent upon master and slave concept. The second one is resource scheduling algorithm based on virtualization technique which can help to provide distributed load balancing. Luo et al. [13] presented fog computing architecture with the extensive usage of containers to improve the resource utilization of fog nodes and reduce latency. Task scheduling algorithm is designed with an objective of reducing energy consumption. Dynamic threshold strategy is used to balance the energy requirement among fog nodes. Performance evaluation is done through Linpack and comparison is done with the virtual machines.

Aburukba et al. [3] implemented genetic algorithm for scheduling internet of things request in fog–cloud hybrid environment with an objective of reducing latency. In the proposed methodology, authors have presented modified genetic algorithm with an objective of providing best possible solution by reducing latency and maximizing resource utilization. Wang et al. [17] presented task-scheduling technique, which is assisted with hybrid-heuristic approach where in features of two optimization algorithms have been incorporated to achieve better results. Improvements have been performed on PSO and ACO to achieve better results in terms of reliability, energy consumption and completion time
.

Sun et al. [15] presented a resource-scheduling algorithm, which works in two phases. The work is focused on using improved genetic algorithm, which is implemented on heterogeneous devices. The first phase of proposed approach performs optimized scheduling among fog clusters and the second phase focuses on scheduling various fog nodes inside individual clusters. Bitam et al. [6] presented optimized task scheduling approach based on nature inspired bees swarm optimization technique. The goal of the proposed method is to search an acceptable balance between the execution time and required memory for achieving services related to fog layer. The major objective is to perform best possible assignment of different jobs submitted in the fog environment on minimum possible fog nodes.

Kabirzadeh et al. [11] developed hyper heuristic algorithm for scheduling and resource allocation. Proposed technique is validated against ant colony and particle swarm optimization techniques. For evaluating the utility of proposed method, case study of smart surveillance system is considered. Fan et al. [8] presented task-scheduling approach, which is implemented in a layered IoT infrastructure. This kind of infrastructure can provide the benefit of executing user's offloaded tasks on the rented cloud resources. Author is considering the task-scheduling problem as complex problem and provides an efficient solution based on (ACO) ant colony optimization heuristic. Simulations are carried out and the methodology results are compared with the traditional methods such as first come first serve and min-max algorithm.

Ghanavati et al. [24] presented a novel task scheduling approach based on ant-mating optimization technique. This technique revolves around managing the trade-off among makespan time and energy consumption. Major objective is

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to assign tasks optimally among various fog nodes. Proposed technique is validated against various existing nature inspired methodologies and it outperformed them in all aspects. Ghobaei-Arani et al. [23] designed a task scheduling approach using moth-flame optimization technique. It is designed with an objective for reducing task execution and time taken for complete transfer. The proposed method is tested for a cyber physical application using iFogSim simulator.

B. Task-scheduling approaches other than nature-inspired based optimizations

Tychalas et al. [16] presented a task scheduling approach for fog computing environment which comprise of bag of tasks workload. The major benefit of the proposed approach is that the prior information of tasks is not required for actual scheduling. Bhatia et al. [5] implemented quantum based fog scheduler for real time IoT applications. The proposed load scheduling technique uses the quantum computing inspired optimization technique with the combination of Neural Network model for prediction. The proposed method is compared with other techniques listed in the literature such as round robin, minimum completion time and min-max. It outperformed them in terms of energy consumption and overall time taken. Authors have used quantum-based load scheduling as it offers various advantages such as high availability, scalability and operational convenience.

Gazori et al. [9] implemented a scheduling approach based on deep reinforcement learning with an objective of saving time and cost. Authors have proposed a deep learning-based scheduling algorithm. The proposed method is also aimed at solving some more problems like: SPoF (Single point of failure) and hardware requirements of scheduler. Sharma et al. [14] presented an architecture which works in four layers. The major objective is to schedule tasks and balance the workload on fog nodes. Initial layer consists of IoT devices. Next layer is responsible for dividing the tasks into two categories, such as: high and low priority. Fuzzy logic is used for performing this categorization. The third layer accomplishes the important task of clustering. Clustering is performed using K-means++ algorithm, where different types of fog nodes are placed in clusters. If the current node is unable to perform the desired function then the task is given to the cloud layer.

Aladwani et al. [4] proposed a new task scheduling technique for IoT based healthcare tasks, where the focus is on improving static task scheduling algorithm using classification of various tasks and VM Categorization based on task importance. Healthcare applications consists of number of tasks, and keeping in view of their criticality, it is must to assign priorities based on their importance. Therefore, the proposed method is focused on scheduling those tasks first which are of higher importance and then the remaining tasks can be performed. Khattak et al. [12] presented a fog environment for health care application which is primarily focused on heart disease. Health care applications cannot tolerate the delay so fog nodes are used as interface between cloud and IoT applications. In the first step request will be generated and it will be identified as critical and normal. If it is normal request, then it can be transferred to the fog server so that the bandwidth requirement can be reduced, but if the request is critical and fog nodes are unable to process it, then request will be forwarded to the cloud environment.

Mtshali et al. [19] presented scheduling technique based on the concept of virtualization for fog computing environment where in different types of scheduling algorithms are tested on video surveillance case study. Algorithms implemented are: Round Robin (RR), Generalized Priority (GP) and First Come First Serve (FCFS). Choudhari et al. [7] presented an improvement of efficient resource allocation (ERA) algorithm in terms of priority scheduling. The proposed approach works in two steps: First the incoming request is assigned to the near most fog server and in the second step, within each fog server the request is assigned to appropriate priority queue to that request can be processed as soon as possible. Three priority queues are maintained in each fog server. Xu et al. [18] presented scheduling of VMs for load balancing in fog-cloud environment. Various types of computing nodes in the fog-cloud environment are scheduled using dynamic load balancing technique which is further dependent upon heuristic approach. Ali et al. [31] presented a task scheduling approach based on fuzzy logic where tasks are divided among fog and cloud layers respectively. Proposed technique is validated on the basis of essential network related parameters such as: makespan, overall delay etc.

Guevara et al. [30] presented a task scheduling approach based on integer linear programming, where dual schedulers are working to schedule the tasks either on fog/ or cloud layers. Shakya et al. [28] presented a new technique for IoT based wearable healthcare devices. The major aim is to reduce the communication delay with the help of dispersed and elastic computing model. Syms et al. [26] presented task scheduling approach for edge computing. It utilizes game theory approach for achieving reduction in waiting and execution time. Pandian et al. [27] implemented minimization technique for fragmentation in cloud environment. Syms et al. [25] presented ANN based system for reducing energy consumption. It focuses on providing judicious management for smart street lights. Healthcare applications also require rapid responses and some novel task scheduling approaches must be designed so that patient health status could be monitored successfully. Manoharan et al. [29] implemented computer aided diagnostic method for the early diagnosis of lung cancer. These types of systems could be implemented at fog and cloud level so that rapid responses could be produced.

Table 1 is providing summary of various approaches implemented in the recent years along with their performance and limitations and Table 2 represents the insights of performance metrics used to validate the utility of proposed methodology.

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TABLE 1
SUMMARY OF TASK SCHEDULING APPROACHES

Author	Approach	Performance	Limitations
Tychalas et al.[16]	Job scheduler for bag of task(BoT) jobs	Reduction in cloud system's cost by 7%, Reduction in cluster energy consumption by 15%	Higher mean response time and overall energy consumption by the system is not calculated
Bhatia et al.[5]	Quantum based fog scheduler, Quantum based optimization technique combined with Neural Network model	Task completion time(avg.):28.15s for 10 nodes, Energy consumption:3.48J	Less number of parameters are used for validation purpose
Gazori et al.[9]	Deep reinforcement learning (Double deep Q-Learning) approach	Achieved reduction in response time and energy consumption	Higher average waiting time for some tasks due to lack of rescheduling mechanism.
Aburukba et al. [3]	Modified Genetic Algorithm	Improvement in latency from 21.9% to 46.6%, Improvements in meeting the request deadlines up to 31%.	Critical resource scheduling is missing and there is no scope of task pre-emption
Aladwani et al. [4]	Task Classification and Virtual Machine Categorization	Results revealed the reduction in the waiting and execution times, such as: AWT: 31, AET:21.67, AFT:52.67	No discussion on energy consumption parameter is done with the proposed methodology
Mtshali et al. [19]	Presented virtualization technique for scheduling purpose.	FCFS outperformed other algorithms in terms of energy consumption, time taken and latency	Implementation missing for dynamic IoT requests. Scalability factor is also missing
Wang et al. [17]	Scheduling using hybrid heuristic algorithm(IPSO+IACO), i.e. Combination of changed particle swarm and ant colony optimization	Hybrid heuristic approach has outperformed the other scheduling algorithms, such as: IPSO, IACO and RR	Task and fog node clustering is not specified
Choudhari et al. [7]	Presented improvement of efficient resource allocation algorithm in terms of priority algorithm	Improved average response time and total cost	Proposed scheduling approach lacks dynamic priority adjustments if network traffic increases
Sun et al. [15]	Resource scheduling approach is proposed with the help of improved genetic algorithm	Better results are obtained in terms of latency and task execution	Higher cost of resource requesters
Bitam et al. [6]	Job scheduling based on bee swarm bio-inspired approach.	Better performance can be observed in terms of Execution time and memory consumption	Less concern on optimization of network bandwidth and no implementation of dynamic job scheduling
Fan et al. [8]	Visualization of the task scheduling problem as 0-1 knapsack NP-hard problem and then providing the solution in terms of ant colony heuristic approach	Better results are observed as compared to existing approaches such as: FCFS and Min-min	No comparison is performed with the other meta-heuristic algorithms for validating the performance of proposed algorithm
Kabirzadeh et al. [23]	Hyper heuristic algorithm for scheduling and resource allocation.	Better results are seen as compared to PSO, ACO and Simulated Annealing, such as 69.99% improvement in average energy consumption and 59.62% improvement in cost.	No scope for virtual machine migration and resource provisioning

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TABLE 2
SUMMARY OF PERFORMANCE METRICS

Author	**Performance Metrics**				
	Energy Consumption	***Task Completion (or Execution) time***	***Cost***	***Latency***	***Average Response time***
Tychalas et al. [16]	✓	×	✓	×	✓
Bhatia et al. [5]	✓	✓	×	×	×
Gazori et al. [9]	✓	×	✓	×	✓
Aburukba et al. [3]	×	×	×	✓	×
Aladwani et al. [4]	×	✓	×	×	×
Mtshali et al. [19]	✓	✓	×	✓	×
Wang et al. [17]	✓	✓	×	✓	✓
Choudhari et al. [7]	×	×	✓	×	✓
Sun et al. [15]	×	×	×	✓	×
Bitam et al. [6]	×	✓	✓	×	×
Kabirzadeh et al. [23]	✓	✓	✓	×	×
Gill et al. [10]	✓	×	×	✓	✓
Sharma et al. [14]	✓	×	×	✓	✓
Yang et al. [12]	✓	×	×	✓	×
Liu et al. [20]	×	✓	×	×	×
Ghobaei-Arani et al. [21]	×	✓	×	×	×

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III. DISCUSSION ON KEY FINDINGS

Table 1 and 2 are highlighting the key aspects in relation to task scheduling approaches implemented over the years. After thorough analysis, various conclusions could be drawn. Following subsections are throwing light on those inferences.

A. Performance metrics used for validation purpose

Improved task scheduling approaches are developed with the motive of bringing efficiency in the fog computing environment. In order to gauge efficiency factor various performance metrics are required to be used. After analyzing Table 2, it has been found that energy consumption and total execution time are the prominent metrics to measure the overall efficiency of proposed task scheduling approach. Fig. 2 is demonstrating the overall usage in terms of percentage of authors used the above stated performance metrics.

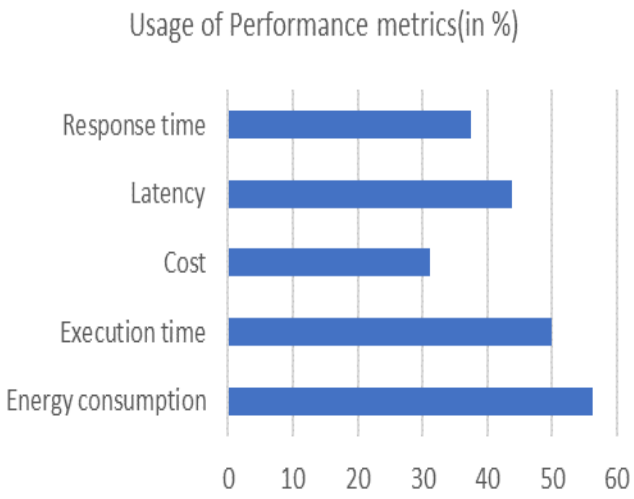

Fig 2:Usage of Performance metrics

B. Implementation tools used for the simulation purpose

Fog computing layer processes the tasks requested by IoT applications. In real time, various resources are required to build up such environment. Researchers are putting up their efforts to construct various novel methods for enhancing the effectiveness of task scheduling approaches. It becomes difficult to test the proposed scheme over real time scenario. So before going for the real implementation, it would be better to test it with some tools which can simulate the fog computing environment. From the literature survey, it has been found that iFogSim [22] is the most preferred tool for validating and testing the task scheduling and load balancing approaches. Apart from this, various other simulation tools used in state of the art are: MATLAB, CloudAnalyst, CloudSim etc.

C. Research challenges and future directions

After introspection of task scheduling approaches from the literature, various research challenges and future directions are identified:

- Fog computing environment may receive dynamic requests from the IoT devices, so it becomes difficult to meet up the desired QoS (Quality of Service) requirements.
- Fog devices are heterogenous in nature, so scheduling tasks in a uniform manner could be challenging.
- Fog servers are often capacity constrained and IoT applications may generate variety of tasks that could not be processed on the fog layer itself
- Maintaining static and dynamic schedulers simultaneously is a tedious task, hence hybrid scheduling mechanisms must be designed
- Most of the implemented strategies are not leaving any scope for scalable fog environments, hence work must be done in that aspect also
- Task scheduling approaches must perform task categorization before its processing. Tasks must be categorized as Critical and Non-Critical, so that minimum delay and energy consumption is there
- Various other performance metrics such as: throughput, load balancing factor, fault tolerance, network congestion, resource utilization must be considered for designing novel task scheduling approaches
- Combination of traditional scheduling approaches with meta-heuristic approaches can bring up more effectiveness in service

IV. CONCLUSION

In this paper, a brief overview of task scheduling approaches in fog computing is presented. After analysis, it has been observed that nature inspired optimization techniques are implemented widely to optimize the resource management in the fog-computing environment. Apart from nature-inspired optimization, various traditional scheduling algorithms are also implemented with the assistance of learning techniques. Although fog-computing paradigm is designed with an objective of reducing delay, but due to its dynamic and resource constrained nature, latency and high energy consumption could be observed. Effective resource management can provide the required assistance and improvements could be done. Researchers could utilize the power of traditional scheduling algorithms and meta-heuristic techniques to formulate new task scheduling approaches.

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