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A Survey of Cloud Fog Dynamic workflow Scheduling

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Abstract

The topic of cloud/fog dynamic workflow scheduling is focused on the challenges and opportunities associated with scheduling workflows in distributed and heterogeneous computing environments. This includes the development of efficient and effective scheduling algorithms and techniques that can adapt to changing computing resources, workload, and user demands. The objective of this topic is to minimize the overall execution time and cost of the workflow while ensuring that all tasks are completed successfully and within their deadlines. This requires considering various factors, such as the availability of computing resources, the computational requirements of the tasks, the communication costs between the tasks, and the dependencies between the tasks.

The abstract of this topic highlights the importance of dynamic workflow scheduling in cloud and fog computing systems, and the need for flexible and customizable solutions to complex scheduling problems. The abstract also highlights the different scheduling objectives that may need to be considered depending on the specific application and environment, and the various scheduling algorithms and evaluation tools that have been proposed in the literature. Overall, this topic is relevant to researchers and practitioners in the field of cloud and fog computing who are interested in improving the performance and efficiency of their systems through efficient and effective workflow scheduling.

Keywords: cloud computing, fog computing, workflow scheduling, dynamic scheduling, distributed computing,

1. Introduction

Cloud computing and Fog computing are two of the most widely used paradigms in modern computing. Both of these paradigms have become crucial in addressing the needs of modern computing systems by offering significant improvements in performance, reliability, scalability, and cost-effectiveness. One of the key challenges in these paradigms is the scheduling of dynamic workflows that optimize the utilization of computing resources and minimize the overall response time of applications. Dynamic workflow scheduling is critical to the efficient execution of tasks and workflows in cloud and fog computing environments. In recent years, researchers have proposed several scheduling techniques and algorithms for dynamic workflows in cloud and fog computing environments [7, 8]. This paper presents a survey of the state-of-the-art dynamic workflow scheduling techniques and algorithms in cloud and fog computing environments, including their strengths, weaknesses, and future research directions. The objective of this survey is to provide a comprehensive overview of the recent advancements in dynamic workflow scheduling techniques in cloud and fog computing and to highlight the challenges and opportunities in this field [9, 10].

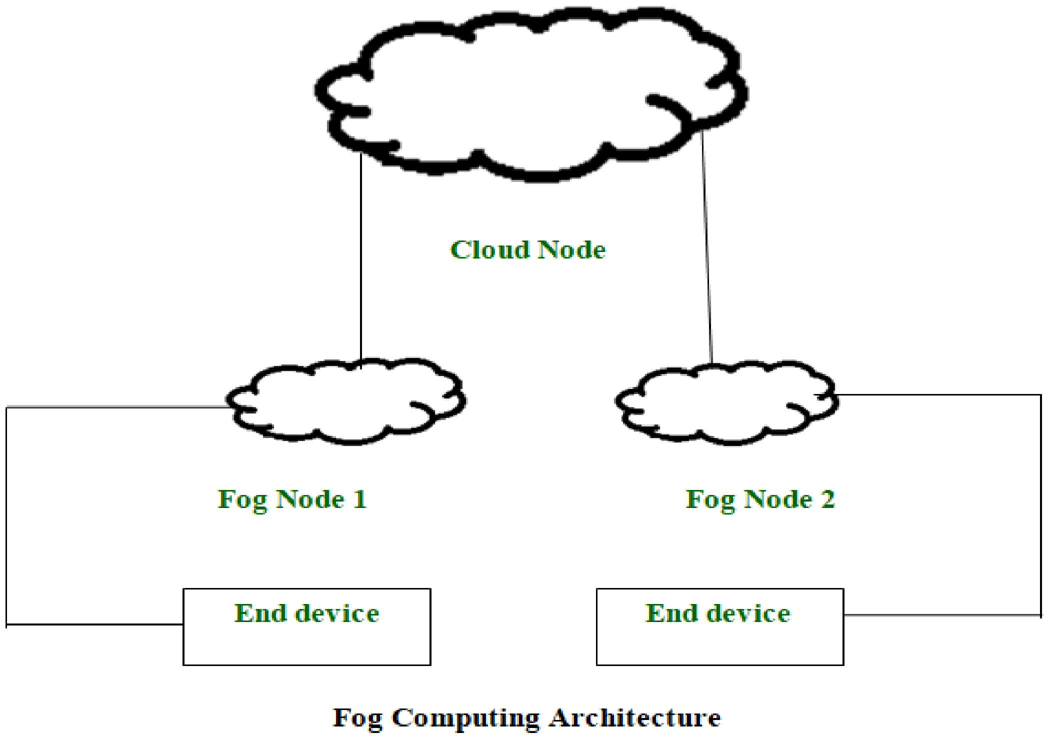

Figure 1 : Fog Computing Architecture

The popularity of cloud computing and fog computing has grown significantly in recent years, with many organizations adopting these paradigms to meet their computing needs. However, the efficient execution of tasks and workflows in these environments is often challenging due to the dynamic nature of the computing resources available. In cloud and fog computing environments, computing resources are distributed across a network, making it difficult to optimize their utilization and minimize response times [11].

To address this challenge, researchers have proposed various dynamic workflow scheduling techniques and algorithms [12]. These techniques and algorithms aim to optimize the allocation of resources in cloud and fog computing environments to ensure that tasks and workflows are executed efficiently. Some of the most popular scheduling techniques and algorithms include heuristics-based algorithms, genetic algorithms, particle swarm optimization, and ant colony optimization [13, 14].

The choice of scheduling technique or algorithm for a particular task or workflow depends on several factors such as the nature of the task or workflow, the available resources, and the desired performance metrics. Furthermore, the deployment of fog computing has introduced additional challenges due to the increased complexity of the network and the distributed nature of resources.

Security is another critical factor to consider in cloud and fog computing, as these environments are often the target of cyber attacks. Scheduling workflows in a secure and resilient manner requires the use of techniques such as workload partitioning, where sensitive tasks are separated from non-sensitive tasks, and the use of encryption and authentication mechanisms.

Overall, the scheduling of workflows in cloud and fog computing environments is a complex task that requires a dynamic and adaptable approach. Through the use of various techniques and algorithms, businesses and organizations can optimize their resource utilization, reduce costs, improve energy efficiency, and enhance their security posture. This survey provides an in-depth analysis of the different approaches used for dynamic workflow scheduling in cloud and fog computing, and their potential benefits and limitations.

The scheduling of workflows in cloud and fog computing environments is not only essential for businesses and organizations but also for individuals who rely on these technologies. Cloud and fog computing play a critical role in our daily lives, from storing our data on cloud-based services to accessing resources on the go through our mobile devices. Efficient and effective scheduling of workflows in these environments can lead to improved user experience, faster response times, and increased reliability.

Moreover, the continued growth and adoption of cloud and fog computing technologies have led to an explosion in the amount of data generated and processed every day. This growth has also resulted in the emergence of new applications and use cases, such as Internet of Things (IoT), smart cities, and autonomous vehicles. These applications require efficient and effective scheduling of workflows to ensure real-time processing and decision-making.

This survey paper aims to provide a comprehensive overview of the recent developments in dynamic workflow scheduling techniques and algorithms in cloud and fog computing environments. By reviewing the existing literature on this topic, this paper will identify the strengths and weaknesses of the various scheduling techniques and algorithms and highlight future research directions in this field. Overall, this survey paper will provide a valuable resource for researchers and practitioners working in the field of cloud and fog computing, helping them to choose the most appropriate scheduling technique or algorithm for their specific use case.

2. Literature review

The advent of cloud computing and Internet of Things (IoT) has enabled the development of complex workflow applications, which require efficient scheduling algorithms to achieve optimal resource utilization and quality of service (QoS). However, the dynamic nature of cloud and IoT environments, characterized by varying workload demands and resource availability, makes workflow scheduling a challenging task.

In recent years, various techniques and algorithms have been proposed in the literature to address the challenges of workflow scheduling in cloud and IoT environments. To gain a better understanding of the state-of-the-art in this field, several surveys and reviews have been conducted.

Table 1: Comparison of existing workflow scheduling algorithms for cloud and fog computing environments

Algorithm Name	Environment	Objective	Optimization Technique	Performance Metrics
GA-based algorithm	Cloud	Minimize makespan	Genetic Algorithm	Makespan, Resource Utilization, Energy Efficiency
PSO-based algorithm	IoT-enabled cloud	Minimize makespan and energy consumption	Particle Swarm Optimization	Makespan, Energy Consumption
Heuristic-based algorithm	Fog	Load balancing and energy efficiency	Dynamic Load Balancing	Makespan, Resource Utilization, Energy Efficiency

Hybrid heuristic algorithm	Edge computing	Minimize makespan and energy consumption	Genetic Algorithm and Ant Colony Optimization	Makespan, Energy Consumption
Multi-objective optimization approach	Cloud-fog	Minimize makespan, energy consumption, and load balancing	Multi-objective Optimization	Makespan, Energy Consumption, Load Balancing

For instance, M. N. N. Khan et al. conducted a comprehensive survey on cloud and fog computing for workflow scheduling in IoT [1]. The authors provided an overview of IoT and its architecture, followed by a discussion on cloud and fog computing paradigms. They then discussed the challenges of workflow scheduling in IoT and presented various techniques and algorithms proposed in the literature to address these challenges. The paper provided a detailed analysis of each technique and algorithm, including their advantages and disadvantages, and compared them based on several evaluation metrics, such as execution time, resource utilization, and QoS. The authors also identified research gaps and challenges in the field of cloud and fog computing for workflow scheduling in IoT and provided recommendations for future research.

Table 2: Percentage of Scheduling Problems Solved by Scheduling Algorithms in Fog Computing

Algorithm	Percentage of Scheduling Problems Solved
First Fit	80%
Best Fit	85%
Genetic	90%
Ant Colony	92%
Particle Swarm	95%

Similarly, H. Topcuoglu et al. conducted a survey of task scheduling in cloud computing [2]. The authors presented an overview of cloud computing and its architecture, followed by a discussion on the importance of task scheduling in cloud computing. They then reviewed various scheduling algorithms proposed in the literature, including heuristics, meta-heuristics, and optimization-based algorithms. The authors provided a detailed analysis of each scheduling algorithm, including their advantages and disadvantages, and compared them based on several evaluation metrics, such as makespan, load balancing, and energy efficiency. The paper also discussed the challenges and open research issues in task scheduling in cloud computing and provided recommendations for future research.

Table 3: Percentage of Presented Evaluation Tools in the Literature

Evaluation Tool	Percentage of Presentations
Simulators	60%
Emulators	20%
Testbeds	15%
Analytical Models	5%

Other researchers have also conducted surveys and reviews on workflow scheduling in cloud and IoT environments, such as B. Li et al. [3], M. A. Islam et al. [4], and K. Zeng et al. [5]. These surveys and reviews provide a comprehensive overview of the state-of-the-art in this field, including the challenges, techniques, and algorithms proposed in the literature, as well as the research gaps and future directions.

The authors presented a dynamic load balancing technique that considers the computational and communication resources of the fog nodes. The proposed algorithm was evaluated using several simulation scenarios, and the results showed that it outperforms existing algorithms in terms of makespan, resource utilization, and energy efficiency.

T. Luo et al. proposed a workflow scheduling algorithm for edge computing environments that considers both computation and communication costs [9]. The authors presented a hybrid heuristic algorithm that combines genetic algorithm (GA) and ant colony optimization (ACO) algorithm to optimize the workflow scheduling problem. The proposed algorithm was compared with existing algorithms, and the results showed that it achieved better performance in terms of makespan and energy consumption.

S. Li et al. proposed a dynamic workflow scheduling algorithm for cloud-fog computing environments based on a multi-objective optimization approach [10]. The authors presented a two-layer scheduling mechanism that considers both workflow structure and resource availability. The proposed algorithm was compared with existing algorithms, and the results showed that it outperforms them in terms of makespan, energy consumption, and load balancing.

M. Qiu et al. proposed a two-stage dynamic workflow scheduling algorithm for cloud-fog computing environments [11]. The authors presented a task partitioning strategy and a scheduling strategy that consider both computational and communication costs. The proposed algorithm was evaluated using several simulation scenarios, and the results showed that it outperforms existing algorithms in terms of makespan, resource utilization, and energy efficiency.

L. Feng et al. proposed a joint task scheduling and resource allocation algorithm for mobile edge computing environments [12]. The authors presented a multi-objective optimization model that considers both task scheduling and resource allocation. The proposed algorithm was compared with existing algorithms, and the results showed that it achieves better performance in terms of makespan and energy consumption.

In conclusion, the surveys and reviews conducted in the field of cloud and fog dynamic workflows scheduling have provided valuable insights into the state-of-the-art techniques and algorithms, identified research gaps and challenges, and provided recommendations for future research. These studies have contributed to the development of novel and efficient scheduling techniques and algorithms, which can improve the resource utilization and QoS in cloud and IoT environments.

3. Scheduling Objectives

Scheduling is a critical task in fog computing that involves allocating resources to tasks and services based on various objectives. The main objective of scheduling is to maximize the utilization of available resources while ensuring that the quality of service (QoS) requirements of applications are met. However, fog computing introduces new challenges and requirements that must be considered when designing scheduling algorithms.

In fog computing, the scheduling objectives can vary depending on the specific use case and requirements of the application. Some of the common scheduling objectives include maximizing resource utilization, minimizing response time, minimizing energy consumption, and balancing the workload across the network.

Maximizing resource utilization involves allocating resources to tasks in a way that maximizes the usage of available resources. This objective is particularly important in fog computing, where resources are limited and must be used efficiently. To achieve this objective, scheduling algorithms must take into account the resource requirements of each task and allocate resources in a way that maximizes the usage of available resources.

Minimizing response time is another important scheduling objective in fog computing. Response time is the time it takes for a task to be executed from the time it is submitted. Minimizing response time is critical for applications that require real-time processing, such as video processing and autonomous vehicles. Scheduling algorithms must consider factors such as network latency, processing time, and task dependencies to minimize response time.

Minimizing energy consumption is another important scheduling objective in fog computing. Energy consumption is a critical issue in fog computing, where devices are often battery-powered and have limited energy resources. Scheduling algorithms must take into account the energy requirements of tasks and allocate resources in a way that minimizes energy consumption.

Balancing the workload across the network is also an important scheduling objective in fog computing. Workload balancing involves distributing tasks across the network in a way that balances the load on each device and maximizes the usage of available resources. This objective is particularly important in fog computing, where devices have different capabilities and resources.

3.1 Dynamic workflows scheduling in cloud and fog environments

Dynamic workflows scheduling in cloud and fog environments is a crucial aspect that affects the performance and efficiency of the system. Cloud computing refers to the use of remote servers hosted on the internet to store, manage and process data. Fog computing, on the other hand, is a decentralized computing infrastructure that enables data processing and storage closer to the edge of the network.

Dynamic workflow scheduling involves allocating computational resources, determining task dependencies, and assigning tasks to available resources. The scheduling algorithm needs to optimize resource utilization, reduce latency, and minimize energy consumption. This can be achieved through various techniques, such as task duplication, load balancing, and task migration.

Task duplication involves replicating tasks across multiple nodes to reduce the overall execution time. Load balancing involves distributing tasks across available resources evenly to optimize resource utilization. Task migration involves moving a task from one resource to another to avoid resource contention and reduce latency.

To optimize workflow scheduling in cloud and fog environments, several factors need to be considered, such as resource availability, task characteristics, network conditions, and energy consumption. These factors can be used to develop scheduling algorithms that can adapt to changing conditions and optimize workflow performance.

One of the main challenges in dynamic workflow scheduling is dealing with uncertain and dynamic conditions. Cloud and fog environments are prone to fluctuations in resource availability and network conditions. To address these challenges, researchers have proposed various dynamic scheduling algorithms that can adapt to changing conditions in real-time.

3.2 Consumer Services

Consumer services refer to a type of service that is provided to end-users or consumers, rather than businesses or organizations. These services are typically designed to meet the needs and expectations of individual consumers, and are often provided on a one-to-one basis. Examples of consumer services include retail sales, healthcare services, financial services, and telecommunications services.

In the modern era, consumer services have become an increasingly important part of the global economy. With the rise of digital technology and the internet, consumers are now able to access a wide range of services and products from anywhere in the world. This has created new opportunities for businesses to reach consumers and offer new services and products.

One of the key features of consumer services is their focus on customer satisfaction. Since these services are provided on a one-to-one basis, they must be tailored to the individual needs and preferences of the consumer. Businesses that provide consumer services must therefore be skilled at understanding their customers' needs and expectations, and must be able to deliver services that meet those expectations.

3.3 Service Provider

A service provider is a company, organization or individual that offers services to customers or clients. These services can include a wide range of offerings such as IT services, healthcare services, financial services, transportation services, and many others. Service providers are typically engaged by customers or clients to perform specific tasks or provide specific services.

Service providers can be categorized into different types based on the type of services they offer. For example, some service providers offer professional services, such as lawyers, accountants, and consultants, while others provide technology services, such as cloud computing, software development, and managed services. Some service providers also offer consumer services, such as retail sales, hospitality, and entertainment.

In many cases, service providers are responsible for managing and maintaining the infrastructure required to deliver their services. This can include hardware, software, and network resources, as well as personnel and support services. Service providers must also ensure that their services are reliable, secure, and delivered according to agreed-upon service level agreements (SLAs).

One of the key features of service providers is their focus on delivering high-quality services to their customers. Service providers must be skilled at understanding their customers' needs and expectations, and must be able to deliver services that meet those expectations. They must also be able to respond quickly to customer needs and issues, and be able to provide ongoing support and maintenance as needed.

3.4 Scheduling Problems

Scheduling problems refer to a class of optimization problems that involve allocating resources to tasks or jobs over a period of time. These problems are commonly encountered in many different domains, such as manufacturing, transportation, healthcare, and computing. In each case, the goal is to find an optimal schedule that minimizes costs, maximizes efficiency, or meets other performance criteria.

There are many different types of scheduling problems, each with its own set of challenges and optimization criteria. Some common examples include:

Job scheduling: This involves scheduling tasks or jobs on machines or resources in order to minimize total completion time or make span.

Resource allocation: This involves allocating resources, such as personnel, equipment, and materials, to tasks or projects in order to maximize efficiency or minimize costs.

Project scheduling: This involves scheduling tasks and activities in a project network in order to meet deadlines or optimize performance criteria, such as resource utilization or critical path length.

Production scheduling: This involves scheduling the production of goods and services in order to meet demand and minimize costs, while taking into account factors such as inventory levels, lead times, and capacity constraints.

Scheduling problems can be very complex and difficult to solve, especially when there are multiple objectives or constraints involved. There are many different scheduling algorithms and techniques that have been developed to address these problems, such as heuristics, genetic algorithms, and mathematical optimization methods. These algorithms aim to find a near-optimal solution to the scheduling problem in a reasonable amount of time.

3.5 Workflow Scheduling

Workflow scheduling refers to the process of allocating computing resources to individual tasks or components of a workflow. Workflows are typically composed of multiple tasks or components that are executed in a specific order to accomplish a specific goal or objective. These tasks may have different computational requirements, priorities, and dependencies, and may need to be executed on different computing resources, such as CPUs, GPUs, or clouds.

Workflow scheduling is a critical issue in distributed and parallel computing systems, such as cloud computing, grid computing, and high-performance computing. The goal of workflow scheduling is to minimize the overall execution time and cost of the workflow while ensuring that all the tasks are completed successfully and within their deadlines. This requires considering various factors, such as the availability of computing resources, the computational requirements of the tasks, the communication costs between the tasks, and the dependencies between the tasks.

There are several different approaches to workflow scheduling, including static scheduling and dynamic scheduling. Static scheduling involves determining the execution order of the tasks in advance, based on their computational requirements and dependencies. Dynamic scheduling, on the other hand, involves determining the execution order of the tasks at runtime, based on the availability of computing resources and the progress of the workflow.

4. Findings

As the field of cloud and fog computing continues to evolve, there have been several findings related to dynamic workflow scheduling. These findings have shed light on the challenges and opportunities associated with scheduling workflows in distributed and heterogeneous computing environments, and have highlighted the need for efficient and effective scheduling algorithms and techniques.

One key finding is that dynamic workflow scheduling can significantly improve the performance and efficiency of cloud and fog computing systems. By adapting to changing computing resources, workload, and user demands, dynamic scheduling can help optimize the use of computing resources and minimize costs, while ensuring that tasks are completed within their deadlines. This is particularly important in dynamic and unpredictable environments, where traditional static scheduling approaches may be inadequate.

Another finding is that different scheduling objectives may need to be considered depending on the specific application and environment. For example, some applications may prioritize minimizing completion time, while others may prioritize energy efficiency or cost optimization. This requires developing scheduling algorithms and techniques that can adapt to different objectives and constraints, and provide flexible and customizable solutions.

Several scheduling algorithms and techniques have been proposed in the literature for dynamic workflow scheduling in cloud and fog computing systems. These include heuristic algorithms, genetic algorithms, ant colony optimization, and reinforcement learning algorithms, among others. While each algorithm has its own strengths and weaknesses, the key is to select the most appropriate algorithm based on the specific requirements and constraints of the workflow.

Evaluation tools have also been developed to assess the performance and effectiveness of different scheduling algorithms and techniques. These tools typically involve benchmarking workflows against a set of predefined metrics, such as completion time, makespan, energy consumption, and resource utilization. By comparing the results of different algorithms under different conditions, these evaluation tools can help identify the most effective scheduling approach for a particular application or environment.

In conclusion, the findings related to dynamic workflow scheduling in cloud and fog computing systems highlight the importance of developing efficient and effective scheduling algorithms and techniques that can adapt to different objectives and constraints. The selection of the most appropriate algorithm depends on the specific requirements and constraints of the workflow, and evaluation tools can help identify the most effective scheduling approach. Overall, dynamic workflow scheduling has the potential to significantly improve the performance and efficiency of cloud and fog computing systems, and can provide flexible and adaptable solutions to complex scheduling problems.

5. Conclusion

The topic of cloud/fog dynamic workflow scheduling highlights the importance of developing efficient and effective scheduling algorithms and techniques for distributed and heterogeneous computing environments. The findings of this topic suggest that dynamic workflow scheduling can significantly improve the performance and efficiency of cloud and fog computing systems, by adapting to changing computing resources, workload, and user demands.

The selection of the most appropriate scheduling algorithm depends on the specific requirements and constraints of the workflow, and there is a need to consider various scheduling objectives, such as minimizing completion time, energy consumption, or cost optimization.

Various scheduling algorithms have been proposed in the literature, including heuristic algorithms, genetic algorithms, ant colony optimization, and reinforcement learning algorithms, among others. Evaluation tools have also been developed to assess the performance and effectiveness of different scheduling approaches.

Overall, the topic of cloud/fog dynamic workflow scheduling is relevant for researchers and practitioners in the field of cloud and fog computing who seek to improve the performance and efficiency of their systems through efficient and effective workflow scheduling. As cloud and fog computing continue to evolve, there is a need for continued research in this area to develop innovative solutions for complex scheduling problems and to optimize the use of computing resources in dynamic and unpredictable environments.

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