Resource Allocation in Fog Computing: A Systematic Review

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Resource Allocation in Fog Computing: A Systematic Review

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***Abstract*— Despite the importance of resource allocation issues, there is no systematic, comprehensive and detailed survey on resource allocation approaches in the fog-computing context. In this article, we provide a Systematic Literature Review (SLR) on the resource allocation approaches in fog environments in the form of a classical taxonomy to recognize the state-of-the-art mechanisms on this important topic and provide open issues. The presented taxonomy is categorized into three main fields: centralized allocation, decentralized allocation, and integrated allocation (published between 2017 and March 2022). According to what is known in fog computing, load balancing and service placement are among the most important basic parameters that ensure service quality. These fields are classified into four methods, approximate, exact, fundamental, and hybrid. In addition, this article investigates resource allocation metrics with all advantages and limitations related to chosen resource allocation mechanisms in networks.**

***Keywords*—** *Fog computing, load balancing, quality of service, Internet of things (IoT), systematic review, resource allocation, service broker, service application placement, edge computing*.

I. INTRODUCTION

During the last few years, cloud computing has significantly improved access to networked computing resources and how they can be utilized, often based on pay-as-you-go pricing models [1,2]. The cloud environment reduces traditional data storage systems' computing and storage load. After the development of IoT, several problems come to light in the cloud computing platform.

The count of Internet of things (IoT) gadgets has expanded to create new IoT applications in a wide range of spaces to improve the nature of human existence [3, 4,5]. With the fast advancement of IoT applications, in order to enhance cloud-computing technology, another approach called fog computing (aka fogging) has recently been introduced [6]. Fog computing is an arising distributed computing paradigm that has a late pulled in consideration of both industry and academic community for ensuring the solicitations of computational applications in IoT smart devices [7, 8]. Fog computing is an architecture for the Internet of Things, where data is transmitted on large remote servers and can be accessed through the Internet. The cloud is effective, but not in the case of real-time systems. Moreover, real-time is the key to the Internet of things: without this readiness, we could not run the cars that drive themselves, smart cities, and so on [9].

Fog Computing is a highly virtualized platform that provides computing, storage, and networking services between end devices and traditional cloud computing data centres, typically, but not exclusively, located at the edge of the network [10]. Resource allocation in fog computing varies from the traditional to distributed computing environment due to various QoS metrics such as CPU memory, speed, and stability. In dealing with resource allocation, multiple requests will be in the queue, waiting to be served at various stages.

Since the available resources are considered exchangeable energy, processing power, and storage capabilities, this network has progressed in performance by allocating these IoT resources efficiently. The IoT has distributed and heterogeneous nature. Therefore, its optimal resource allocation is not negligible [11, 12]. However, there are many new challenges for resource allocation in fog computing, which needs new solutions. Resource discovery and monitoring play an important role in supporting resource allocation, and resource allocation plays an essential role in fog computing.

Furthermore, because the fog nodes have largely energy consumption issues, proficient resource allocation affects fog nodes' lifetime. Then again, because of the exceptional factor and unpredictable fog environment, it requires the asset of the executive's issues as one of the provoking issues to be considered in the fog scene. Thus, for the contextual investigations' most extreme burden and high versatility, the sensible administration of fog nodes, in any event, is important to build fog computing effectiveness [14].

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Despite the significance of resource allocation in the fog environment, there is no comprehensive review or systematic literature on the resource allocation issues in the fog computing environment that assist the scholars' necessities in the resource allocation field. For that reason, this research aims to study and review the existing resource allocation approaches in fog computing comprehensively and systematically. This research provides a systematic review of the resource allocation approaches in a fog computing environment. This paper classifies the resource allocation approaches into three main categories: centralized allocation, decentralized allocation, and integrated allocation.

The primary contributions of this research are as follows:

- A summary of the existing challenges and the significant issues regarding the resource allocation branches in the fog environment.
- Presenting a systematic review of the existing resource allocation approaches in a fog-computing environment.
- Analyzing the main sides of resource allocation approaches in fog computing for enhancing their mechanisms in future works.
- Introducing the open issues and future challenges that resource allocation approaches can be applied in fog computing.

The remainder of this paper is coordinated as follows:

Section 2 gives the essential writing survey of resource allocation issues in fog computing. In section 3, the research selection methodology is presented. Section 4 discusses resource allocation approaches in fog computing and classifies them according to a presented taxonomy. The comparison and a discussion about the reviewed techniques are provided in section 5. In addition, section 6 shows new challenges and key open issues for future works. Finally, we present the conclusions in section 7.

II. LITERATURE REVIEW

The fog environment is an extended part of the cloud that enables edge computing and real-time applications with the benefits of low latency, mobility, and location accuracy. They find fog computing reliable for real-time data processing in IoT services and the cloud for bulk data analysis. The fog environment is not far from the end node, and it can reduce latency, response time and other quality of service parameters like cost, energy, and network usage. Another thing is the increase of nodes with the passage of time [15].

Furthermore, because of the diversity of resource heterogeneity and dynamic negotiations, the highly variable and unstable fog network needs resource allocation as one of the difficult issues to be addressed to increment the fog computing efficiency. For the rest of this section, first, display a brief overview six-layer architecture of the fog environment and then discuss some related review and survey studies in the resource allocation issues on the fog and edge computing.

A. *Abbreviated Overview of the Fog Computing Architecture*

In this sub-section, illustrate a generic fog environment six-layer architecture and then discuss the abbreviated overview of the details related to each layer, as shown in Fig.1. The overall architecture consists of six distinct layers, a physical and virtualization layer, a monitoring layer, pre-processing layer, temporary storage layer, security layer and transport layer [1]. Starting from the bottom layer, at the physical layer, the edge nodes that contain any type of IoT devices, virtual nodes, sensors, and actuators are distributed geographically, and data is collected, normalized, and accumulated from them. At the monitoring layer, the data collected from edge nodes is monitored as to which type of devices is performing what type of tasks, when and how resources are being used, which are available, and how many are inactive. Energy consumption is also noted from the nodes scattered across the network. The collected data is refined at this layer, and meaningful information is taken out of it. That data is temporarily stored locally on a temporary storage layer, but as soon as it moves to the cloud, it is removed from the storage layer. At the security layer, security measures are taken to keep the data in its form. The integrity of data is ensured by using encryption and decryption techniques. After processing, data is transported to the cloud via the transport layer, and only the data required for bulk analysis in the cloud is stored there to reduce storage utilization.

B. *Related Works*

This sub-segment depicts some related review and survey articles on the resource allocation problems on edge and fog computing. A few benefits and limitations of each related study are discussed and analyzed.

Lahmar and Boukadi [16] have conducted one of the significant studies on fog environments. Their article introduces a systematic mapping study covering the literature's different aspects of resource allocation. It summarizes the distribution of work based on the identified literature target: Fog only, Fog to Cloud computing and fog, and it found that 46% of the selected papers proposed solutions to the resource allocation in fog computing. Most of these papers propose solutions specifically to placement or scheduling problems. However, the offloading or workload distribution solutions have been proposed mainly in the context of Fog-to-Cloud computing or Fog-to-Fog computing. Nonetheless, there is a lack of publications for resource allocation in Fog-to-Fog computing, which is limited to 18%. Regarding the resource allocation algorithms, they noticed that a large amount of work had been conducted using heuristic or exact optimization-based algorithms compared to that meta-heuristic based-algorithm.

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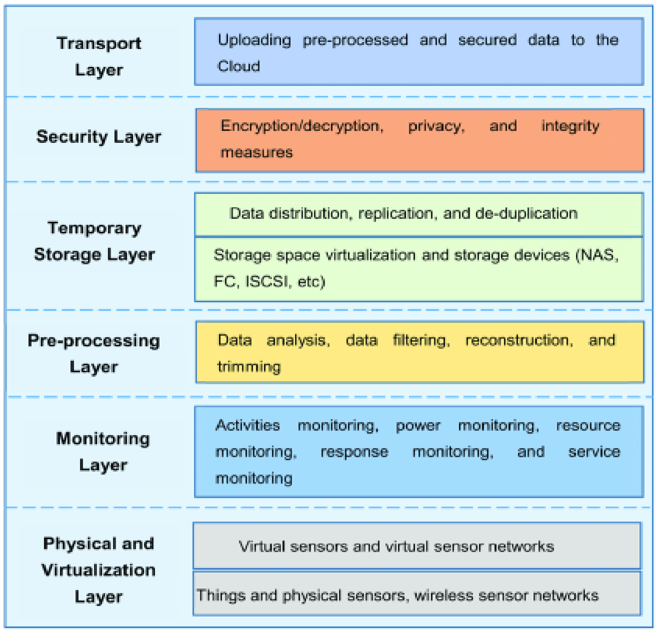

Fig. 1 Six-layer mechanism of fog landscape

Also, revising the resource allocation methods in fog computing environments has been illustrated by Ahmed et al. [17]. The summarized lessons from the literature review and assessment reveal that fog computing and resource distribution are complex processes.

Mehta et al. [18] work on presenting a comprehensive study that underlines the current advancements in machine learning techniques associated with the management of three important aspects of fog computing: accuracy, resource, and security, as well as highlights the role of machine learning in edge computing. Analyzing the studies shows that the primary focus is on resource placement, offloading or scheduling issues. Effective balancing of workload for optimal resource allocation also remains a big challenge, which they need to work on.

Also, Patil-Karpe, et al. [19] have studied the issue of resource allocation in different areas, which can also apply to the efficient working of fog computing. The unstable occurrence of the Internet of things (IoT), fog computing, and big data within the perception of cloud computing makes this enormously challenging to explore both cloud and fog resource scheduling strategies, which can satisfy the users' QoS requirements and enhance the efficiency of resource utilization.

Furthermore, V. Sindhu and M. Prakash. [20] have surveyed task scheduling techniques for extracting resource allocation methods in fog-based IOT applications. However, several challenges were addressed in fog computing with respect to scheduling the tasks and allocating the resources. The advancements that have been made recently in the allocation of resources and scheduling the tasks in fog were addressed in this article.

Finally, the authors in [104] analyze the implications of fog and edge computing technologies in the design and deployment of enterprise systems and their impact on the enterprise environment. The authors analyze existing contributions from different domains such as medicine, automotive, the oil industry, it, and smart homes. The purpose of this research is to provide a better understanding of the existing implementations, current issues and what can be improved. Based on the research, the authors propose building blocks for developing a framework that can fit the requirements of the business environment.

III. RESEARCH METHODOLOGY

This part presents the Systematic Literature Review (SLR) technique as a research finding and assessment for classifying the resource allocation approaches in fog computing [22, 23]. The following investigated string ward are implemented to find essential keywords and synonyms of the allocation resource approaches. [24]:

(“Resource” OR “Resource allocation” OR “Application
Placement” OR “Load balancing” OR “Allocation”) AND
(“Fog”) OR (“Fog Computing” OR (“Edge computing”))
AND (“review” OR “survey” OR “Systematic Reviews”)
AND (“centralized” OR “decentralized”)

According to the SLR method, the research questions (RQs) define our motivation, i.e., answers give us an evidence-based review of resource allocation mechanisms. Six research questions are defined that clarify the basis for obtaining the search strategy for extracting literature, as shown in Table I.

TABLE I. RESEARCH QUESTIONS

RQ1 Which kind of classification in research approaches are presented in fog systems resource allocation?
RQ2 What case studies are presented in the resource allocation approaches?
RQ3 which evaluation tools are applied for evaluating the resource allocation approaches?
RQ4 which assessment factors are ordinarily utilized to assess resource allocation approaches and advance them?
RQ5 what techniques are used to resource allocation approaches?
RQ6 What are the open perspectives for resource allocation approaches and future research directions in fog computing?

The exclusion and inclusion techniques are utilized to select and filter papers to achieve the essential studies refinement. 70 papers meet our selection criteria, which contain some of the research papers published by IEEE, Elsevier, Wiley Online Library, ACM, Taylor & Francis, Science Direct and Springer. as shown in Table II

In addition, numerous research papers have been published as books, conferences and journals.

TABLE II. SEARCH RESULTS ON DIGITAL LIBRARIES

No	Academic Database	Result
1	ACM	5
2	IEEE	57
3	Taylor & Francis	7
4	Wiley	30
5	Google Scholar	189
6	Science Direct	19
7	Springer	42
Total		**349**

TABLE III. SELECTION CRITERIA

Relevance	Criteria
Title	The language used (English) related to RA, LB and AP in Fog computing
By search	Search string publication year form (2017–2022)
Abstract/introduction/conclusion	Fog computing background in its related area
Full text	An empirical study of challenges and issues, and techniques used for RA, LB and SP in FC

The study selection criteria exclude research by title and abstract. We only examined the publication of an influential magazine in Fog Computing. It has been filtered based on Resource Allocation information, the Fog computing load balancing and placement using the inclusion and exclusion process throughout the paper. Table IV shows that our defined research represents the selection procedure. The following steps performed for the selection process are given below:

Step 1 To identify the corresponding paper related to our research work, seven databases such as IEEE, Elsevier, Wiley Online Library, ACM, Taylor & Francis, Science Direct and Springer with some search strings are used, displayed in TableII. Then from them, the related paper relevant to our work is taken as a reference.

Step 2 We have identified the related 349 papers from the seven databases in search string-wise, year-wise (2017–2022) and top-wise. From those, we filtered and selected 70 papers using the inclusion process and removed 259 papers by exclusion process which do not have the keyword in the table of the paper as detailed in Table IV.

TABLE IV. INCLUSION/EXCLUSION CRITERIA

Inclusion	➢ Research articles that present techniques or innovative solutions on resources allocation mechanisms in fog computing ➢ Peer-reviewed articles in conferences and JCR-indexed journals ➢ Articles published between 2017 and March 2022
Exclusion	➢ Review articles, editorial articles, short articles (less than six pages), write articles, and non-English articles. ➢ Research articles that do not mention solutions and methods to improve resources allocation in fog computing explicitly ➢ Books, book chapters, and theses

IV. RESOURCE ALLOCATION APPROACHES IN FOG COMPUTING

As previously explained, fog is the extension of the cloud where the storage and computation are moved from the core network to the edge to serve the real-time applications (RTA) and to decrease the network load of the data centre. A fog computing network consists of a huge number of fog nodes (FNs). Several cloud data centres deploy the FNs in various geographic areas to supply services like data to the client's application needs. The fog nodes are not visible to the clients, but the clients can be provided with the resources they need for their next working process [25]. Due to the incredulity, dynamicity of fog computing, and heterogeneity, mechanism allocation of resources is necessary to make the fog environment a reality. This section provides a technical review of the approaches allocation of resources in fog environment for selected peer-reviewed according to a systematic literature review employed. This research study utilized a data-driven approach to select primary problems allocation of resources in fog computing. To do so, a subject selection solution was utilized. As a result, the resource allocation approaches have been classified into three basic categories, as shown in Figure 2. : Centralized allocation, Decentralized allocation, and Integrated allocation. Note that the resource allocation issue in fog computing is categorized according to the necessary relationships established to load balancing and application placement that depend on service brokering in fog computing [2]. Also, Based on the available literature, It was a natural move to review the literature from these perspectives since most studies in this domain deal with the issues from each perspective that permits categorizing the reviewed articles under common superordinate. However, other taxonomies are also possible (e.g. Fog computing, fog-fog computing and fog-cloud computing, or auction-based and optimization).

As indicated by the given taxonomy in Figure 2, the first category of our taxonomy is Centralized allocation, where centralized load balancing centralized controller balances the load in fog nodes, as shown in Figure 3. [26]. While in Centralized placement, a central control loop is deployed either on the fog computing or cloud platform (depending on the application scale) to regulate the operation of the different control loops at the same level. [27].

Decentralized allocation is the following efficient classification of the whole fog resource allocation scenario. In decentralized load balancing, as shown in Figure 4, a distributed controller is used, which coordinates with the local controller and the computation overhead is distributed.

The distributed controller improves the reliability and scalability of the network, as shown in Figure 4. [26]. While in decentralized placement, a set of control loops of the same level is coordinated to accomplish the four activities (monitoring, analysis, planning and execution) [27].

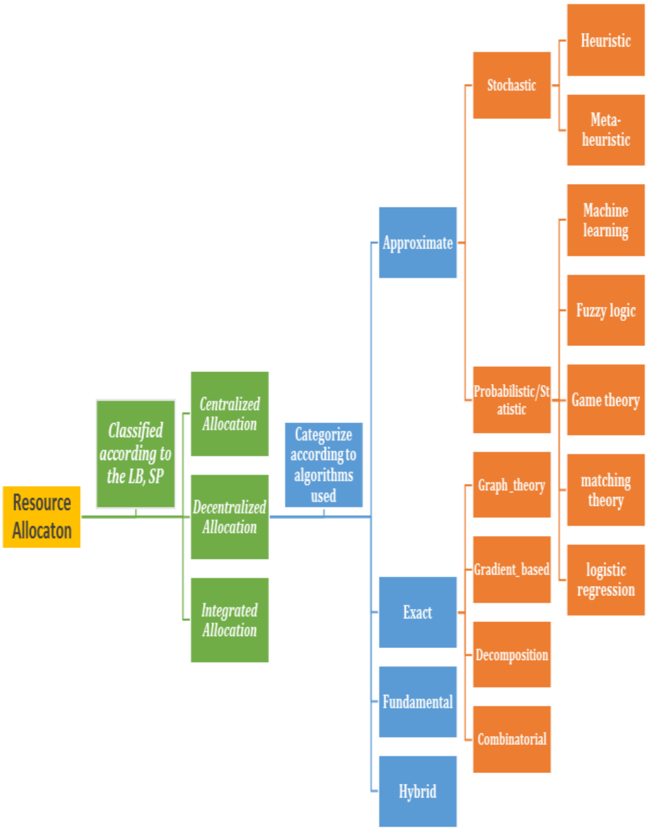

FIG.2 RESOURCE ALLOCATION APPROACHES TAXONOMY IN FOG COMPUTING.

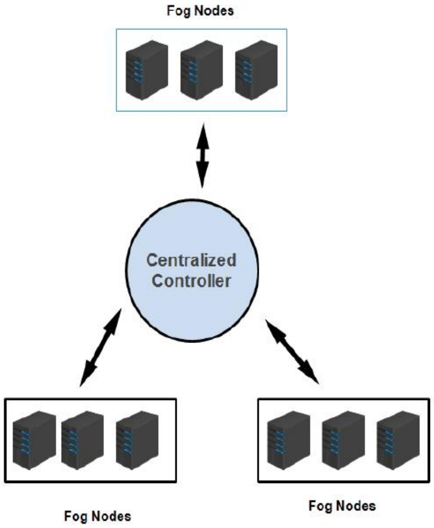

FIG. 3: CENTRALIZED CONTROLLER

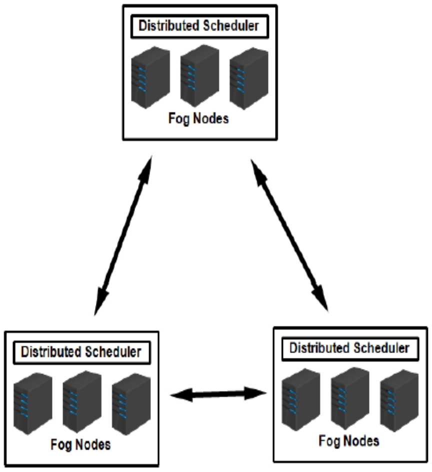

FIG. 4: DECENTRALIZED CONTROLLER

At last, the last essential classification of our taxonomy is Integrated allocation, where hybrid load balancing provides a trade-off between the advantages of both decentralized and centralized solutions. While hierarchical placement [28, 29] makes numerical semi-international, many regional managers and both managers are working together to supply both advantages of decentralized and centralized approaches. The first factor that depends on our taxonomy is Application placement, how and where placed of applications. The application deployment approach straightforwardly affects network and hardware productivity [29]. For example, a disjointed application spread solution for a significant volume of data in decentralized fog architecture may cause a network bottleneck [30]. Since the application deployment and evaluation plan might impact the most proficient method to put the application on the resource is one of the primary factors we have to allocate fog resources. Besides resource utility effectiveness, time-critical applications require a strategy to distribute arriving loads with an accepted mechanism across all available resources. Load balancing can help with task scheduling, application placement and task offloading, where all might resolve a similar issue with alternate points of view [38]. Hence, the second factor that depends on our categorization is load balancing.

Resource allocation refers to determining a resource for IoT services among active cloud resources, available resources in the fog node, or other dynamic fog resources in the area to utilize a wide range of accessible resources [13].

In the following, explain the resource allocation categories and sub-classifications for each category in more detail according to Figure 2.

1. Centralized Allocation Category

In this subpart, this research will first represent the Centralized Allocation problem in fog computing. Then, it provides an overview of the different classified of the Centralized Allocation subject.

1.1 Centralized Allocation Issue

This issue depends on centralized load balancing and centralized application placement in the allocation of resources. In contrast, in centralized load balancing strategies performed in a central node, the centralized load balancer has a general controller that needs knowledge of overall fog resources and IoT requests. With respect to a single point of control in centralized load balancing, this construction is not resilient and scalable [31, 32]. While in centralized placement, the centralized broker needs data from every one of the substances in the fog environment (e.g. IoT services, fog gadgets, cloud, customers) to take worldwide optimization decisions.

We can classify this approach based on the available algorithms or models used to solve the problem of literature. Four main classifieds were recognized: approximate, exact, fundamental, and hybrid methods. This section reviews 20 selected articles based on the criteria mentioned before, and their main features, differences, evaluation parameters, tools, pros and limits, and models architectures are defined.

1.2 Centralized Allocation Classified

1.2.1 Approximate Methods

This part includes studies on approximate methods, including stochastic, probabilistic, and statistical techniques. Section A investigates stochastic methods, including heuristic and metaheuristics related to the research field. Then, in Section B, probabilistic/statistic methods are reviewed.

1.2.1.1 Stochastic methods

I. HEURISTIC METHODS

Heuristic methods are made by "experience" for particular optimization problems, intending to find the best solution to the problem through "trial-and-error" in an optimal amount of time [33]. The solutions in heuristic approaches might not be the best or optimal solution; however, they can be much better than an educated guess. Heuristic approaches make use of the problem particularities. As exact approaches consume a considerable amount of time to get the optimal solution, heuristic approaches are preferable, gaining near-optimal solutions in an optimal amount of time [33]. Some of the heuristic methods in the literature reviewed include Path-Clustering Heuristic [41] and the greedy-in-principle algorithm [42].In this section, selected heuristic-based methods are discussed.

Toniolli et al. [41] studied the problem of scheduling multiple applications in the cloud-fog environment for three-layered architecture. They adopted the Path-Clustering algorithm for the cloud-fog environment aiming to maintain the trade-off between cost and schedule length. They also implemented three other algorithms (Cost-Makespan aware Scheduling, Heterogeneous Earliest Finish Time and Cost-Conscious Scheduling Heuristic) in this context of multiple applications scheduling. Simulation results demonstrated that the proposed adaptation could achieve the best overall performance in cost and time compared with the other strategies in the cloud-fog environment. In addition, Yao et al. [42] presented a practical case where several candidate cloudlet servers have different resource capacities and costs to be deployed on a given set of APs where users randomly roam among them with some known statistics. The candidate heterogeneity was considered, and the problem was formulated into an ILP form.

II. META-HEURISTIC METHODS

A meta-heuristic method, as a higher-level heuristic method, is problem-independent and can be applied to a wide range of problems. Today's "Meta-heuristics" indicates all modern higher-level methods [33]. We have two major parts in modern meta-heuristics: diversification and intensification [34]. It is important to balance diversification and intensification to gain an influential and effective meta-heuristic method. A metaheuristic method investigates the whole solution space; different solutions should be produced. The search has to be heightened near the neighbourhood of the optimal or near-optimal solution. Some of the metaheuristic methods in the literature reviewed include Firefly Algorithm [43] and Particle Swarm Optimization [44].

Kanza, et al. [43] proposed a system there considered a Geographical area consisting of six regions. Where each region has a cluster of buildings, the single cluster was associated with a single fog, which handled requests from users of clusters. Each fog had several VM and DC for processing tasks. Furthermore, there use a Service Broker Policy known as Optimize Response Time (ORT) for routing traffic to the cloud. ORT maintains the list of all fogs available in any geographical region. Also, based on the fog network, Khan, et al. [44] suggested a three-layered architecture comprising cloud, fog and consumer layers is proposed. A meta-heuristic algorithm: Improved Particle Swarm Optimization with Levy Walk (IPSOLW), is proposed to balance the load of fog. Consumers send a request to the fog servers, which then provide services. Further, the cloud is deployed to save all consumers' records and provide services to the consumers if the fog layer fails.

1.2.1.2 Probabilistic/statistic methods

In this section, centralized allocation mechanisms based on probabilistic/statistic methods, including machine learning [45], fuzzy logic [46, 47], and game theory [48], are discussed.

Abedi et al. [45] discuss an artificial intelligence (AI) based task distribution algorithm (AITDA), which aims to reduce the response time and the internet traffic by the distribution of the tasks between fog and cloud servers. Their case study was a delay-sensitive application that ran in a situation where the computing capability of fog servers was restricted, and the internet connection was unstable (like vessels on the oceans). Further, Talaat, et al. [46] introduced a new Effective Load Balancing Strategy (ELBS) for the FC environment, which was suitable for healthcare applications. ELBS tried to achieve effective load balancing in a fog environment via real-time scheduling and caching algorithms. It introduced several rules to accomplish reliable interconnections among fog servers. Moreover, the proposed ELBS guaranteed a suitable

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interconnection among fog servers and cloud and dew layer servers.

Singh, et al. [47] devised a fuzzy load balancer using different levels of design and tuning of fuzzy controls. This fuzzy logic-based algorithm has been implemented for conducting link analysis as interconnects for managing traffic. The analysis showed that the 3-level design is energy efficient for load balancing in the fog zone due to the reduced number of intervals in fuzzy design, reduced overhead in provisioning and improved responsiveness. Moreover, a computation offloading strategy and resource allocation optimization scheme in multiple wireless access point networks with MEC was proposed by Li, Zhao and Gong [48], which aimed to minimize the system cost by providing the optimal computation offloading strategy, transmission power allocation, bandwidth assignment, and computation resource scheduling.

1.2.2 Exact Methods

Exact methods can optimally solve optimization problems. Each optimization problem might be solved by applying the exact search, but the more significant the instances, the more time it takes to get the optimal solution. The exhaustive search is considerably slower than the exact methods [35]. Some of the exact methods in the literature reviewed include graph theory [49], gradient-based [50], decomposition [51], [52], [31], and combinatorial [54], [55]. In this section, the studied articles that are based on exact methods are summarized below:

The module mapping algorithm was used by Taneja, et al. [49] to efficiently utilize resources in the network infrastructure by efficiently deploying application modules in fog-cloud infrastructure for IoT-based applications. With fog computing in the picture, computation is dynamically distributed across the fog and cloud layer, and the modules of an application can thus be deployed closer to the source on devices in the fog layer. In addition, Zhou et al. [50] suggested a centralized allocation technique to provide a solution to minimize the network delay from a contract-matching integration perspective. First, they proposed an efficient incentive mechanism based on contract theoretical modelling. The contract is tailored for each vehicle type's unique characteristics to maximize the base station's expected utility.

Also, REHMAN, et al. [51] proposed Dynamic Energy Efficient Resource Allocation (DEER) strategy for balancing the load in fog computing environments. In the presented strategy, initially, the user submits tasks for execution to the tasks manager. Resource Information provider registers resources from cloud data centres. The task and resource information is then submitted to the resource scheduler. The resource scheduler arranges the available resources in descending order per their utilization. In [52], a resource allocation scheme for community-based fog computing is based on a reputation mechanism. When fog network provides computing services for users, they use a reputation mechanism to enable users to obtain reliable resources in fog computing. In their proposed scheme, a user first submits his/her task request to the community-based fog network. Then, the fog server makes a reliable resource allocation process based on multiple-layer communities and reputation calculation. Moreover, leveraging the SDN (Software Defined Network) centralized control and fireworks algorithm (FWA) was presented by Shi, et al. [31] to solve the load balancing problem in the SDC-FN. The simulation results demonstrate that the SDN-based FWA could remarkably decrease the latency and improve the SDC-FN architecture QoS.

Cai, et al. [54] proposed an optimal solution algorithm based on branch-and-price for addressing this complicated mixed integer nonlinear programming problem. A suboptimal greedy algorithm with significantly reduced computational complexity is also developed to facilitate practical implementation in large-scale systems. According to [55], develop a truthful online resource allocation mechanism called exible online greedy. The key idea is that the mechanism only commits a certain amount of computational resources to a task when it arrives.

1.2.3 Fundamental Methods

In the existing literature, some research on centralized allocation strategy in fog computing is based on simple methods without complex computations classified in the fundamental methods. They include such methods as Throttled, Round Robin (RR), Active Monitoring [56], First Fit [58] and TRAM [57]. In this part, the selected fundamental methods are reviewed.

El-karadawy, et al. [56] suggested an empirical analysis of both (Load Balancing and Service Broker) techniques using a cloud analyst simulator. The analysis target is to study the behaviour of three different load-balancing algorithms (Round Robin, Throttled and Active Monitoring). Those algorithms contain several service broker techniques in virtualized cloud data centres. The results of both average response time and average DC process time, as both (Round Robin) and (Active monitoring), are almost equal. At the same time, the (Throttled Policy) showed a lower output value than theirs. Also, Ahmad, et al. [58] proposed an integrated cloud and fog-based platform to manage energy effectively in intelligent buildings. The first fit (FF) method for load balancing chooses VMs based on partitioning memory blocks. In the cloud/fog-based model, smart buildings having many apartments consist of IoT devices that were regarded. In addition, Wadhwa et al. [57] designed a novel resource allocation and management approach. TRAM, a resource allocation and management technique, is proposed to ensure resource utilization at the fog layer. This approach tracks the intensity level of existing tasks using the expectation maximization (EM) algorithm and calculates the current status of resources. All the available resources manage by using a wireless system. It provides a scheduling algorithm for resource grading in the fog computing environment.

1.2.4 hybrid Methods

Hybrid methods apply various methods, such as approximate, exact, and fundamental, for accomplishing centralized allocation in fog networks [59], [60]. Studies with hybrid methods are reviewed in this section.

In [59], to efficiently handle load balancing, a particle swarm optimization-based Enhanced Dynamic Resource Allocation Method (EDRAM) has been proposed, which in turn reduces task waiting time, latency and network bandwidth consumption and improves the Quality of Experience (QoE). The Enhanced Dynamic Resource Allocation Method (EDRAM), in turn, helps allocate the required resource by removing the long-time inactive, unreferenced and sleepy services from the random-access memory. Furthermore, they shall highlight resource allocation and edge computing in Internet-of-Things (IoT) networks through machine learning approaches. To be specific, every single end device is categorized as an agent, helping in deciding whether the computation task should be offloaded to edge devices. In order to reduce long-term weighted sum costs, such as task execution latency and spiralling levels of power consumption, we consider the channel conditions between the gateway and the end devices [60].

1.3 Summary and Discussion Centralized Allocation:

The centralized allocation is an essential matter in resource allocation of fog computing that little work has focused on. Most studies have considered IoT applications as the proposed contextual analysis. A few papers have assessed their proposed strategies utilizing linear programming, graph theory, differential algorithm, and approximate method. Different papers have evaluated their proposed strategies with heuristic algorithms. Large portions have evaluated response time metrics, cost, complexity and latency.

Likewise, energy consumption is one of the fundamental difficulties yet to be studied to assess and improve the centralized allocation approach. Cloud analyst and iFogSim toolkits were utilized more for the simulation environment to assess the centralized allocation methods.

The classification of the articles mentioned above and essential factors in analyzing the approximate, exact, fundamental and hybrid centralized resource allocation mechanisms in fog computing are depicted in Table V.

2. Decentralized Allocation Category

In this subsection, his research will first represent the Decentralized Allocation problem in a fog environment. Then, it provides an overview of the different classifieds of the Decentralized Allocation subject.

2.1 Decentralized Allocation Issue:

This issue depends on Decentralized load balancing and Decentralized application placement in the allocation of resources, wherein Decentralized load balancing, the overall nodes in the system are classified into clusters with the goal that every one of them uses central nodes to perform load balancing of the system.

Decentralized solutions [36-38] are more encouraging for fog resource management since there is no single mark of control. Placement approaches during the decentralized application [30, 39, 40] comprise a few local optimizations, making them immensely scalable. Since it is decentralized, additional overseeing centres can be effectively added, and scalability does not rely upon a single management centre. The communication overhead between the executive's centres in decentralized approaches makes these approaches wasteful compared with centralized ones. Nonetheless, network overhead due to moving information on all IoT applications to a centralized managing centre and, generally, the execution season of centralized application placement explains how the execution of decentralized approaches outperforms centralized ones.

We can classify this approach based on the available algorithms or models used to solve the problem of literature. Four main classifieds were recognized: approximate, exact, fundamental, and hybrid methods. This section reviews 23 selected articles based on the criteria mentioned before, and their main features, differences, evaluation parameters, tools, pros and limits, and Models Architectures are defined.

2.2 Decentralized Allocation classified

2.2.1 Approximate Methods

In this part, studies on approximate methods in decentralized allocation, including stochastic, probabilistic, and statistic techniques, are performed. Section A investigates stochastic methods, including heuristic and metaheuristics related to the research field. Then, in Section B, probabilistic /statistic methods are review

2.2.1.1 Stochastic methods

I. HEURISTIC METHODS

Heuristic methods are planned to be adaptable and are utilized for smart choices, particularly when finding an ideal arrangement that is either impractical or impossible and when working with complex data. The heuristic approach is a numerical technique to verify a decent answer for an issue. Countless various issues could utilize excellent arrangements. At the point when the handling speed is as significant as the got arrangement. Some heuristic methods in the literature review include the differential evolution algorithm [61] and the decentralized optimization algorithm [53]. In this section, selected heuristic-based methods are discussed.

Manasrah, et al. [61] proposed an optimized service broker routing policy based on different parameters that aimed to achieve minimum processing time, response time and cost by employing a searching algorithm to search for the optimal solution from a possible solution space.

[53] presented a decentralized algorithm for the Fog Service Placement Problem to optimize the distance between the clients and the most requested services. Their policy reduces the distance between the clients and the most requested services, and the latency of those services and the overall network usage are improved.

II. META-HEURISTIC METHODS

Meta-heuristics are particularly suited for combinatorial optimization problems, given that, although they are not usually guaranteed to find the optimal global solution, they can often find a sufficiently good solution in a decent amount of time. So, they are an alternative to exhaustive searches, which would take exponential time. Meta-heuristics can also be easily applied to many problems, given that they are not

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problem-specific. Meta-heuristics often incorporate some form of randomness to escape from local minima. Some of the metaheuristic methods in the literature reviewed include improved genetic algorithm (IGA) [62] and bat algorithm Optimization [63].

LI, et al. [62] introduced an improved genetic algorithm (IGA) to support many device connections and transfer big data with low latency and limited resources. They consider the deployment of non-orthogonal multiple access (NOMA) in IoT networks, which enables multiple IoT devices to of multiple IoT devices, subject to the respective QoS requirements. Furthermore, they simultaneously transmit data to the same FN at the same time, frequency, and code domain. They jointly optimize the allocation of resource blocks, and transmit power optimization problem is formulated as a mixed-integer nonlinear programming problem to minimize the system energy consumption since it is an NP-hard problem. Also, based on the load balancing strategy, Yang, et al. [63] used the bat algorithm to solve the optimization problem in medical big data scenarios. The bat algorithm was better than the genetic algorithm and particle swarm optimization on the unconstrained optimization problems. However, it also needs help with problems such as local optimization and slow convergence. They utilize load balancing to initialize bat population data to solve this problem, improving the solution quality for initial samples.

2.2.1.2 Probabilistic/statistic methods

In this section, decentralized allocation mechanisms based on probabilistic/statistic methods, including machine learning [64] [65] [66], fuzzy logic [67], and matching theory [68], are discussed.

In [64], Prabhu et al. proposed a distribution of minimum resources between multiple autonomous agents by settling conflicts using events of random nature. They focus on two specific events, the tossing of a coin and the game of rock, paper, and scissors (RPS). And then seamless communication interface to enable secure interaction is set up using blockchains with smart contracts.

Similarly, Mseddi, et al. [65] proposed an intelligent online resource allocation approach adapted for dynamic fog computing environments, aiming at maximizing the number of satisfied user requests within a predefined delay threshold. They model the fog-computing environment as a Markov discrete process, where dynamic fog node behaviour/mobility and resource availability are considered. Then, they present their intelligent deep-reinforcement learning resource allocation algorithm. Furthermore, they developed a prototype of Fog-based unsupervised machine learning big data analysis for discovering patterns in physiological data. They employed Intel Edison and Raspberry Pi as Fog computers in the proposed architecture. They performed validation studies on real-world pathological speech data from in-home monitoring of patients with Parkinson's disease (PD) [66].

In addition, Singh, et al. [67] introduced a load balancer based on fuzzy logic using different levels of tuning and designing fuzzy controls in fog networks. The proposed fuzzy logic model was used to conduct link analysis as interconnects for managing traffic.

Also, Battula et al. [68] proposed a micro-level compensation cost model and a new resource-allocation method based on the cost model, which benefits providers and users. Experimental results showed that the proposed algorithm ensured better resource allocation performance and lowered application processing costs compared to the existing best-fit algorithm.

2.2.2 Exact Methods

Some of the exact methods in the literature reviewed include graph theory [69], gradient-based [70] [71], decomposition [72], [73], and combinatorial [74], [75]. In this section, the studied articles that are based on exact methods are summarized below:

Dechouniotis, et al. [69] proposed the DRUID-NET framework to address these challenges by dynamically distributing resources when the demand rapidly varies. It includes analytic dynamical modelling of the resources, offered workload, and networking environment. It incorporates phenomena typically met in wireless communications, mobile edge computing, and new estimators of time-varying profiles.

Moreover, Abouaomar et al. formulated the resource allocation as a Lyapunov problem [70] to a resource representation scheme which allows exposing the resources of each device through Mobile Edge Computing Application Programming Interfaces (MEC APIs) DGS/MEC-0009 in order to optimize resource allocation by the supervising entity in the fog. Therefore, [71] analyzed the energy efficient (EE) resource allocation problem in fog computing networks with the candidate FNs mechanism to ensure the network loading balance under the transmission performance constraints. In the scenario, the associated computation capability allocated to IoT devices from FNs is related to the historical and current energy consumption. The FN, which reports nonzero computation capability, is considered the candidate FN and included in the candidate set.

Chen and Kuehn [72] considered the downlink of the cache-enabled fog-radio access network (F-RAN) and investigated minimizing power consumption to communicate green. Based on channel states, an efficient load-balancing algorithm was suggested. With the proposed algorithm, an increasing cache memory for a greater content-hitting rate was considered an economical method for achieving greener networks. Further, Naik, et al. [73] solved the scheduling problem at the server level rather than on the device level. Moreover, at last, they presented an optimization problem formulation for balancing the load and reducing missed deadlines. Also, the time required for running the task in these cars will be minimized with the help of fog computing. It also performs better than standard algorithms such as active monitoring, weighted round robin and throttled load balancer.

Xu, et al. [74] proposed a dynamic resource allocation method, named DRAM, for load balancing in a fog environment. Technically, a system framework for fog computing and the load-balance analysis for various computing nodes are presented first. Then, a corresponding resource allocation method in the fog environment is designed through static resource allocation and dynamic service migration to achieve the load balance for the fog computing systems. In addition, [75] proposed the use of a combinatorial auction. That allows bidders to define bids containing combinations of discrete sets of resources. These bids aim to reserve and allocate those resources for a fixed period of time; resources are auctioned again for other adjacent time slots. Further, Dao, et al. [21] presented an adaptive resource balancing (ARB) model to maximize serviceability in FRANs in which the resource block (RB) utilization within remote radio heads (RRHs) by applying the Hungarian method and backpressure technique are balanced, considering a time-varying network topology issued by potential RRH mobility.

2.2.3 Fundamental Methods

In the existing literature, some research on decentralized allocation strategy in fog computing is based on simple methods without complex computations classified in the fundamental methods. They include such methods as encryption algorithm [76], face recognition methodology [77] and load balancing algorithm [80]. In this part, the selected fundamental methods are reviewed.

Fawcett et al. [76] take an approach appropriate to the heterogeneous nature of a fog environment: these bids are to reserve and allocate those resources for a fixed period of time; resources are auctioned again for other adjacent time slots. This system enables multiple providers to use the same resources at different times during the same day.

Perala, et al. [77] proposed a methodology that balances the cameras' content generation rate in an IoT environment. Specifically, the targeted use case is face recognition for video surveillance under local storage, network utilization and computational constraints while achieving the highest possible accuracy. Also, a decentralized scheduling architecture was presented by Chekired, et al. [80] for energy management of electric vehicles (EVs) based on the fog system paradigm, where, by applying a priority-queuing model, an optimal load balancing algorithm (LBA) was performed.

2.2.4 Hybrid Methods

Hybrid methods apply approximate, exact, and fundamental methods to accomplish decentralized allocation in fog networks [79], [80]. Studies with hybrid methods are reviewed in this section.

Minh, et al. [79] proposed an approach to optimize service placement on the Fog landscape in the Internet of Things (IoT) context. A multi-tier fog computing architecture that supports IoT service provision is devised. Based on this architecture, a novel service placement mechanism that optimizes service decentralization on the Fog landscape leveraging context-aware information such as location, time, and quality of services (QoS) has been proposed. Furthermore, Ali, et al. [80] proposed a four-layered SG-based architecture to improve communication between consumers and Electricity Companies, and this model covers a massive area of residents. Three load-balancing mechanisms were applied to allocate VM, and the service broker policies applied for simulations are dynamically reconfigurable and are the closest to data centres.

2.3 Summary and Discussion Decentralized Allocation

This research recognized that most of the Decentralized resource category's useful exact method [69–75] to add and remove fog resources to satisfy the application requirements according to workload fluctuations. From the execution metric point of view, we comprehend that most studies are not viewed simultaneously as all QoS parameters in resource allocation issues. For instance, some approaches focus on cost, latency and complexity, while others focus on performance, better resource provision, and energy consumption.

From the assessment apparatuses point of view, we discovered that a large portion of the decentralized resource approaches utilized various tools like Cloud Analyst, MATLAB, Open fog, iFogSim and CloudSim toolkits to validate the viability of their answer while we need tools for considering proficient parameters to simulate a fog-computing environment.

The classification of the articles mentioned above and essential factors in analyzing the approximate, exact, fundamental and hybrid decentralized resource allocation mechanisms in fog computing is depicted in Table VI.

3. Integrated Allocation Category

In this subsection, this research will first represent the integrated allocation problem in fog computing. Then, it provides an outline overview of the different classified of the integrated allocation subject.

3.1 Integrated Allocation Issue

This problem depends on hybrid load balancing and hierarchical application placement in the allocation of resources. In contrast, hybrid load balancing gives a trade-off between the benefits of both decentralized and centralized solutions.

We can classify this approach given the available algorithms or models used to solve the problem of literature. Four main classifieds were recognized: approximate, exact, fundamental, and hybrid methods. This section reviews 27 selected articles based on the criteria mentioned before, and their main features, differences, evaluation parameters, tools, pros and limits, and model architectures are defined.

3.2 Integrated Allocation classified:

3.2.1 Approximate Methods

In this part, studies on approximate methods in integrated allocation, including stochastic, probabilistic, and statistic techniques, are performed. Section A investigates stochastic methods, including heuristic and metaheuristics related to the research field. Then, in section B, probabilistic /statistic methods are review

3.2.1.1 Stochastic methods

I. HEURISTIC METHODS

Heuristic methods are planned to solve in a reasonable time frame that is good enough for solving the problem at hand. There may be better solutions to this problem, or it may approximate the exact solution. However, it is still valuable because finding it does not require long. Heuristics may produce results by themselves or be used with optimization algorithms to improve their efficiency (e.g., they may be used to generate good seed values). Some of the heuristic methods in the literature reviewed include the proposed heuristic algorithms [81] and [82]. In this section, selected heuristic-based methods are discussed.

Lee et al. [81] proposed a VFC resource allocation algorithm that considers the short-term and long-term resource allocations obtained from the proposed heuristic and RL algorithms. The extensive performance evaluation showed that their VFC resource allocation algorithm outperforms several widely used conventional resource allocation schemes regarding service satisfaction. Many heuristic algorithms [82] have been proposed for near-optimal solutions. Therefore, Aazam, et al. Introduce CSC's historical record-based resource estimation. They provide a mathematical model incorporating customers' give-up probabilities while estimating resources. The algorithm maps the outcome of the historical record ratio module to the type of device that is requesting the resources. Eventually, resources are estimated under these factors. As a result, dynamic resource estimation is performed, which helps in minimizing resource underutilization.

II. META-HEURISTIC METHODS

Metaheuristic is a higher-level procedure or heuristic designed to find, generate, or select a heuristic (partial search algorithm) that may provide a sufficiently good solution to an optimization problem, especially with incomplete or imperfect information or limited computation capacity. A Metaheuristic sample is a set of solutions which is too large to be thoroughly sampled. Metaheuristics may make a few assumptions about the optimization problem being solved so that they may be used for various problems. Compared to optimization algorithms and iterative methods, metaheuristics do not guarantee that a globally optimal solution can be found on some class of problems. [2] Many metaheuristics implement some form of stochastic optimization so that the solution found depends on the set of random variables generated. Some metaheuristic methods in the literature review include the multi-objective crow search algorithm [83] and hybrid genetic simulated annealing [84].

Subbaraj, et al. [83] utilize a multi-objective population-based metaheuristic optimizer called the crow search algorithm for resource allocation and scheduling in the fog computing environment. The two objectives considered by the proposed work are the success ratio and the security hit ratio. Both of these objectives need to be maximized. A local search method is utilized to enhance the crow search algorithm's performance. The work applies the metaheuristic technique for solving resource allocation and scheduling in the fog environment.

Also, based on offloading and resource allocation decisions, Wang, et al. [84] presented a hybrid genetic simulated annealing-based latency-minimum offloading decision algorithm to optimize the offloading decision. The numerical results demonstrate that their proposed scheme gains significant performance advantages in the completion time, energy consumption, convergence speed, and accuracy. After getting the best genetics, simulated annealing is performed on them, which speeds up the convergence of their algorithm.

3.2.1.2 Probabilistic/statistic methods

In this section, Integrated allocation mechanisms based on probabilistic/statistic methods, including machine learning [85] [86] [15], Fuzzy logic [88], Logistic regression [87], and Game theory [89] [90], are discussed.

Wang et al. [85] introduce a wireless communication and computation model of partial computation offloading and resource allocation considering the time-varying channel state, the bandwidth constraint, the stochastic arrival of workloads, and privacy preservation. To simultaneously optimize the computation and execution delays, the power consumption, and the bandwidth resources, they model the optimization problem as a Markov decision process (MDP) to minimize the weighted sum cost of the system. Owing to the complex problems of lack of prior knowledge and the curse of dimensionality.

Furthermore, they introduced a novel SDN-based framework for computation offloading in MEC wireless networks. Then, they proposed reinforcement learning-based approaches to solve the delay minimization Problem, which considers both reward and punishment as a sign of being experienced, which is very important for a dynamic-based MEC system [86]. In addition, Khalid, et al.[15] employed a deadline-aware scheme to migrate the data between cloud and Fog networks based on data profiling and then used K-Means clustering and service-request prediction model to allocate resources to all requests efficiently.

From another perspective, Wang, et al. [88] proposed a fuzzy logical offloading strategy for IoT applications characterized by uncertain parameters to optimize both agreement index and robustness. A multi-objective Estimation of Distribution Algorithm (EDA) is designed to learn and optimize the fuzzy offloading strategy from various applications. The algorithm partitions applications into independent clusters so each cluster can be allocated to the corresponding tier for further processing.

However, in [87], the authors proposed a dynamic resource allocation strategy for the cloud, fog node, and users. In the framework, they first formulate the ranks of fog nodes using TOPSIS to identify the most suitable fog node for the incoming request. Simultaneously logistic regression calculates the load of individual fog nodes and updates the result to send back to the broker for the next decision.

Moreover, Zhang, et al. formulated resource allocation as a matching theory problem [89]. They proposed a joint optimization framework in the multi-FN, multi-DSO and multi-DSS scenarios for IoT fog computing. In the framework, they first modelled the Stackelberg games to

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solve the pricing problem of the DSOs and the resource-purchasing problem of the DSSs. Then a many-to-many matching was proposed between the DSOs and the FNs to deal with the DSO-FN pairing problem. Therefore, [90] proposed an optimal resource allocation scheme for a fog-based IoT environment to maximize resource utilization; they model the resource allocation problem as a double-stage Stackelberg game and propose three algorithms to achieve Nash equilibrium and Stackelberg equilibrium.

3.2.2 Exact Methods

Some of the exact methods in the literature reviewed include graph theory [91], gradient-based [92] [100], decomposition [93], and combinatorial [94]. In this section, the studied articles that are based on exact methods are summarized below:

Ni, et al. [91] proposed a resource allocation strategy for fog computing based on Priced Timed Petri nets (PTPN), by which the user can choose the satisfying resources autonomously from a group of pre-allocated resources. Their strategy comprehensively considers the price cost and time cost to complete a task, as well as the credibility evaluation of both users and fog resources.

Rodrigo and Nelson [92] introduce a novel mechanism named Gaussian Process Regression for Fog-Cloud Allocation (GPRFCA) for resource allocation in infrastructure composed of cooperative fogs and clouds. The GPRFCA mechanism employs a Gaussian Process Regression to predict future demands to avoid blocking requests, especially delay-sensitive ones. Moreover, Chang et al. formulated resource allocation as a Lyapunov problem [100]. They proposed a joint computation offloading and radio resource allocation algorithm based on Lyapunov optimization. By minimizing the derived upper bound of the Lyapunov drift-plus-penalty function, they divide the main problem into several sub-problems at each time slot and address them accordingly. Through performance evaluation, the effectiveness of the proposed scheme can be verified.

Therefore, [93] fog computing architecture is proposed for the proper resource provisioning of smart city container-based applications. Fog computing provides practical ways to overcome the highly demanding requirements introduced by IoT use cases, such as low latency, high energy efficiency and high mobility. The popular open-source project Kubernetes has been used to validate the proposed solution.

Gasior, D. [94] presented two approaches to the hybrid fog and cloud computing environment. The first is based on the assumption of centralized management performed by the cloud, while the latter utilizes the self-managing concept enabling distributed resource allocation carried by fogs. The appropriate mathematical models are introduced, and the optimization problems are formulated. While the first concept turned out to be mixed nonlinear programming,

3.2.3 Fundamental Methods

In the existing literature, some research on Integrated allocation strategy in fog computing is based on simple methods without complex computations classified in the fundamental methods. They include the ReRaP algorithm [95] and the PRA algorithm [96]. In this part, the selected fundamental methods are reviewed.

Naha, et al. [95] propose resource allocation and provisioning algorithms by using resource ranking and provision of resources in a hybrid and hierarchical fashion. The proposed algorithms are better than existing algorithms in terms of overall data processing time, instance cost and network delay, with the increasing number of application submissions. Compared with existing solutions, the average processing time and cost are decreased by 12% and 15%, respectively.

Mani et al. [96] proposed a methodology that tries efficient resource allocation architecture. The algorithm is suggested and implemented in the CloudSim tool to evaluate the working of the proposed algorithm in the fog environment.

The results show that the proposed method can optimally allocate resources compared to the default resource allocation strategy.

3.2.4 Hybrid Methods

Hybrid methods apply such various methods as approximate, exact, and fundamental to accomplish Integrated allocation in fog networks [97], [98], [99]. Studies with hybrid methods are reviewed in this section.

Verma, et al. [97] tried to draw attention to ensure the QoS quality of services for end-users by allocating the resources limited with efficiency to the heterogeneous applications associated with IoT. They tried to propose a RECK algorithm for a self-organizing distributed association of users and resource allocation that is better applicable and has the scalability to the dense environment of fog computing, unlike various schemes of resource allocation schemes for the applications associated with IOT considering RECK algorithm in context with this algorithm analytics, resource demands, type of applications associated with QoS parameters. Furthermore, Tang, et al. [98] proposed a joint caching and computing resource allocation mechanism to schedule the resources of the mobile edge networks effectively. They formulate a Stackelberg game to analyze the allocation problem between the MEC server and multiple base stations (BSs). The MEC server aims to impose the prices on the BSs to maximize its revenue, while the BSs compete to determine the caching/computing space they can occupy at the MEC server to improve the quality of experience of their service users. From another perspective, Nassar, et al. [99] formulated the resource allocation problem for FRAN in a heterogeneous IoT environment as an infinite horizon Markov Decision Process (MDP) problem. Then, they provided the optimum solution (decision policy) for the MDP problem through a Reinforcement Learning (RL) algorithm.

3.3 Summary and Discussion Integrated Allocation:

Based on one next to other comparisons of the existent studies on the Integrated resource allocation approaches, this research has seen that some studies have introduced a dynamic Integrated resource in the resource allocation of fog computing. These systematic were proposed the dynamic integrated strategy on the IoT applications dependent on three layers theoretical that have assessed with an approximate algorithm to minimize response time and low latency and increase dynamic efficiency resource allocation. Other exploration studies have proposed an exact method for managing existing resources on the fog nodes to reduce energy, better QoS and minimize latency.

Furthermore, the fundamental method minimizes the response time and increases the throughput. On the other hand, hybrid algorithms work on low response time, high flexibility and high resource utilization. Most of these algorithms have assessed the proposed strategy utilizing MATLAB, CloudSim and iFogSim tools.

The classification of the articles mentioned above and essential factors in analyzing the approximate, exact, fundamental and hybrid Integrated resource allocation mechanisms in fog computing are depicted in Table VII.

V. DISCUSSION AND COMPARISON

This part shows an analytical assessment and discussion of current resource allocation studies in a fog environment. The analytical assessment and reports depend on the existent TQs in section 3:

& TQ1: Which kind of classification in research approaches are presented in fog systems resource allocation?

Figure 5 shows a statistical comparison of the resource allocation approaches in the fog environment, restating the illustrated taxonomy's signification (Fig. 2). This research studied three resource allocation approaches: centralized allocation, decentralized allocation, and integrated allocation. The highest percentage of the resource allocation approaches has the integrated allocation by 38% usage in the literature. Of course, the centralized allocation has 29%, and the decentralized has 33% usage in fog computing. Of course, the centralized allocation approach has an open challenge to assess the dynamic allocation of intelligent services and IoT devices in fog computing.

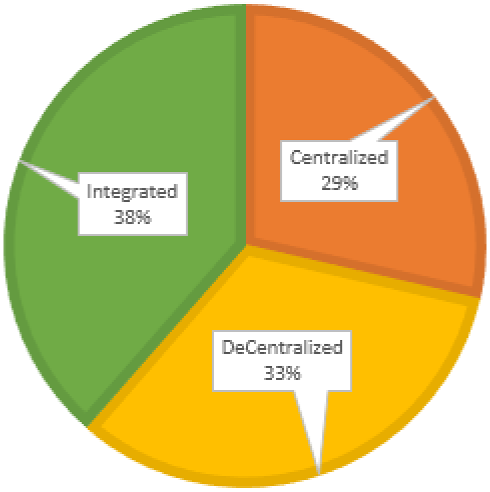

Fig. 5 Classified approach percentage in resource allocation

& TQ2: What case studies are presented in the resource allocation approaches?

The presented case studies of resource allocation are shown in Fig. 6. This research observed that IOT applications have more utilization with 19 studies, and general applications have 15 studies. In the integrated allocation approaches, existent case studies that were introduced in experimental results are as the following: radio access networks, mobile applications, traffic systems and integrated IoT ecosystems. As a case study, the mobile application has been utilized for integrated allocations in fog computing. Some main topics such as redistribution offloading, data offloading and location offloading, have been applied in the existing research studies that focus on decreasing the delay and response time and increasing accuracy to help the portability of the IoT end-utilizer.

In the Decentralized allocation approaches, some latency-sensitive case studies are utilized to assess experiments such as intelligent grid manufacturing, smart cities, healthcare applications, smart homes, fire alarm systems, emergency robots and vehicular traffic systems. Also, the Decentralized allocation approaches have suggested a heuristic-based algorithm for solving the service placemen issue of intelligent IoT applications over the fog resources as an NP-hard problem. The SLA and QoS factors should be considered to assess the service placement in the fog resources. The information stream is a critical matter that prompts support for information consistency and integrity. Additionally, load balancing can impact latency minimization and energy consumption. A couple of exploration studies have talked about the energy utilization issue. Real-time components and IoT applications are more feasible than the case studies in fog computing.

Supporting the arrangement of the current fog resources as intelligent services or IoT applications can be challenging for assessing the decentralized allocation approach in fog computing. In all studies, the scalability and energy factors have not been assessed for considering the decentralized allocation approach in fog computing.

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Table V: CENTRALIZED RESOURCE ALLOCATION METHODS IN FOG COMPUTING AND THEIR PROPERTIES

In the Model Architecture column, P=>Prototype, S=>Simulation, E=>Evaluation and N=>Not-mentioned.

Category	Method		Article	Main idea	publication year	Model Architecture	Tool	Advantage	Limitation
APPROXIMATE	Stochastic	Heuristic	[41]	presents an adaptation of the Path-Clustering Heuristic to the cloud-fog environment for multiple workflows quality of service. d	2019	E	Java / JDK1.8	• Minimize makespan • Better performance • better tradeoff	• Better performance while keeping similar costs compared to others.
			[42]	Deploy the servers in a cost-effective manner without violating the predetermined quality of service.	2017	S	Barabasi-Albert Model	• low-complexity • cost-effective • polynomial-time	• Low scalability • Low security
		Meta-heuristic	[43]	A Cloud Fog Based Framework for Efficient Resource Allocation Using Firefly Algorithm	2019	S	Cloud Analyst	• high performance • low cost	• low security • maximum computational time
			[44]	Energy Management in Smart Sectors Using Fog Based Environment and Meta-Heuristic Algorithms	2019	S	Cloud Analyst	• Low response time • Low processing time • Low cost	• Low scalability • Low security
	Probabilistic/Statistic	Machine learning	[45]	Resource Allocation in Combined Fog-Cloud Scenarios by Using Artificial Intelligence	2020	S	MATLAB	• Low response time • Low internet traffic	• high energy • Low performance • High overhead
		Fuzzy logic	[46]	Effective Load Balancing Strategy (ELBS) for Real-Time Fog Computing Environment Using Fuzzy and Probabilistic Neural Networks	2019	S	iFogSim	• fast response • high priority • low network latency	• Worst (QoE) • Worst (QoS)
			[47]	a fuzzy load balancer is devised using different levels of design and tuning of fuzzy controls	2020	S	jperf and fuzzy lite api	• reduced number of intervals • reduced overhead • improved response	• Low reliability • Low security
		Game theory	[48]	a computation offloading strategy and resource allocation optimization scheme in a multiple wireless access points network	2019	S	Not-mentioned	• minimize cost • high bandwidth	• High complexity • Extra overhead at execution time
EXACT	Graph _theory	Module Mapping Algorithm	[49]	Module Mapping Algorithm for efficient utilization of resources in the network infrastructure	2017	S	iFogSim	• Low Response Time • Low Energy • Low cost	• Low scalability • Worst (QoS) • Low security
	Gradient_ based	matching theory	[50]	Computation Resource Allocation and Task Assignment Optimization in Vehicular Fog Computing	2019	S	Not-mentioned	• Low cost • High flexibility • Low latency	• High complexity • Extra overhead at execution time • low security
	Decomposition	Linear programming	[51]	Dynamic Energy Efficient Resource Allocation Strategy for Load Balancing in Fog Environment	2020	S	CloudSim	• less computational • less cost • less energy	• fault-tolerant • High execution time
			[52]	Resource Allocation Scheme for Community Based Fog Computing Based on Reputation Mechanism	2020	S	CloudSim	• low latency • high security	• High delay • low reliability
		Weighted sum	[31]	leveraging the SDN centralized control and fireworks algorithm (FWA) to solve the load balancing problem in the SDC-FN	2018	S	SDC-FN	• reducing latency • fast response time • improve the QoS	• Low scalability • Low availability • Low security
	Combinatorial	Greedy algorithm	[54]	joint resource management for device-to-device (D2D) communication assisted	2021	S	Not-mentioned	• reduced complexity • Low cost	• High complexity • High power
			[55]	A Truthful Online Mechanism for Resource Allocation in Fog Computing	2019	S	FlexOG	• Low response time • Low energy	• High execution time • Low reliability
FUNDAMENTAL	Throttled, RR, Active Monitoring		[56]	An Empirical Analysis on Load Balancing and Service Broker Techniques using Cloud Analyst Simulator	2020	S	Cloud Analysis	• Low response time • Low cost	• high energy • high execution time
	TRAM		[57]	TRAM: Technique for resource allocation and management in fog computing environment	2021	S	iFogSim	• min execution time • min network consumption • min energy • min average loop delay of tasks	• High complexity • low security
	Throttled, RR, First Fit		[58]	Resource allocation in fog/cloud system considering load balancing	2018	S	CloudSim	• Low response time • Low energy	• High cost
HYBRID	DRAM + PSO		[59]	Load balancing in the fog nodes using particle swarm optimization-based enhanced dynamic resource allocation method	2021	S	Linpack software tool + Arduino UNO R3	• reduce waiting time • reduce latency • reduce bandwidth consumption • improve QoE	• low security • low scalability • high complexity
	nonlinear program + Perron - Frobenius theory		[60]	Proposed resource allocation scheme for low delay data transmission in fog based vehicular networks.	2021	S	Not-mentioned	• improve spectral efficiency • decrease transmission delay • increase reliability	• fault-tolerant • High cost

*Table V*I: DECENTRALIZED RESOURCE ALLOCATION METHODS IN FOG COMPUTING AND THEIR PROPERTIES

Category	Method		Article	Main idea	publication year	Model Architecture	Tool	Advantage	Limitation
APPROXIMATE	Stochastic	Heuristic	[61]	optimized service broker routing policy based on differential evolution algorithm in fog/cloud environment	2019	S	Cloud Analyst	• Low processing time • Low response time • Low cost	• Low reliability • Low security
			[53]	presented a decentralized algorithm for the Fog Service Placement Problem to optimize the distance between the clients and the most requested services	2019	S	iFogSim	• reduces distance between the clients • low latency • improve performance	• high cost • low security
		Meta-heuristic	[62]	Optimizing Resources Allocation for Fog Computing-Based Internet of Things Networks	2019	S	NOMA	• low-complexity • better performance • low energy • low latency	• Low reliability • Priorities cannot be set
			[63]	A fog/cloud system and big medical data based on bat algorithm considering load balancing	2020	S	MATLAB	• Low latency	• High complexity • The possibility of bottleneck • Low scalability • Low reliability
	Probabilistic/Statistic	Machine learning	[64]	Decentralized Decision Making for Limited Resource Allocation Using a Private Blockchain Network in an IoT with Conflicting Agents	2020	M	python	•determine faults in the system • develop solutions to required problems • making a decision	• limited to the ability to setup cmmunication between agents using blockchains. • integrating sensors and identify agents before they even begin interacting
			[65]	a smart online resource allocation approach adapted for dynamic fog computing environments	2019	S	Not-mentioned	• success ratio • maximizing user requests within a predefined delay threshold.	• Low reliability • Low security • high processing time
			[66]	Evaluated use of low-resource Machine learning on Fog devices kept close to the wearable's for smart healthcare.	2017	P	Intel Edison and Raspberry Pi	• Low cost • Low response time • Low processing time	• Low security • Low privacy • Low reliability
		Fuzzy logic	[67]	A load balancer based on fuzzy logic in fog computing	2020	N	Not-mentioned	• Low energy consumption • Low latency	• Low reliability • Low security
		matching theory	[68]	a micro-level compensation cost model and new resource allocation method based on the cost model, which benefits both providers and users	2019	S	CloudSim	• low latency • better resource allocation • lower costs	• Fewer resources for the submitted request. • High execution time
		Game theory	[25]	Provided a game theoretical analysis of a fog computing system. They proposed an efficient decentralized Algorithm based on an equilibrium task allocation in static mixed strategies.	2019	S	Not-mentioned	• best response time • improve performance	• Low reliability • high energy
EXACT	Graph theory	Graph theory	[69]	develop novel resource allocation mechanisms that explicitly include service differentiation and context-awareness	2020	S	Not-mentioned	• Low response time • High mobility • Improve QoS • Low latency	• Low security • Low scalability
	Gradient_ based	Lyapunov-function	[70]	resource representation scheme which allows exposing the resources of each device through Mobile Edge Computing Application	2019	M	ETSI	• minimize latency • improve the performance • minimizing delay	• High complexity • High execution time
			[71]	analyze the energy efficient (EE) resource allocation problem in fog computing networks with the candidate FNs mechanism	2020	S	Not-mentioned	• Customizable design • Low energy • Low complexity • Low latency	• High complexity • The possibility of a bottleneck • Low scalability
	Decom-position	Weighted sum	[72]	considered the downlink of the Cache-Enabled F-RAN, where minimization of power consumption is investigated for the Green Communication	2016	S	Not mentioned	• Low energy • Low cost	• low energy consumption • Increasing the cache memory
	Combinatorial	Linear programming	[73]	Load balancing for minimizing total runtime and deadline in fog-based vehicle systems	2017	S	Not mentioned	• Low energy • Low response time • Low latency	• Low reliability • Priorities cannot be set
			[74]	dynamic resource allocation method, named DRAM, for load balancing in fog environment	2018	S	CloudSim	• low computational cost • Dynamically balanced load	• High complexity • High execution time
			[75]	Combinatorial Auction-Based Resource Allocation in the Fog	2016	platform	MANOs	• Low response time • Low energy	• High execution time • Low reliability
		Hungarian Method	[21]	Resource balancing scheme in FRAN	2017	S	Not mentioned	• High reliability • Low response time • High throughput	• Low performance • In different network conditions, the amount of service migration is not considered
FUNDAMENTAL	encryption algorithm		[76]	Secure Computing Resource Allocation Framework For Open Fog Computing	2020	S	Open fog	• high security • high privacy • high reliability	• high cost • high response time • high processing
	face recognition methodology		[77]	methodology that tries to balance the content generation rate of cameras in an IoT environment	2018	S	iFogSim	• high accuracy • low energy • High flexibility • Low cost	• Proposed approach isn't capable of decreasing the network traffic • Low security
	LBA algorithm		[78]	Load balancing method in distributed fog architecture	2018	S	NS-2 MATLAB	• High scalability • Low energy • Low response time • Low latency	• Not stable at evening peak hours • Standard case without scheduling is not stable at peak hours
HYBRID	SPM		[79]	novel service placement mechanism that optimizes service decentralization on Fog landscape	2017	S	iFogSim	• reduce energy • reduce latency • better resource provision	• Low security • Low privacy • Low reliability
	RR, Honey Bee Optimization		[80]	State-based load balancing method for SG energy management in fog	2018	S	Cloud Analyst	• High performance • Low cost • Low response time • Low latency	• There are some changes of values in different fogs, but overall the average cost remains the same

*Table V*II: INTEGRATED RESOURCE ALLOCATION METHODS IN FOG COMPUTING AND THEIR PROPERTIES

Category	Method		Article	Main idea	publication year	Model Architecture	Tool	Advantage	Limitation
APPROXIMATE	Stochastic	Heuristic	[81]	a heuristic algorithm to efficiently find the solutions of the problem allocating the limited fog resources to vehicular applications	2020	S	Python 3.7	• Low response time • Highly dynamic • minimized latency • higher service satisfaction	• Low performance • High complexity
			[82]	IoT resource estimation challenges and modeling in fog computing	2017	S	CloudSim	• Low cost	• Not assessing time • Not breaking down cost
			[107]	addresses the resource management issue by proposing Energy model to optimizing the utilization of connected devices in fog computing	2020	S	Not mentioned	• min energy • min cost • min time consumption	• high latency • low security • low availability
		Meta-heuristic	[83]	A smart fog computing based real-time secure resource allocation and scheduling strategy using multi-objective crow search algorithm	2021	S	IFogSim	• reduced latency • improved security • reduced costs	• low scalability • high complexity
			[84]	Latency-minimum offloading decision and resource allocation for fog-enabled Internet of Things networks	2020	S	Not mentioned	• low completion time • low energy consumption • low latency • high accuracy	• low security • low convergence speed
			[105]	A novel 5G IoV architecture based on fog computing and SDN. With this architecture, a crucial issue is how to efficiently use heterogeneous computing resources to guarantee the QoS.	2019	N	Not mentioned	• low delay • high task execution • low energy consumption	• Lack of an the switching efficiency
	Probabilistic/Statistic	Machine learning	[85]	Deep reinforcement learning-based computation offloading and resource allocation in security-aware mobile edge computing	2021	S	Jetbrains Pycharm with Tensorflow	• min the weighted sum cost • min power consumption • min bandwidth resources	• higher offloading failure ratios • the lower threshold of the risk probability
			[86]	investigated the task offloading and resource allocation problem in wireless MEC aimed to minimize the delay while saving the battery power of user device simultaneously	2020	P	Prototype	• Reducing total cost • High scalability	• Lack of an appropriate simulation • Energy consumption and delay have not evaluated
			[15]	efficiently distributing workload between the Fog Layer and the Cloud Network to ensure better utilization and quick response time of the resources available to the end user	2020	S	iFogSim	• Low response time • Minimizing the number of VM	• Low scalability • High cost
			[101]	focuses on developing a dynamic and autonomous computing resource allocation scheme for F-RAN considering delay requirements of users at a node	2020	S	Not-mentioned	• reduce cost • low energy consumption • minimizing the maximum delay	• low reliability • high complexity
			[103]	optimize the use EVs energy for both computation and moving vehicles	2019	S	Matlab	• Low delay • Low latency	• High Energy consumption • High cost
		logistic regression	[87]	Resource allocation through logistic regression and multicriteria decision making method in IoT fog computing	2019	S	MATLAB and Hadoop	• Improve QoS • Improve response time • efficient resources allocation	• Low scalability • Low security
		Fuzzy logic	[88]	Proposed a fuzzy logical offloading strategy for IoT applications characterized by uncertain parameters to optimize both agreement index and robustness.	2021	S	Not-mentioned	• low latency • reducing energy	• high complexity • high respones time
		Game theory	[89]	proposed a joint optimization framework for all FNs, DSOs and DSSs to achieve the optimal resource allocation schemes in a distributed fashion	2017	S	MATLAB	• Low delay • High utility	• Not evaluating time • Not analyzing cost
			[90]	proposed an optimal resource allocation scheme for a fog-based IoT environment	2020	M	Not-mentioned	• low computational complexity	• Energy consumption has not evaluated
			[102]	Propose a polynomial complexity decentralized algorithm and characterize the structure of equilibria computed by the algorithm.	2020	M	Not-mentioned	• low latency • high computational • low response times	• Low security • high cost
EXACT	**Graph theory**	**Priced Timed Petri nets**	[91]	Resource Allocation Strategy in Fog Computing Based on Priced Timed Petri Nets, which the user can choose the satisfying resources autonomously from a group of pre-allocated resources	2017	S	Not-mentioned	• Automatic formal approach • decreased makespan • decreased cost	• Omitting fairness and rightness assessments • Not examining time
	Gradient based	**GPRFCA**	[92]	introduced a novel mechanism named Gaussian Process Regression for Fog-Cloud Allocation (GPRFCA) for resource allocation in infrastructure composed of cooperative fogs and clouds	2018	S	iFogSim	• reducing energy • decreased latency • reducing complexity	• Low availability • low security
		Lyapunov-function	[100]	Proposed a dynamic optimization scheme for the IoT fog computing system, where can be dynamically coordinated and allocated with the variation of radio resources and computation demands.	2020	N	Not-mentioned	• low execution time • minimize latency • low energy	• low security • low scalability • high complexity
	Decomposition	**NAS_ Algorithm**	[93]	Fog architecture based on Kubernetes, an open source container orchestration platform, is proposed to solve Resource Provisioning in Fog Computing	2019	S	Kubernetes platform	• Reducing total cost • High scalability	• Lack of a proper Simulation • Energy utilization and delay have not assessed
	Combinatorial	**nonlinear programming**	[94]	Two Approaches to Resource Allocation in Hybrid Fog and Cloud Systems	2019	N	Not-mentioned	• Low energy consumption • Low latency	• Low reliability • Low security
FUNDAMENTAL	**(ReRaP) algorithms**		[95]	Deadline-Based Dynamic Resource Allocation and Provisioning Algorithms in Fog-Cloud Environment	2020	S	CloudSim	• decreased cost • decreased processing time	• Low scalability • High latency
	PRA algorithm		[96]	The allocation of task and placement of virtual machine problems is explained in the single fog Computing environment.	2020	S	cloud Analyst	• minimizing the response time • increasing the throughput	• low security • low scalability
HYBRID	**RECK algorithm**		[97]	design a better framework for IOT resource allocation scheme with better efficiency and better QoS in fog computing	2020	S	Not mentioned	• better efficiency • better QoS • low latency	• High complexity • low security • increasing time
	Stackelberg game + BI Method		[98]	a joint caching and computing resource allocation mechanism is proposed to effectively schedule the resources of the mobile edge networks	2019	S	MATLAB	• effective storage • effective computational • improve the QoE	• maximize energy consumption • low system performance
	MDP+(RL) algorithm		[99]	They formulated the problem as a Markov Decision Process (MDP), for which they presented the optimal decision policy through Reinforcement Learning (RL). The proposed resource allocation method learns from the IoT environment	2019	S	Not mentioned	• High scalability • Low response time • High flexibility • High resource utilization	• Low performance • High overhead
	deep-reinforcement learning + game theory + RNN		[106]	This paper studies the design of a joint task offloading and resource allocation control for heterogeneous service tasks in multi-fog nodes systems	2020	S	Python-Tensorflow	• higher average success rate • lower average overflow	• low Scalability • low Interoperability

& TQ4: which assessment factors are ordinarily utilized to assess resource allocation approaches and advance them?

The QoS details are compared and systematized as the assessment factors for resource allocation approaches in Fig.10. The systematic report of the QoS determinations shows that the latency has most utilized in the resource allocation approaches by 19%, the energy, cost and response time has 16%, the delay has 11%, performance has 5%, and the complexity has 4%. As a significant QoS factor, latency has the highest assessment in all resource allocation approaches. Of course, scalability as a significant problem in the QoS factors is introduced as an open challenge in the load balancing and the application placement factors. Supporting response time minimization and low latency are two significant advantages of the integrated allocation approaches in fog computing. In addition, self-adaptive integrated allocation is one of the basic issues of the resource allocation of fog computing.

In the centralized allocation approaches, vehicular cloud applications, intelligent surveillance applications, word count stream processing and surveillance application are applied to assess the suggested allocation approach. Some utilized case studies that are used in centralized allocation approaches are real-time applications and IoT applications. In centralized resource allocation, face recognition methods and cloud applications are utilized.

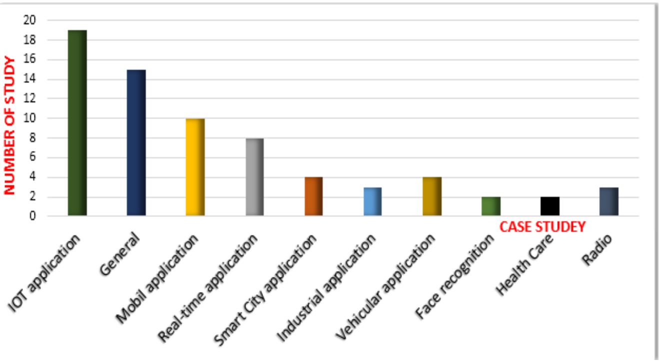

Fig. 6 The applied case studies percentage in resource allocation of fog computing

TQ3: which evaluation tools are applied for evaluating the resource allocation approaches?

According to Figs.9, 29% of the research papers have not mentioned or specified a measurement environment and tool for evaluating their methods. In addition, 16% of the research articles applied the Cloud Analyst tool to evaluate and analyze the existing case studies. Also, 14% of the studies have applied an assessment of their case study utilizing the iFogSim tool. In comparison, 13% of the research articles applied the CloudSim tool to implement the existing case studies. In addition, 6%, 3%, and 3% of the research papers used the Matlab environment, Java/JDK and Python tools to evaluate the existing case studies. Of course, some research studies have determined tools and a measurement environment for assessing their methods and explained this in Figs.7 because these tools are less used.

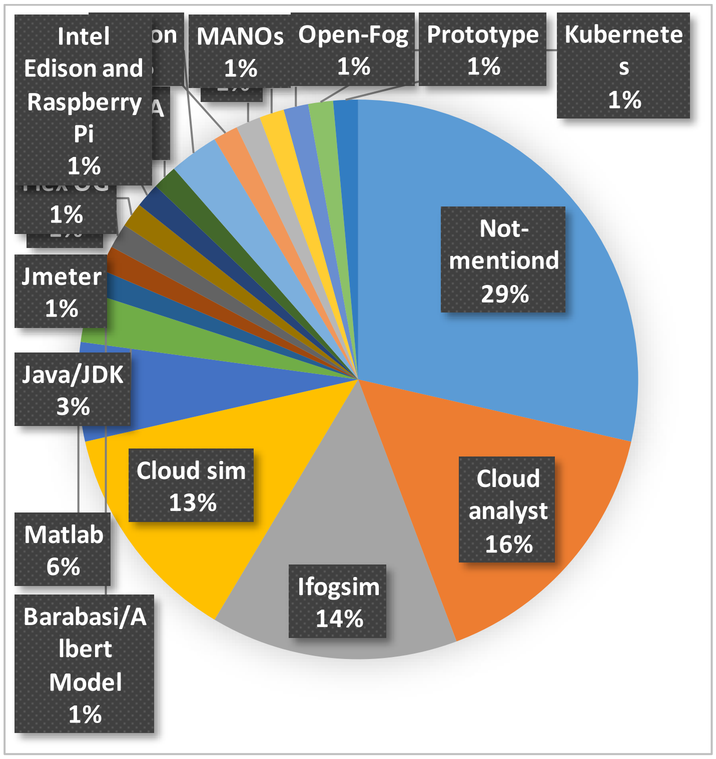

Fig.7 The presented evaluation tools percentage in the literature

& TQ4: which assessment factors are ordinarily utilized to assess resource allocation approaches and advance them?

The QoS details are compared and systematized as the assessment factors for resource allocation approaches in Fig.8. The systematic report of the QoS determinations shows that the latency has most utilized in the resource allocation approaches by 19%, the energy, cost and response time has 16%, the delay has 11%, performance has 5%, and the complexity has 4%. As a significant QoS factor, latency has the highest assessment in all resource allocation approaches. Of course, scalability as a significant problem in the QoS factors is introduced as an open challenge in the load balancing and the application placement factors. Supporting response time minimization and low latency are two significant advantages of the integrated allocation approaches in fog computing. In addition, self-adaptive integrated allocation is one of the basic issues of the resource allocation of fog computing.

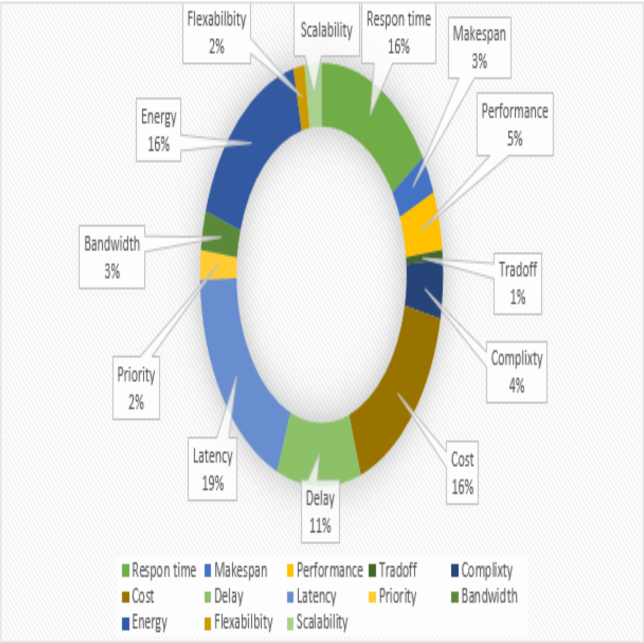

Fig. 8 QoS metrics Percentage for assessing resource allocation approaches

& TQ5: what techniques are used to resource allocation approaches?

The applied used methods for resource allocation approaches are considered in Fig.9. The statistical percentage of the applied used strategies presents that the Machine Learning algorithms have the best use in the resource allocation assessment with nine studies. Since resource allocation approaches are determined as an NP problem, the meta-heuristic methods can impact the productivity of the resource allocation approaches in fog computing.

The centralized allocation concept has been discussed for fog computing's decreasing response and utilization time factors.

Conversely, when the number of requests is increased in fog nodes, the scalability factor should be supported for managing existing resources.

In decentralized allocation approaches, linear programming algorithms are the most applied algorithm to evaluate. There are formal strategies to assess the functional and accuracy determinations such as reachability, deadlock and safety. These formal strategies are excellent mathematical proof techniques that assess highly scalable state exploration of resource allocation approaches in fog computing. Just the Petri-net is applied to assess functional properties in the existent studies.

VI. OPEN ISSUES

This part illustrates some open issues regarding algorithmic and engineering challenges in resource allocation of fog computing. Likewise, existing evaluating measures dependent on QoS management address a research direction challenge. As indicated by TQ6, we present new open issues and approaching difficulties. We examine new open issues in the resource allocation field as follows:

& TQ6: Which are the open perspectives for resource allocation approaches and future research directions in fog computing?

Interoperability: one of the primary variables of interconnections between fog nodes is interoperability to move resources and information between the fog nodes and IoT objects. The resource interoperability upholds a management controller to discuss the intelligent applications with each solicitation. Some new difficulties to this open issue remember the dynamic for the-fly cooperations, ideal information trade, and data sharing.

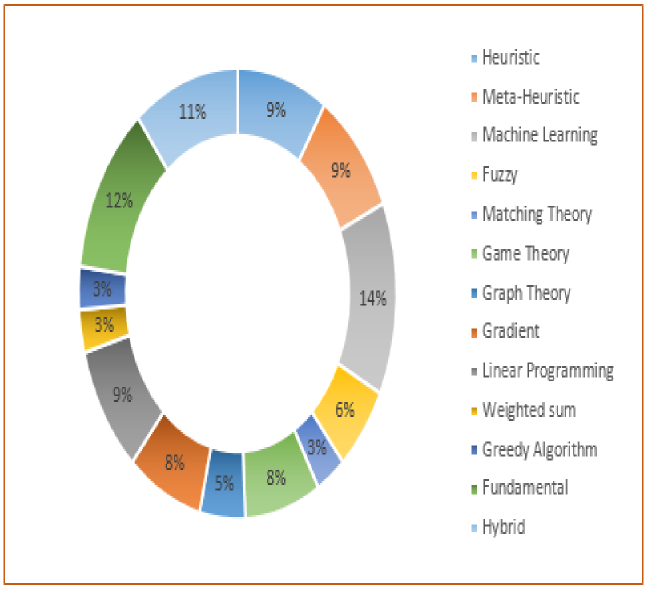

Fig. 9 Utilized techniques percentage for resource allocation approaches

Scalability: To further develop scalability measures in a fog environment, it is necessary to cover resources, the assets from a couple of remembered spaces for the fog layer and the utilized gadgets in the IoT/end customers layer. The scalability issue is a significant test in application placement way to deal with cover mobile entities, for example, medical services and transportation applications. Utilizing a vehicular specially appointed organization (VANET) design can impact covering application portability in fog computing.

Security: Fog nodes will manage a ton of individual information, and protecting such information is of prime significance. Privacy-protective algorithms can be run on fog nodes, and a portion of the protection techniques can be applied for resource allocation in fog computing. Trust is a

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likely danger in fog computing due to its straightforwardness to dispatch and hard to address, and its solution is as yet an open test. Verification at different levels of the fog is additionally quite tricky, for which an ideal arrangement is yet to be recognized. Confirmation cost can likewise be reduced by detecting phoney or unfit fog nodes. Supporting the security of resources would recognize the lightweight well-being guidelines with fast preparation and dependable methodologies in fog computing. Some new difficulties to this open issue include analyzing external attacks, trust getting to, and dynamic validation.

VII. CONCLUSION

In this paper, a comprehensive SLR was provided on the resource allocation approaches in the fog computing environment. This review categorized the resource allocation approaches into three basic categories: centralized allocation, decentralized allocation and integrated allocation. Some important advantages and weaknesses of each research study were analyzed. According to the literature review analysis, the integrated allocation has the highest percentage of resource allocation approaches, with 38% usage in the literature.

The centralized allocation of the fog computing should be hidden from the application developer, and it should be easy for the developers to run the applications on the fog programmers are responsible for partitioning the functions of applications between the fog and the cloud. Also, we observed that IOT applications have the most usage with 19 studies, and general applications have 15 studies. According to the implementation platform, we concluded that 29% of the existing papers have not mentioned or specified a measurement environment and tool for evaluating their methods. In addition, 16% of the research papers applied the Cloud analyst tool to evaluate the proposed algorithms. Also, 14% of the studies have presented an evaluation of their case study using the iFogsim tools. Also, the analytical reports of the QoS factors show that the latency has the most evaluation in analyzing the resource allocation approaches by 19%, the response time has 16%, energy has 16%, the cost has 16%, and the delay has 11%. Latency as an important QoS factor has the highest evaluation in all of the QoS factors in resource allocation approaches.

Finally, the statistical percentage of the applied utilized techniques presents that the Machine Learning algorithms have been applied to assess the resource allocation approaches with nine studies. Since resource allocation approaches are specified as an NP problem, the meta-heuristic algorithms affect the efficiency of these approaches in fog computing. In future work, we will consider the SLR method on the open challenges of the resource allocation approaches in fog computing that include privacy-aware resource allocation methods, interoperability and security architectures in resource allocation and formal analysis of resource allocation in fog computing.

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