Resource Allocation in Fog Computing based on Meta-Heuristic Approaches: A Systematic Review

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Abstract
Resource allocation in fog computing is a rigorous and challenging task and the allocation of appropriate resources to tasks generated by IoT users depends upon the QoS requirements of applications used by IoT users. Due to heterogeneity, mobility, uncertainty and limited availability of resources, the challenge of efficient resource allocation in fog computing cannot be addressed with traditional resource allocation strategies. Researchers are still facing problem in selecting an efficient resource allocation algorithm for wide variety of applications. This research study represents a systematic literature analysis of resource allocation in the fog computing. The current status of resource allocation in fog computing is distributed in several categories such as auction-based techniques, heuristics techniques and metaheuristic techniques etc. Methodological analysis of resource allocation techniques based on meta-heuristic approaches has been presented in this research paper. This research work will assist the researchers to find the important parameters of resource allocation algorithms and will also help in selecting appropriate resource allocation algorithm for tasks generated by IoT users.

Keywords:
Fog Computing, Meta-heuristic, Bio-inspired, Resource Allocation, QoS

1. Introduction

Fog computing is an emerging distributed computing model which provide storage, communication and computational services at the proximity of end user. Fog computing is an extension vision of cloud computing introduced by CISCO that deals with ever increasing demands of internet users by processing data in proximity of IoT devices instead of sending data to cloud [1]. Request for extremely diverse services, expectation of real time response and high-speed data exchange by internet users is hardly manageable by centralized cloud and most of the network edge devices do not use their full computation and storage capacities every time. To resolve these problems fog computing has been evolved as a solution to provide localized services to mobile users by acting as an intermediate layer between cloud and IoT devices [2]. Several Telecom network operators have started providing storage, computation and communication facilities at the edge of network, to build fog computing environment, so that bandwidth hungry and real time applications can be processed with minimal cost and reduced latency[3].

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Resource allocation is the way to select efficient resources available in fog network including cloud resources and available resources of nearby fog nodes for IoT users' requests. It helps to improve the responsiveness and satisfy the QoS requirements of requests [4]. Resources can be allocated statically or dynamically in fog environment. IoT services have a high operational cost due to static resource allocation. Allocating more resources than required number of resources to meet the QoS will lead to under-utilization and also increases the cost incurred. On the other side, employing fewer resources than necessary will result in over-utilization of resources but will undermine QoS standards. As a result, efficient and effective resource allocation is essential to evade the problem of under and over-provisioning [4].

The challenges for resource allocation in cloud and fog computing are totally different. Heterogeneous and unpredictable fog nodes should be allocated efficiently for execution of various service requests having dissimilar QoS requirement. Fog computing consists of numerous entities including IoT users, fog nodes and cloud servers. Therefore, efficient resource allocation in fog computing is an equally challenging task as cloud computing and cannot be addressed with existing resource allocation techniques because of resource limitation, resource heterogeneity, dynamic and uncertain nature of fog environment [5]. The main objective of resource allocation in fog computing is to allocate best available resources to tasks generated by edge devices so that QoS requirements can be fulfilled. Research in the area of resource allocation in fog computing is still in progress and selection of efficient and appropriate resource allocation algorithm is still troublesome. Hence, methodical literature survey for resource allocation in fog computing is the need of an hour.

Traditional methods of resource allocation are not able to resolve the problem for fog environment in optimal way in many cases. Hence, resource allocation is expounded by using various approaches based on heuristic and metaheuristic methods to achieve optimal solutions. There is problem of heuristic methods that they usually get stuck in local minima problem but meta-heuristic approaches are more efficient and avoid the local minima problem [6]. Metaheuristic approaches deliver better solution than heuristic approaches in term of QoS and computing time, also these can be applied to any real-life optimization problems to enhance the efficiency and performance. It has been observed that no systematic study is exist to cover the aspects of resource allocation in fog computing using metaheuristic approaches. Primary objective of this paper is to present a summary of available metaheuristic approaches for resource allocation in fog computing and to introduce the future research challenges.

This paper is arranged in following order: Section II presents the work related to resource allocation. Section III describes the methodology followed in conducting this review. Section IV lists the main research questions raised and their answers, followed by conclusion in Section V.

2. Related work

Fog computing environment consisted of several networking components such as gateways, routers, switches, base stations, proxy servers etc. as fog nodes, to provide computing and storage capabilities to tasks generated by edge devices [7] [8] . It supported mobility of fog nodes, scalability, location awareness, real time interactions, heterogeneity and interoperability to deal with the latency sensitive tasks [9]. Due to heterogeneous and dynamic behavior of fog nodes resource allocation in fog computing became an NP-hard problem and to increase the efficiency of fog computing this challenging issue was addressed appropriately. Several review and surveys exist in resource management in fog computing, but very few studies had discussed the aspects of resource allocation based on metaheuristic approach, in fog computing.

A systematic survey on fog computing encompassing detailed description of fog computing, architecture, future challenges and research directions had been presented by the authors in [10]. Prospect of fog computing paradigm in the emerging technologies had also been discussed in this research work. A systematic review of resource allocation presented by Lahmar et al., considered research papers till 2019 and had not discussed various resource allocation techniques and approaches. It has been observed that no other work has presented any systematic mapping for resource allocation. Resource scheduling is the way to decide the execution sequence of tasks but resource allocation is performed before resource scheduling and it is a way to assign resources to end user tasks [5]. Similar type of algorithms can be used in both allocation and scheduling. Based upon several researches in this field resource allocation algorithms were broadly categorized as auction based, heuristic, Meta heuristic and AI based.

Auction based mechanism was adopted to control the demand and supply and for determination of fair market value of resources in fog computing. Both resource provider and buyer followed the appropriate auction mechanism to maximize the resource utilization. Buyers specified the price they were ready to pay, and the buyer who bid the highest amount was the winner and was allowed to purchase the resources for utilization. Service providers bid over resources they wished to use to run the services in their infrastructure [11] [12]. Resources were sold to the highest bidder and resources were assigned to winner, by a stated auction based resource allocation mechanism [12] [13][14]. Auction based techniques were mostly profit oriented and other QoS metrices were given least preferences. Allocation of resources according to the usage pattern of resources was also an emerging approach for resource allocation. AI techniques such as reinforcement learning were used to predict the pattern followed by end user for resource allocation [15][16]. Implementation of AI based approaches were very complex on resource constrained fog environment because these techniques exhaust a huge amount of data.

Several heuristic-based approaches had been designed to solve the resource allocation problem without generalization possibility to other analogous problems. Heuristic approaches were based on traditional search techniques such as greedy, brute-force, first, worst or best fit allocation approaches to find a global optimum. A multi-criteria based resource allocation techniques was presented, which considered previous history of tasks to deal with delay sensitive applications [17]. A path clustering heuristic approach for multiple workflows in cloud-fog environment was proposed to maintain the tradeoff between cost and task length [18]. Heuristic approaches based upon list based task scheduling was proposed for fog environment to enhance the processor selection phase so that overall makespan and execution time was minimized [19]. Heuristic techniques had a limitation of being stuck in local minima, so this research study is focused on meta heuristic approaches for resource allocation in fog computing.

Several metaheuristic approaches were designed to resolve the problem of resource allocation in fog computing. The meta-heuristic algorithms or techniques had the capability to deal with diverse constraints and provide optimal and better result [20]. A Comparative performance of several metaheuristic algorithms in terms of QoS and SLA for cloud computing had been presented [20]. It enlightened the future scope of metaheuristic approaches in other distributed environments. Genetic Algorithm (GA) was proposed by number of research studies to resolve the issue of resource allocation in fog computing [21] [22]. Particle swarm optimization(PSO) [23], Ant Colony Optimization (ACO) [24], Firefly algorithms[25] , Gray Wolf Optimization [26] and several other bio inspired algorithms had been used in fog computing for the purpose of resource allocation. Several research papers used hybridization of more than one meta heuristic approaches

[27] [28] [29] [30] to achieve more optimized solutions and to get better QoS to meet the objectives of research problem. Usage of meta heuristic approaches is emerging in fog computing and very few review papers has been published till date. So, this research work is more focused on metaheuristic approaches in fog computing to deal with resource allocation problem.

3. Review Methodology

In order to provide a systematic and transparent study the methodology given in [31] is depicted in figure 1.

3.1. Source of Information

i. As fog computing is an emerging technology, so the search for specific and relevant publications is inclined towards admissible papers required to fulfil the admissible goal.
ii. The studies published between 2014 to May 2022 has been searched and collected on following electronic databases. Before 2014, no research studies for resource allocation in fog computing were available.

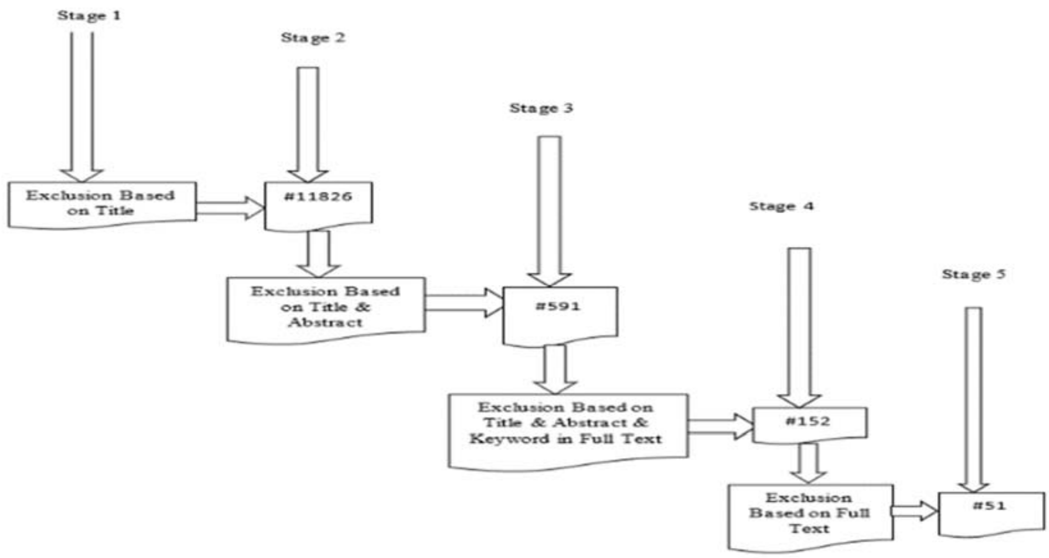

Fig.1 Selection Procedure for the Study [31]

- Taylor & Francis Online (<www.tandfonline.com>)
- Wiley InterScience (<www.onlinelibrary.wiley.com/>)
- ACM Digital Library (<www.acm.org/dl>)
- Springer Link(<www.springerlink.com>)
- IEEE Xplore (<www.ieeexplore.ieee.org>)
- Science Direct (<www.sciencedirect.com>)

3.2 Search String

The various search strings used for different databases for an efficient mapping are described in table 1.

Table1: Search strings used

Data-base	Search String	Article Count	Search String	Article Count	Search String	Article Count
Taylor & Francis Online	Title: “Fog Computing”	33	Title: “Fog Computing” Anywhere: Resource Allocation”	17	Title:” Fog Computing” + Anywhere: “Resource Allocation” + Anywhere: (“Bio inspired” OR “Nature inspired” OR” Meta Heuristic” OR "Heuristic”	5
Wiley	Title: “Fog Computing”	139	Title:” Fog Computing” Anywhere: “Resource Allocation”	21	Title:” Fog Computing” OR “fog” Abstract: “Resource Allocation”	6

					Full Text: “Bio?inspired” OR ”Nature?inspired” OR “intelligent” OR “Heuristic” OR “Meta?heuristic”	
ACM	Title: “Fog Computing”	112	Title: “Fog Computing” Abstract:” Resource Allocation”	29	Title: “Fog Computing” OR “Fog” Abstract: “Resource Allocation” Full Text:”Bio?inspired” OR “Nature?inspired” OR ”Intelligent” OR ”Meta?heuristic” OR “Heuristic”	12
Springer Link	Title: “Fog Computing”	543	Title: “Fog Computing” Word in Full Text: “Resource Allocation”	154	Title:”Fog Computing”, Exact Phrase:” Resource Allocation” Words in full text: "Bio?inspired" OR "Nature?inspired" OR ”Meta?heuristic”	37
IEEE Explore	Title: “Fog Computing”	1542	Title: “Fog Computing” Abstract: “Resource Allocation”	172	Title:”Fog Compuing”, Abstract: “Resource Allocation” Words in Text: “Bio? inspired” OR ” Nature? inspired” OR “Heuristic” OR “Meta?heuristic”	51
Science Direct	Term: “Fog Computing”	9457	Term:” Fog Computing” Title, abstract, keyword: “Resource Allocation”	198	Term: "Fog Computing" OR "Bio?inspired" OR "Resource Allocation" OR ”Meta?heuristic”	41

4. Research Questions

The research questions are required for systematic investigation. The research questions formulated on the basis of several search stages are given in Table 2.

Table 2: Research Questions

RQ	Question
RQ1	How have publications on resource allocation in fog computing been distributed over time?
RQ2	What are the various metaheuristic techniques for resource allocation?
RQ3	How metaheuristic techniques assist efficient and effective resource allocation and its challenges?
RQ4	What are the various aspects which are considered during resource allocation in fog computing?
RQ5	Which case studies are used as basis for resource allocation strategies?
RQ6	What are the different simulation tools being used for resource allocation in fog computing?
RQ7	What are the future research challenges in resource allocation in fog computing?

4.1 Results and Discussions

The research conducted and trend pattern in the area of resource allocation in fog computing is analyzed, and discussed in this section. Seven research questions are addressed in this subsection.

RQ1. How have publications on resource allocation in fog computing been distributed over time?
The RQ1 has been interpreted through figure 2 and 3. The research work related to fog computing began in 2014 but the research in fog computing has gained momentum after 2017. Almost around 97% of work in resource allocation in fog computing has done from 2017 onwards, but still there is vast scope for research in the area of resource allocation in fog computing. This timeline information would help to know about latest research trends.

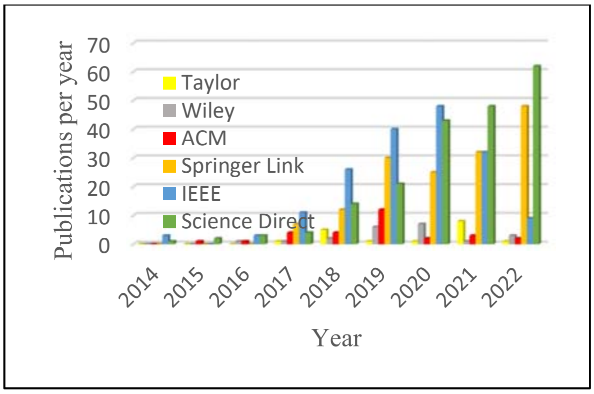

Fig. 2 Time based count of Resource Allocation in Fog Computing

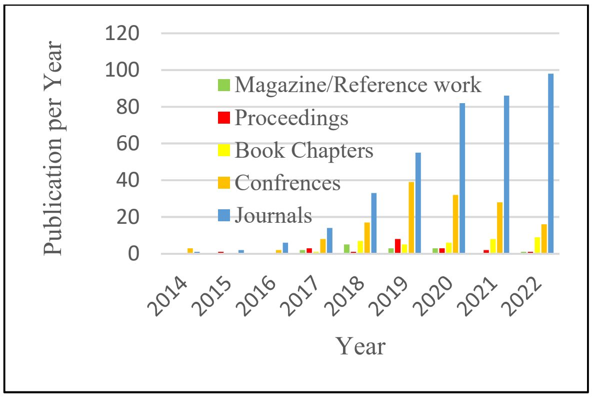

Fig 3: Time based count of Resource Allocation in Fog Computing

RQ2. What are the various metaheuristic techniques for resource allocation?

The objective of resource allocation problem is to allocate optimal and efficient resources to the end users' tasks or requests. As per available literature meta-heuristic techniques are not explored widely for the purpose of resource allocation in Fog Computing. The commonly used metaheuristic techniques for resource allocation are GA, PSO, ACO, hybridization of GA and PSO and GA or PSO combined with any other metaheuristic technique. Several novel metaheuristic techniques have been presented and used by several researchers till now, but it is observed that emerging metaheuristic techniques are still in very early stage and have not been given much attention to address the resource allocation problem in fog computing.

The metaheuristic approaches applied by researchers in resource allocation in fog computing are shown in figure 4. GA is the most commonly used approach in researches. 20% of researches have used GA as their proposed approach to solve the resource allocation problem, followed by which PSO is used by 10% and ACO which is used by 8% studies. Hybridization of GA and PSO is commonly proposed approaches as 8% of studies have used this amalgamation. 2% of studies have used hybrid approach in which GA, PSO, ACO and Simulated Annealing (SA) has been combined. GA and ACO has been combined with Graywolf Optimization (GWO) in 2% of researches. 4% of research papers have used Chemical reaction Optimization (CRO) as optimization technique in their proposed approach. Other emerging meta heuristic techniques which need to be explored extensively and may be used to solve the issue of resource allocation are BAT algorithm, Bees Life Algorithm (BLA), Crow search approach, Firefly algorithm, Wind Driven optimization (WDO), Fireworks optimization, Water Cycle algorithm, Salp Swarm Optimization (SSO) etc. This discussion would give insight to the researchers on different meta-heuristic techniques used in resource allocation in fog computing.

RQ3. How metaheuristic techniques assist efficient and effective resource allocation and its challenges?

With the help of fog layer several applications based on low latency and delay are being executed nearer to the end devices. Availability of limited resources and heterogeneous and dynamic nature of fog nodes are the constraints of fog computing. Therefore, the task of optimal and efficient resource allocation in fog computing is rigorous and challenging. Several algorithms have been proposed to resolve the problem of resource allocation in fog computing so that delay and latency are minimized and resource utilization is maximized along with other QoS constraints. The comparative analysis of various meta-heuristic algorithms and approaches which worked to optimize the objective parameters of research studies has been presented in table 3. This analysis would help researchers to select appropriate algorithm or technique to achieve the objective of efficient and effective resource allocation.

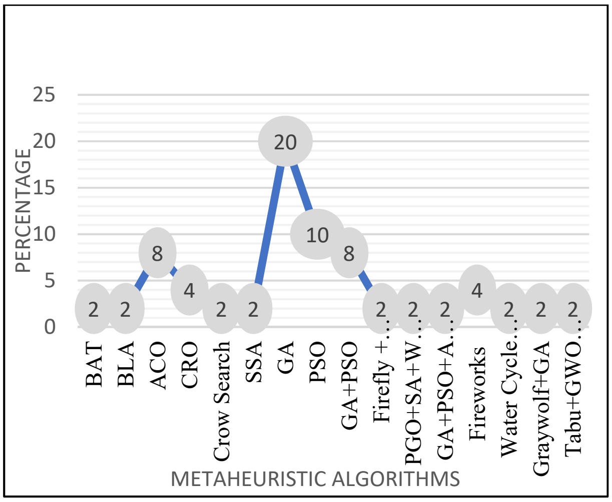

Fig. 4 Metaheuristic approaches for resource allocation

Table3. Comparative Analysis

Citation	Algorithm	Advantages	Disadvantages
[21]	Non-Dominating Sorting Genetic Algorithm– II (NSGA-II)	Energy efficient, Minimised cost and execution time	Does not support mobility, Network optimization is not considered
[23]	Hyper-Heuristic Resource Allocation Algorithm	Prevented local optima, minimized delay and energy consumption	Time metrices was not considered
[24]	ACO with Fuzzy Logic	Improved network utilisation and less network traffic	Very few parameters for QoS have been selected
[26]	Non-Orthogonal Multiple Access (NOMA), GWO and GA	Reduced latency and energy consumption	As number of devices increased, energy required for convergence also increased.

[28]	Tabu Search, GWO and ACO	Enhanced resource utilization	Network utilisation is not optimised
[29]	GAPSO	Gave optimal solution in reduced time	Poor performance for dynamic workload
[30]	PSW-Fog Clustering Algorithm	Minimised time delay, computational cost, and energy consumption	Security is not considered
[32]	Binary BAT Algorithm (BAT)	Acquired more resources with minimum cost	Time metrices is not considered
[33]	Bees Life Algorithm (BLA)	Efficient in term of allocated memory and execution time	Dynamic approach and Optimization of network bandwidth has not been considered
[34]	Particle Swarm Optimization (PSO)	Reliable	Low accuracy
[35]	Genetic Algorithm (GA)	Provide high quality solutions for large search space problems	Does not support mobility
[36]	GA and Genetic Algorithm and Discrete PSO (GA and DPSO)	Minimized processing and transmission burden	Impact of migrations in dynamic scenarios is not considered.
[37]	Firefly and WDO	QoS is achieved	Response time not optimized
[38]	Artificial Ecosystem-based Optimization with Salp Swarm Algorithm (AEOSSA)	Improved quality of solutions, high throughput, minimum execution time	Single objective optimization
[39]	Crow Search Algorithm	Optimal solutions are provided in minimum time	Less Parameters are considered
[40]	Technique for resource allocation and management (TRAM)	High resource utilization	Dynamic approach for resources and security parameter not considered.
[41]	GA	Low application delays, energy consumption, cost and network usage	It is difficult to increase the battery lifetime of sensors
[42]	Opposition-Based Chemical Reaction (OBCR)	Increase in the stability	QoS is not achieved
[43]	(Modified)MGAPSO and (Elitism Based) EGAPSO	Minimized service time, energy consumption and service cost	Energy consumption increased as the number of fog nodes increased
[44]	BH-FWA- (Bi-Objective Hybrid Fireworks Algorithm)	Improved QoS	Works only for fixed bandwidth
[45]	Evolutionary Game with Water Cycle Algorithm (EG-ERWCA)	Improved response time, minimised power consumption and maximised CPU usage	Dynamic behaviour of resources is not considered
[46]	Smart Ant Colony Optimization (SACO)	Improved processing time and latency	Mobility in sensor nodes is not considered
[47]	Self-Adapting Algorithm	Improved throughput and network utilisation	Security measures are not fulfilled
[48]	Directed Artificial Bat Algorithm (DABA) and PSO	Minimised delay and improved packet delivery ratio	Time metrices is not considered
[49]	Non-dominated Sorting Genetic Algorithm II (NSGA-II)	Minimised response time and provide security	Dynamic behaviour of nodes cannot be handled
[50]	Modified Fireworks Algorithm	Better convergence, improved resource utilisation, minimised cost and makespan	Algorithm is resistant to task migration
[51]	Round Robin (RR), PSO, Throttled and Active VM Load Balancing Algorithm	Improved delay and time	In different scenarios performance is not stable
[52]	Fog Computing aided Swarm of Drones (FCSD) Architecture/ Linear Programming based /Proximal Jacobi ADMM and convex optimal algorithm	Energy efficient, minimised cost and execution time	Limited battery capacity of drones
[53]	GA, PSO, ACO and SA (Hyper Heuristic)	Decreased risk in security services	Data confidentiality service incurred high overhead and high cost.
[54]	CRO with Real-Coded CRO	Energy efficient	QoS needs attention

[55]	Sub Task Dynamic Priority List	Perform better when tasks require more computational cost, computational capacity and security	Network utilisation is not optimised.
[56]	Improved Two Arch2 algorithm with Novel Fitness Evaluation	Improved the quality of service and task execution stability	Less constraints for fog computing are considered
[57]	GA and Gini coefficient-based MUEs allocation and Distributed Algorithm	Improved resource utilization	QoS metrices are not improved
[58]	Improved GA	Energy efficient, less delay	Multiple optimization objects posed challenges for improving the overall network performance
[59]	Predictive Offloading and Resource Allocation	Minimized power consumption with guaranteed queue stability	Mobility of devices is not considered
[60]	Genetic Convex Optimization Algorithm using GA	Minimised delay and latency	Not energy efficient
[61]	PSO with NSGA	Improved convergence and computation time	On demand traffic cannot be dealt with
[62]	Quantum PSO	Energy efficient	Time metrices is not considered.

RQ4. What are the various aspects which are considered during resource allocation in fog computing?

Parameters considered for resource allocation in fog environment has been detailed in table 4. The parameters have been divided into 7 categories. First category is network constraints which include delay, latency and network usage bandwidth. Second category is time constraints such as execution time, waiting time, make span and processing time. Third category is resource constraints in terms of storage, processing and RAM. Fourth category is cost whether it is monetary cost or Computational cost, fifth category is energy efficiency and power consumption, security is considered as sixth category, QoS such as Task Success Ratio (TSR), mobility support, throughput, deadline, scalability falls under seventh category.

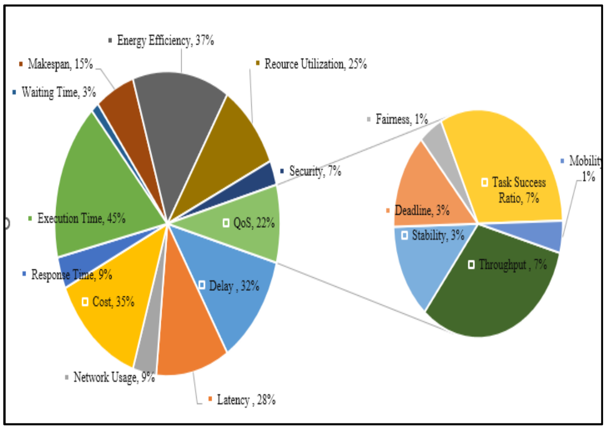

Fig. 5 Percentage share of metrics in evaluating resource allocation techniques

The categories of metrices for evaluating resource allocation approaches is shown in figure 5. The analytical report illustrates that the time and energy have most usage in resource allocation approaches. Execution Time and energy efficiency are the two important metrices used for evaluation in resource allocation approaches. The percentage wise share of each of the metrics is shown in figure 5. It is analyzed that execution time metrics is used 45 % times and energy efficiency metrices is used 37% times in resource allocation approaches. This discussion will help the researchers to determine the objective and to develop new research fronts in the area of the resource allocation challenges in fog computing environment that further contribute to the adoption of fog computing. In addition, studying the relationship among QoS, security, scalability, stability, fairness, mobility can be discussed in future. No study has discussed about scalability. Security, throughput, deadline, stability, mobility, fairness, task success ratio, waiting time are evaluation metrices which are considered by very few studies. There is large scope of research in these parameters in resource allocation problem of fog computing.

RQ5. Which case studies are used as basis for resource allocation strategies?

Various case studies are applied in resource allocation of fog computing such as vehicular system [24][64][74][80][75][76], smart home [77][74], smart city [46][69], smart healthcare system [53][59][78][77][79][80], online gaming and virtual reality [29][62][71], industrial applications [42][51][62], client-server scenario [70][68][81], emergency and public safety systems [21][35][59] and scientific workflow and others [13][28][30][55] are shown in figure 6. Several papers have used general scenario which is not included in figure 6. It has observed that most of researchers used smart healthcare and vehicular system as case studies to evaluate the performance of their work. In resource allocation latency sensitive case studies have been applied which mainly focus on minimizing the delay and response time. This analysis gives insight into the applications where resource allocation plays an important role. This observation will help the researchers in understanding of resource allocation problem through various case studies and enlighten detailed investigation of the problem through real life problems.

Table 4. Performance Metrices

Category	Parameter	Papers
Network	Delay	[24][26][30][35][37][41][48][51] [53][56] [58][60][61][63]][65][66]
	Latency	[26][29][34][42][44][45][46][49] [52][59] [60][62][66]
	Network usage	[24][41][48][49][53]
Time	Response Time	[22][45][49][51][69]
	Execution Time	[13][21][23][26][28][29][30][33] [34][35][38][39][43][46][53][51] [55][56][70][67][68][69]
	Waiting Time	[28][34]
	Makespan	[13][21][28][38][42][44][50][68]
Resource	Resource Utilization	[28][30][32][33][34][45][50] [51][53][56] [57][67]
Cost	Cost	[13][21][23][28][29][30][32][41] [46][49][50][55][56][61][67][68] [69][79]
Energy	Energy Efficiency	[21][22][26][28][30][37][41][45] [49][52][53][54][58][59][61][62] [63][65][67][71]
Security	Security	[39][49] [53][55]
QoS	Throughput	[38][44][50][58]
	Stability	[42][56]
	Deadline	[29][35][71][72]
	Fairness	[70]
	TSR	[34][39][48][73]
	Mobility	[73]

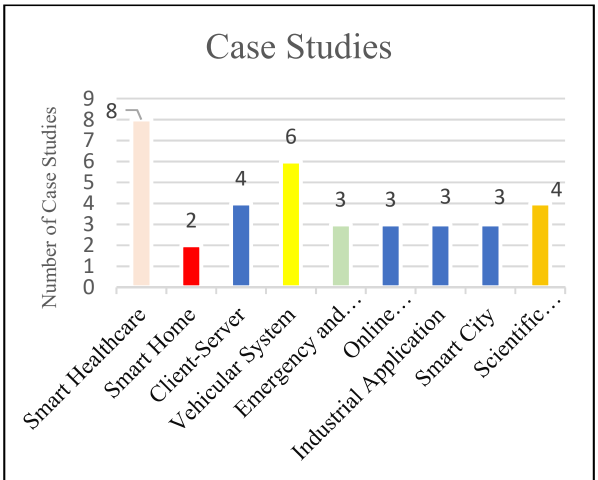

Fig.6 Number of Case Studies used in various researches

RQ6. What are the different simulation tools being used for resource allocation in fog computing?

Simulation tools are being used to evaluate the performance of resource allocation algorithms and techniques. Most of the papers used iFogSim. Some of the studies used Matlab followed by CloudAnalyst. But there are some research papers which have not specified any simulation tool or measurement environment for evaluating the performance of their methods.

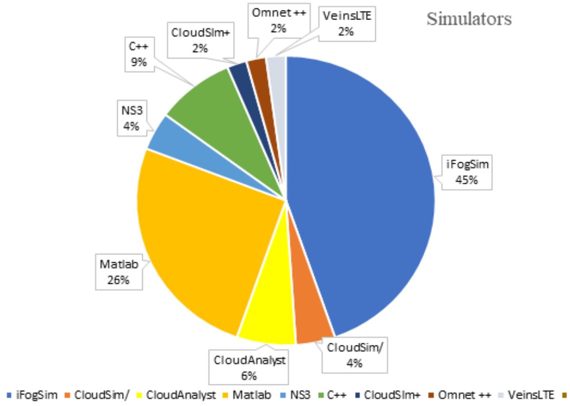

Fig. 7 Percentage of the Simulators presented in Literature

According to the figure 7, 45% studies used iFogSim , 26% studies used Matlab , CloudAnalyst is used by 6% researchers, 4% studies have used NS3, CloudSim and CloudSim++ is used by 4% and 2% studies respectively , Omnet++ and VeinsLTE is also being used 2% each for simulation purpose in fog computing. There are 9% researchers who have written and evaluated their proposed algorithm code in C++. This study will guide the researchers for better decision making in selecting the appropriate simulation tool for their research work.

Table 5. Simulators used for Resource Allocation in Fog Computing

Simulator	Paper
iFogSim	[19] [23] [28] [30] [39] [40] [42] [44] [50] [56] [23]
Matlab	[21] [26] [32] [34] [37] [38] [46] [57]
CloudAnalyst	[51][69]
CloudSim	[82] [65]
C++	[33][72]
NS3	[24] [47]
Omnet+	[49]
CloudSim+	[67]
VeinsLTE	[76]

RQ7. What are the future research challenges in resource allocation in fog computing?

This survey has presented that fog computing has some major issues which are listed below:

i. *Limited Resources:* Fog nodes have limited and heterogeneous computing and storage resources than cloud computing. So, coordination among these heterogenous and capacity constrained resources is one of the challenging tasks for researchers.

ii. *Hierarchical Fog Paradigm:* Fog paradigm is basically a hierarchical network structure where latency sensitive tasks are processed at fog or edge devices, whereas latency insensitive tasks are being forwarded to cloud. However, it is very complex task to partition a task into sub tasks and distribute them over fog as well as cloud for fast and concurrent execution. So, there is need of efficient partitioning methods and accurate prediction algorithms.

iii. *Security:* Fog nodes are vulnerable to various attacks and threats on data, so privacy preserving resource allocation techniques are required in fog computing. Another significant problem is authentication on various levels in fog layer that requires an optimal solution to support the security.

iv. *QoS:* In future research resource allocation based on QoS parameters such as Stability, scalability, mobility, fairness, waiting Time, Task success ratio is one of the main challenges. Based on present research, there is necessity to consider these QoS requirements properly so that most efficient resources will be allocated to execute the workload to prevent the overloading and underloading of fog resources.

v. *Efficient and Optimal Techniques:* Emerging Metaheuristic techniques are still not being used in recent research works. GA, PSO and ACO are the most commonly used metaheuristic approaches for resource allocation problem in fog computing. In future researches, novel and emerging approaches has a large scope of being implemented for optimal and efficient resource allocation techniques.

vi. *Testbeds for fog computing:* There are very small number of infrastructure options for evaluating the performance of real fog environments. Most of the studies are rely on simulation tools such as iFogSim, CloudAnalyst, CloudSim, and Matlab. So, it is highly required to build testbeds that can pursue real time fog computing environment studies at large scale.

5. Conclusion

This paper has conducted a systematic literature review to investigate the use of metaheuristic approaches in resource allocation in fog computing by framing the research questions and inclusion and exclusion based on strings. According to the study it has been observed that use of metaheuristic techniques to resolve the issue of resource allocation in fog computing is taking momentum since past years, but still very few metaheuristic algorithms has been designed for this purpose. From the analysis it has been observed that GA and PSO are the most used metaheuristic techniques for resource allocation purpose. From the comparative result it has been analyzed that execution time and energy consumption are most used metrices in maximum research studies. Also, it has been observed that smart healthcare and vehicular system are most used case studies and iFogSim is the highest used simulator for the evaluation of performances of proposed algorithms. It is prerequisite to evaluate the resource allocation algorithms in real environment of fog computing. Dynamic behavior of fog nodes, resource allocation based on QoS is an open research challenge to be addressed in near future.

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