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A Comparative Analysis of different Vehicular Fog Computing Scheduling Algorithms

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Abstract— Fog computing (FC) is considered one of the smart and effective solutions for service provisioning to the Internet of Everything (IoE) layer. IoE layer means the platforms including homes, vehicles, infrastructures, and alike others. FC supports the IoE layer in a smart and charismatic manner by providing services near the smart devices, from vehicles to other mobilities, and fitting the response and delay time requirements. In the proposed paper, the authors focused on discussing vehicular fog computing (VFC) and how FC supports smart vehicles operating on the IoT layer. In the previous decade, scheduling algorithms are proposed by different scholars such as RTFRS, FCFS, ILP, and others to improve the working and efficacy of VFC. In the proposed paper, an analysis is done on the VFC scheduling algorithms published in the last three years in accordance with areas such as traditional, meta-heuristic, deep reinforcement learning, fuzzy logic, heuristic, and integer linear programming. The analysis is done to examine the areas of scheduling such as task scheduling, resource allocation, and others on which the existing solutions are working. This helps in inspecting the gap across which in future further work can be done.

Index Terms— Cloud Computing; Fog Computing, Vehicular Fog Computing, Scheduling, Algorithms, Internet of Everything

I. INTRODUCTION

Cloud computing (CC) is the technology platform that shaped the new future in terms of data accessibility and availability from anywhere at any time. It is a model that enables access to computing resources more effectively. CC becomes a key business model for the provision of applications, mechanisms, and Infrastructure associated with the domain of information technology (IT) [1]. CC has shifted the phenomena of IT-as-a-product to IT-as-a-Service. With the help of CC, a product-centric IT provisioning model is transformed into a distributed, global, service-centric model, which plays an adequate role in the provision of ease and comfort to end-users in terms of accessibility, availability, and productivity [2]. CC advent has altered the way in which services of IT are developed, invented, deployed, updated, scaled, paid for, and maintained. It enables entities and end-users to access IT resources ubiquitously as a measured service. Cloud infrastructures such as Infrastructure as a service (IaaS), Software as a Service (SaaS), Functionality as a Service (FaaS), Backend as a Service (BaaS), and many others have shaped the new way for end-users to obtain ease, usability, and effectiveness [3].

From server less computing to networking through enabling on-demand access to a shared computing resources pool, such as storage, service, and applications. Therefore, it can be said that CC has been considered or referred to as the new and smart era of traditional computing and is setting new milestones and ranks in some tech-based domain advancements such as in hardware it is supporting in multi-core chips, virtualization, and likewise other aspects, similarly, in web services and service-oriented architectures under Internet technologies [4]. Despite the role and rank of CC, there are some issues and challenges. It can also be said that in the future, as technology advances, these issues and challenges will affect the ins and outs of CC as it is related to data handling, storage, and management. For this, it is considered that FC, referred to as a corresponding and smart add-on to CC and its infrastructures, supports solving these aforementioned issues and challenges.

FC addresses some of CC's limitations by distributing resources closer to the network edge where data is created and consumed. This proximity reduces latency, making it ideal for real-time applications and IoT edge devices that cover vehicles, telemedicine education, smart applications, and others. In addition, FC improves privacy and security by processing sensitive data locally, minimizing the need to send data to CC servers. It improves reliability by distributing workloads across a network of interconnected devices, ensuring continuity even in the event of a network or server failure. Overall, FC complements cloud infrastructure and provides an efficient and resilient approach to data processing and analysis at the edge of the network. The proposed paper is designed and prepared accordingly. In the proposed paper, the focus of the authors is associated with FC, and under FC, it is focused on vehicles referred to as FC for vehicles or VFC. VFC is playing an adequate role in the recent era which can be further seen with the news of the recent Mercedes and Google strategic partnership [5]. VFC provides computing services at the edge of networks by optimizing the unused resources of vehicle-loaded computing systems. It utilizes the computing capabilities of vehicles to provide computing services at the edge of networks and utilize the unused resources of the vehicles' computing systems. This approach can improve efficiency and reduce risks in offering services, notably in conditions where vehicles are distributed like urban areas or highways. Hence, a basic overall structure and architectural representation of vehicular fog computing are depicted in Fig 1. The projected paper is divided into six sections where Section 1 is the introduction, section 2 is the methodology, section 3 is the literature review, section 4 is the discussion, section 5 is the conclusion, and lastly, section 6 is the future directions.

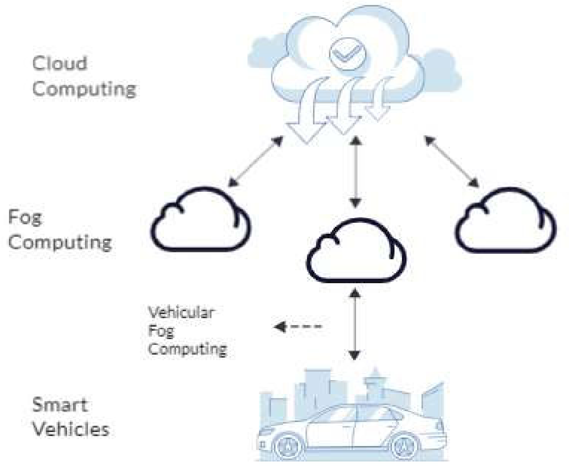

Figure 1 Basic Architecture of Vehicular Fog Computing

II. METHODOLOGY

The proposed paper's nature is to conduct a comprehensive and quality discussion and analysis on the entitled topic. For this, qualitative research methodology has been incorporated, i.e., further supported by an inductive approach and interpretivism philosophy. The rationale for using the qualitative method is due to the examination and exploration of the VFC algorithms in a profound manner where interpretivism supports interpreting the study elements and assists the researchers in integrating the interests and notions into the study. In this flow, inductive also assists in detailed observation of the data as well as it starts with the theories and observations that are proposed towards the end of the research process as an outcome of observation [57]. For data collection, a secondary data collection technique has been used where databases: IEEE, ACM, Google Scholar, Semantic Scholar, and Science Direct are used. The search range for data collection is from 2020-2023; nonetheless, to support the arguments, data that is published in 2018-19 is also referred to with minor inclusion. The keywords used for gathering the data are vehicles, fog computing, algorithms, scheduling, cloud computing, the Internet of Everything, and smart cars. These keywords were also used in combinations with their alternatives or synonymous words; for example, smart cars were substituted with smart vehicles, smart vehicular technology, and likewise others. Thus, the algorithms under traditional, meta-heuristic, deep reinforcement learning, fuzzy logic, heuristic, and integer linear programming are considered and have been examined in the projected study. Under these categories, five areas were the key focus: resource allocation, resource scheduling, task scheduling, workflow scheduling, and job scheduling [6].

III. KEY TERMS AND TERMINOLOGIES

In this section, resource allocation, resource scheduling, task scheduling, workflow scheduling, and job scheduling have been discussed. This is to develop the insights and knowledge of the readers.

A. Resource Scheduling (RS) and VFC

RS supports finding a suitable matching resource for the client to attain the optimal goal of scheduling, like the quality of service, reducing the delay in processing, and improving resource utilization [6-7]. Under VFC, RS's purpose can be considered as the core player in the process of effective allocation of computing resources that includes memory, processors, and network bandwidth to different operations or tasks. It helps to ensure the optimal utilization of computing resources, improve energy efficiency, reduce latency, and maximize system performance. It plays a significant role in the VFC efficient operation networks that allow multiple tasks and operations to run instantaneously [8].

B. Task Scheduling (TS) and VFC

TS aimed to assign a task set to fog nodes to connect with entities like vehicles for the sake of meeting quality-of-service satisfaction, which further leads to minimizing the transmission and execution tasks time [9]. Under VFC, TS supports allocating computing resources like memory and processors to diverse applications and tasks. It assists in ensuring that operations, tasks, and applications are executed in an optimal and timely manner, which further assists in latency reduction and in attaining an energy-efficient system.

C. Job Scheduling (JS) and VFC

JS classification intends to assign a cluster of jobs to the least number of cloudlets and fog nodes, such as less memory in the shortest execution time of CPU [7]. In the VFC context, it can be said that JS supports scheduling jobs/asks processes on cloudlets and fog nodes in the network of VFC. The key goal is the minimization of response time, and at the same time, it aims to improve service quality while optimizing resource utilization.

D. Workflow Scheduling (WS) and VFC

WS aims to assign resources with diverse abilities of processing to the workflow tasks applications that can minimize the cost and make-span [7]. In the context of VFC, it can be said that WS is the scheduling and allocation of computing resources process for executing the set of computational tasks, or it also is referred to as works that are independent in a timely and effective manner [10].

E. Resource Allocation (RA) and VFC

RA is considered the systematic approach of the available resource allocation to the client's needs over the Internet [7]. In VFC, RA supports the process of allocating communication and computing resources amid the cloudlets and fog nodes in the VFC network. The RA goal is to make sure that the resources available are effectively utilized to meet the offload tasks' computational demands from vehicular users [11].

TABLE I CATEGORIES, ALGORITHMS, AND INSPECTED PROBLEMS

Categories, Algorithms, and Inspected Problems			
Five Categories	**Existing Algorithms**	**Problems Inspected**	**References**
RS	Algorithms found from different studies are Fuzzy Clustering Algorithm with the PSO (FCAP) algorithm that is actually a combination of Particle Swarm Optimization (PSO) with Fuzzy C-Means (FCM) clustering algorithm. This algorithm deals with computing, storage resources, and bandwidth.	Resources and their dynamic changes, as well as low resource utilization.	[12-13]
	A scheduling mechanism has been found that is grounded on an improved Non-dominated Sorting Genetic Algorithm II (NSGA-II) for the sake of reducing service latency and stability of the task execution.	Accuracy and efficiency in complex structures are still debatable topics under this algorithm.	
TS	Laxity-Based Priority and Ant Colony System (LBP-ACS), which is associated with the notion of task scheduling strategy in the fog layer. This algorithm is divided into two sects such as LBP and ACS, where LBP sets the priority of tasks, and ACS applies a task scheduling scheme.	The algorithms only support the dependent tasks, which somehow limits the accessibility and availability of tasks that could be assigned independently.	[14-16]
	To balance the workload and minimize response latency among the fog nodes and cloudlets Edmonds-Karp-based algorithm is there.	This algorithm is not effective in the cases of considering the heterogeneity of the cloudlets and fog nodes in terms of their available resources as well as processing capabilities.	
	To reduce the average time of response in accordance with offloaded computational tasks, a modified genetic algorithm (MGA) based task scheduling scheme has been proposed.	It is often supported in the VFC domain; however, some problems have been associated with this, such as Computational overhead, Premature convergence, and VFC environment heterogeneity.	
JS	Particle Swarm Optimization-based Scheduling (PSOS) is an algorithm that is based on population optimization inspired by the birds flocking social behavior or fish schooling. It supports allocating resources efficiently and dynamically to meet the energy constraints and latency of mobile devices.	PSOS can prematurely converge to suboptimal solutions, particularly in the process of dealing with a sizable number of resources and jobs.	[17-18]
	Dynamic Threshold Job Scheduling (DTJS) improves the utilization of resources and minimizes the time of response in VFC. It is grounded on the dynamic threshold concept, where the threshold value is dynamically set based on resource availability and current load.	Requires calculations of dynamic thresholds based on the current fog and cloud nodes state. This can lead to a major computational load, especially when dealing with large numbers of jobs.	

WS	To curtail the energy consumption for heterogeneous FC architectures, there is an Energy Minimization Scheduling (EMS) algorithm.	Resource heterogeneity has been considered one of the key problems in this algorithm. In VFC, diversified cloudlets and fog nodes may have different energy consumption rates, memory capacities, and processing speeds that make it a challenge for the system to optimize resource allocation.	[19-20]
	There is an Ant Colony Optimization-based Workflow Scheduling Algorithm (ACOWS). This is based on a metaheuristic algorithm and is inspired by the ant's behavior to find the shortest path between the nest and food. It uses a trail to guide the search for workflow scheduling by considering the quality of service and the available resources.	The algorithm convergence speed might be slow, which may lead to extensive processing time requirements for workflow scheduling.	
RA	For allocating resources appropriately Greedy Knapsack-based Scheduling (GKS) algorithm is there.	It might not be able to always lead to a correct solution because the Greedy approach incorporation in GKS may not be able to view all probable tasks and resources combination that results in suboptimal decisions in accordance with resource allocation.	[21-23]
	The adaptive Resource Allocation Algorithm (ARAA) supports optimizing the communication and computing allocation of resources in VFC networks. It is based on reinforcement learning tactics that assist in the process of dynamic adjustment of resource allocation based on network change and task demand conditions.	This algorithm is quite complex as it involves several parameters as well as a process for decision-making that could make it a resource-intensive and expensive approach. This may also lead to reduced system performance and, at the same time, increased latency.	
	The hierarchical Resource Allocation Algorithm (HRAA) is another algorithm that is proposed for resource allocation classification. It supports optimizing VFC resource allocation by focusing on the hierarchical structure of cloudlets and fog nodes. It segregates the process of resource allocation into two levels such as high and low-level allocation.	It relies heavily on centralized control and has a high overhead. It also lacks adaptability and comes with limited fault tolerance capability. This can impact the scalability of the entire system.	

IV. DISCUSSION

A. *Fog Computing and Vehicular Fog Computing – An Overview*

It is said that FC and VFC link to distributed computing. It is found from [24] study that FC is referred to as the distributed computing architecture that extends cloud capabilities to the network edge, closer to where data is either consumed or generated. In FC, storage, processing of data, and management take place on devices located between the cloud as well as end devices that include routers, gateways, and sensors. FC aims to improve the performance and efficiency of the cloud by reducing the amount of data that is supposed to be transferred between the edge and the cloud by enabling analytics and data processing in real-time.

VFC pushes communication and computing resources to the network edge. VFC's idea is computational tasks offloading from the vehicles to fog nodes, and it utilizes the computational resources integrated into the vehicles to aid the task processing that has been generated by the end-users [25]. In addition, it is a technique enabling ultra-low-service latency by utilizing the storage and computation resources of both Serving Vehicles (SVs) and Roadside Units (RSUs) like trams, buses, and likewise others with rich resources [26]. In VFC, each vehicle is equipped with communication and computation that permits the vehicles to communicate and connect with clouds and other vehicles. These vehicles form a network that is distributed in nature and has the ability to share, store, and process data in real time. It assists these smart vehicles in making suitable decisions, helping them to meet the parameters of safety-critical systems. It helps in mitigating issues and risks like roadside accidents and complexities for pedestrians in the real-time environment [27]. Hence, it can be said based on the analysis that FC and VFC distributed nature allows for efficient processing of data and, at the same time, assists in reducing the latency issues alongside bandwidth, security, as well as resilience.

FC stresses the usage of local resources at the edge of the network rather than remote cloud resources. By processing data near the place where it is generated, FC supports bandwidth usage, latency, and data cost while enabling the decision-making and analytics of real-time data [28]. It assists in setting up the practices required to minimize the possibilities of security and resilience issues that exist in the traditional architecture of the CC. Similarly, in VFC, data processing is distributed across numerous vehicles, where each vehicle performs a specific processing or task on a data set collected via communication and computation. This enables faster data processing as well as a reduction in load in the cloud. This new association of smart vehicles with clouds under the banner of fog helps in mitigating the bottleneck issues such as latency, bandwidth, security, and resilience of traditional architectures of cloud computing [29].

Therefore, VFC is a complementary technology linked with FC to extend the capabilities to the network edge so that issues or challenges allied with traditional cloud computing in dealing with smart vehicles as well as other entities linked with FC, in general, can perform effectively. Table 2 helps the readers in developing relevant insights and knowledge about these gaps and how they work.

TABLE II CLOUD COMPUTING CHALLENGES AND THE ROLE OF FOG AND VEHICLE FOG COMPUTING

Cloud Computing Challenges and the Role of Fog and VFC		
	Challenges and Explanation	**Reference**
	Latency	
CC	In the cloud, processing, and storing of data is done on remote servers that are accessible over the Internet. This is the reason behind latency or delays, especially when a significant amount of data needs to be transmitted amid the network edge and the remote servers.	[30-32]
FC	Fog reduces latency by bringing storage and data processing closer to the data source enabling real-time processing of the data and, at the same time, mitigating the need to transmit the data to remote servers.	
VFC	In the context of the vehicle, it enables real-time decisions and, at the same time, supports reducing the transmitted data amount over the network.	
	Bandwidth	
CC	The cloud can be bandwidth intensive, mainly when large data sets need to be transmitted between the network edge and remote servers. This could consume significant network resources as well as costs.	[33-35]
FC	Fog computing comes with a solution where it reduces bandwidth usage by analyzing and processing the data locally at the edge, supporting in reducing the data amount that needs to be transmitted to the cloud.	
VFC	In a vehicle context, this can be principally useful in situations where network bandwidth is limited, such as in mobile networks or remote areas. By reducing the data amount over the network, fog computing in vehicles improves the efficiency of the network and reduces network load, improving utilization of bandwidth and system performance.	
	Security	
CC	Cloud computing involves the process and ways of transmitting sensitive data over a network that can be vulnerable to security threats like data breaches and hacking. This can be related to the condition when the data is transmitted via the public Internet.	[36-38]
FC	Fog computing has been playing an adequate role in the course of solving this issue by improving security by processing data locally at the edge. Therefore, this also aids in reducing the data amount that needs to be transmitted over the network and, at the same time, also assists in reducing the attack surface for threats allied with security.	
VFC	In the vehicle context, VFC supports maintaining the security and privacy of end-user data, for example, personal information or data location. By storing and processing data locally, fog computing in vehicles supports in effective utilization of encryption techniques along with other measures for security and privacy.	
	Resilience	

CC	The cloud can be vulnerable to network failures and disruptions that can result in service downtime and interruptions.	
FC	Fog computing supports the process of improving resilience by offering a distributed computing infrastructure that can also continue to operate even if some distributed parts of the networks fail or are disrupted. Also, by storing and processing data locally at the edge, fog computing may support ensuring critical data availability even if the cloud is unavailable on a temporary basis.	[39-41]
VFC	It supports maintaining the availability and reliability of the systems that are critical. For example, those systems that are linked with autonomous driving. Therefore, enabling the local storage and processing of data supports reducing the dependency of the entities on centralized cloud services.	

Thus, FC and its association with vehicles, which makes the new paradigm referred to as VFC, has the potential to solve these issues by extending the cloud computing capabilities to the network edge via enabling real-time processing, reducing the latency as well as usage of bandwidth.

B. *Vehicular Fog Computing and Scheduling Algorithms*

The main agenda is to discuss the scheduling algorithms aimed at VFC in accordance with the five categories mentioned in section 2 of the proposed paper. The need to use scheduling algorithms in VFC is to adequately manage resources so that vehicles and the FC layer can communicate and connect with each other in a scalable, smart, and effective manner. The presence of scheduling algorithms is pictorially demonstrated in Fig 2.

Scheduling algorithms in VFC are segregated into basic stages, as depicted in Fig 3 [6]. Even though [6] has covered these algorithms with respect to FC; however, they can be used and implemented in the VFC with a minimal number of changes. In addition, each scheduling algorithm plays an adequate role in the performance and efficacy of vehicles and the fog layer. It can be classified into five categories resource scheduling, task scheduling, job scheduling, workflow scheduling, as well as resource allocation, as highlighted in section 2 [6-7].

To limit the scope of the proposed paper and in accordance with Fig 2, in the following section, the algorithms proposed under each of the stages depicted in Fig 3 from 2020-2023 are examined with 1 exceptional case for the comparison where the paper of 2018 is chosen. In addition, to further limit the scope minimum 1 and maximum 3 algorithms are discussed. This helps to develop insights and knowledge with respect to the recent development that took place in the defined time.

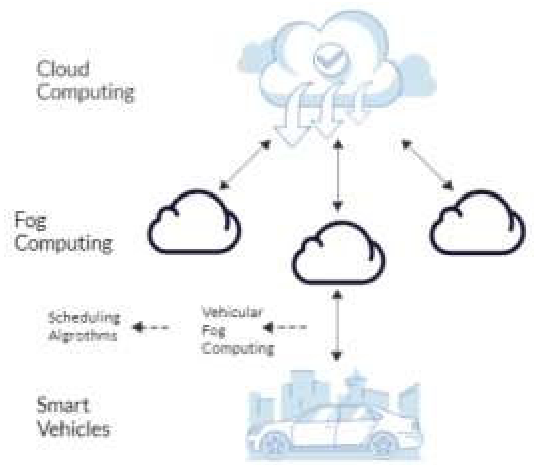

Figure 2 Extended Architecture of Vehicular Fog Computing

Figure 3 Scheduling Algorithms and Categories – VFC

1) Traditional Scheduling Algorithms and VFC: Under traditional scheduling algorithms, there are three most common algorithms that are also used and discussed in accordance with VFC; Priority Based Scheduling (PBS), First-Come-First-Serve (FCFS), and Round Robin (RR). It is found in [42], where the author proposed a priority-based RSA algorithm (PRSA). It supports replacing roadside units in the VFC network with a dynamic structure to minimize the physical Infrastructure of the VFC network. This, according to the authors, supports the provision of a larger service scope and assists in maintaining service quality for the user. Moreover, PRSA circulates the entire traffic information to all nearby cars or vehicles and also shares the information with the centralized unit for controlling the data so that issues associated with quality of service can be mitigated. PRSA uses RSA, which is a round-robin with a Starvation Algorithm variant with respect to the scheduling of resources and tasks/data. "P" is introduced with RSA in order to adjust the RSA algorithm time quantum so that information amid the vehicles can be shared effectively. PRSA segregates the data into least used data, emergency data, average user data, and urgent data. The data is also shared in accordance with the different traditional scheduling algorithms such as SJF, FCFS, and NDS. Therefore, PRSA is considered well in the context of bandwidth and consumption of energy, as demonstrated in the results examined via the MATLAB simulation technique [42]. In [43], based on FCFS, an algorithm is proposed. A situation is taken by the authors where multiple vehicles pool computing resources to realize their benefits related to VFC. A community where vehicles can enter and exit without restraint is sponsored by a Roadside Unit (RSU), and thus a resource pool is set up so that tasks can be accomplished with enough computing resources. RSU is the coordinator responsible for decision-making in task planning. In addition, the permutation of community members is established beforehand and updated regularly to make the most appropriate decision. A task scheduling strategy based on FCFS has been proposed by the authors. In [44], for efficient handling of the task, the Real-Time Flexi Forwarded Cluster Refreshing System (RTFRS) algorithm has been proposed. The authors considered the Standard Round Robin Mechanism (RRM) for job distribution among the fog nodes in the entire network and can also be considered the same in the case of VFC. According to the authors, in their algorithm RTFRS, RRM is a job distribution method that supports the algorithm in distributing the jobs to a resource stack simultaneously. Thus, the results demonstrate that RTFRS can surpass the standard methods and supports in areas like average waiting time, turnaround time, average failure rate, resource utilization, and gateway load.

2) Integer Linear Programming and VFC: For ILP, it is found from [45] study that it supports solving and modeling a wide range of optimization glitches under VFC. For example, computation offloading, task scheduling, as well as resource allocation. The model proposed in the [46] study assists in minimizing energy consumption while focusing on quality-of-service requirements. In addition, also works on a similar concept; however, ILP is used for considering the energy consumption of both vehicles and fog nodes alongside the delay in data transmission as well as the computational latency of tasks offloading. In [46], the model based on ILP works in the edge servers and vehicles. The focus is also connected with the time of task completion and the quality-of-service constraints linked with task offloading.

3) Heuristic Scheduling Algorithms and VFC: In [47], the algorithm for learning-based applications entitled Agile Service Provisioning (ASP) is proposed. The algorithm focuses on addressing the challenge associated with task scheduling and efficient resource allocation in FC environments. ASP consists of 3 main factors: task scheduling, resource allocation, and service allocation. The service selection module covers the most suitable services from the services that are available for task execution. The allocation of resources modules allocates the resources to the selected services based on the available and required resources and requirements. The task scheduling factor schedules the task to the services that are selected, and it also focuses on their deadline, resource requirements, and execution time. The author, under heuristic learning, uses a reinforcement learning approach for modeling the ASP algorithm and focuses on the dynamic adjustment of parameters based on the feedback received from the environment [47]. Quality-of-service has also been optimized by ASP, where areas like completion time of the task, consumption of energy, and utilization of resources are the core areas. The algorithm has been evaluated with the help of simulation techniques, and the results that have been included in the paper depict that the algorithm is effective compared to the traditional ones in terms of quality-of-service parameters. Hence, it can be said that the ASP algorithm supports enhancing the effectiveness and efficiency of task scheduling and resource allocation for learning-based applications. In the VFC context, it can be said that fog nodes and cloudlets are also deployed in a vehicle equipped with computing resources and sensors, which supports in providing numerous services to the users like data processing, data collection, and data storage based on the data they gathered from the real-time environment. Therefore, ASP supports optimizing the process of service provisioning and, at the same time, also supports improving the quality of service in vehicles as they are also considered learning-based applications as they learn and react based on the data collected from the real-time environment [47].

[48] proposed an intelligent heuristic (IH) algorithm for VFC. With the rapid development of applications for vehicles, the need for resources to oversee time-sensitive and computationally intensive tasks is increasing. In this article, a two-tier VFC architecture that includes the client tier and the fog tier has been proposed. Vehicles can create tasks as clients that are further allocated to fog layer nodes for processing. The fog layer nodes amalgamate available Infrastructure and vehicle resources by using their computing, communication, and storage functions. Each task calls for a certain resource amount to be processed by the fog nodes. A DTA, Distributed Task Assignment problem that accounts for the deadline, mobility linked with the vehicle, and fog capacity and intends to maximize the overall system resource utilization through vehicle and fog node collaboration. The authors also linearize DTA to a 0-1 ILP to find the optimal solution. In addition, they developed an algorithm based on a heuristic

approach for near-optimal performance, focusing on low computational overhead by decomposing DTA into two threading tasks and programming each fog node independently. Finally, the authors also create the simulation model and perform an experiment series constructed on real vehicle trajectories, demonstrating the scalability and effectiveness of the algorithm that is proposed. [48] focus is on proposing a heuristic schedule distribution mechanism for high-demand tasks within a two-tier vehicle fog computing architecture. The research aims to improve the efficiency and reliability of task scheduling in a VFC computer environment.

In [49], for task scheduling in VFC, an improved heuristic algorithm has been proposed. The paper focuses on the offline RSU unit by focusing on off/on scheduling issues in vehicular networks. The authors design the problem as mixed-integer-non-linear programming, and in accordance with this, they propose a Multi-Level Greedy (MLG) algorithm under the umbrella of a heuristic scheduling algorithm to explore a suboptimal approximation. The authors of [49] introduce the optimal service location concepts and suboptimal service location. The author attains the OFF_ON state RSU matrix. Therefore, it is found from the simulation results that the proposed algorithm can substantially reduce the RSU deployed energy consumption and, at the same time, can play a role in energy-efficient scheduling of the network of vehicles and fog computing. The algorithm considers a range of factors like vehicle density and traffic demand, as well as a range of communication, to make informed planning decisions. By strategically turning on and off RSUs based on these factors, the algorithm aims to conserve power without impacting the network's ability to keep connectivity and provide services. Hence, it can be said that it focuses on TS and RA parameters.

4) Meta-Heuristic Scheduling Algorithms and VFC: According to [50], meta-heuristic algorithms or evolutionary are inspired by the concept of natural evolution. Compared with the simple and exact heuristic, meta-heuristic offers a more effective search for complicated and large problems and helps in setting up the best means and methods for memory, time, as well as the quality of the system or application. In [50], a model for multi-object optimization is proposed, which supports the process of investigating the VFC network facility location. The authors stated that already existing solutions for VFC network facilities generate topologies that are optimal in optimized trade-offs among the energy consumption and service delay aspects. To solve this, a hybrid evolutionary multi-objective algorithm Swarm Optimized Non-dominated sorting Genetic algorithm (SONG). EMO algorithms come under the resolution methods referred to as meta-heuristic algorithms. The algorithm works on the convergence and search efficacy of two other algorithms, Speed-constrained Particle Swarm Optimization (SMPSO) and Non-dominated Sorting Genetic Algorithm (NSGA-II). It is found that the proposed algorithm comes with improved and effective solutions compared to the other two EMO algorithms, and the proposed algorithm can be used as a key technique in the designing and planning of VFC networks by service providers. [51] the study aims to optimize the process of task offloading in a VFC environment. The study also enables the task computation offloading from vehicles to fog nodes that are near for effective processing. The authors present the Time-Cost-aware Task-Node Mapping (TCaTNM) algorithm, which helps in the process of optimizing the process of task offloading by working on multiple factors covering time for task computation, the latency of the network, and consumption of energy. The algorithm used an evolutionary tactic also based on genetic algorithms and swarm intelligence tactics to find the effective solution for task offloading. Furthermore, the algorithm has been evaluated via simulation, comparison with the PSO algorithm has also been done. The results showed that the proposed algorithm is effective compared to the PSO algorithm. Hence, the algorithm is effective in task offloading optimizing processes in VFC and can be used for performance enhancement in FC. In [52], a unique offloading algorithm, which supports the process of energy optimization entitled Energy-SLA-aware genetic algorithm (ESGA), is proposed for tasks associated with offloading computation in vehicular networks. This algorithm intends to meet SLA by minimizing the energy consumption of end-users by optimizing the task allocation between cloud and edge computing resources. It considers various parameters such as time for task completion, energy consumption, and violation rate associated with SLA. It is based on evolutionary GA while upholding the service level agreement of application. ESGA uses an adaptive penalty function to integrate the optimization constraints within EGA. In addition, numerical experiments and comparative analysis have been conducted amid the genetic and random algorithm-based offloading proposed one and with no offloading baseline approaches. Thus, the results depicted that the ESGA saves 2.9+ and 1.3+ times more energy compared to no offloading and random algorithms. It has 0.3% of violations compared to random and no offloading, which is 52+% and 62+%.

5) Fuzzy Logic Scheduling Algorithms and VFC: A Fuzzy Logic-based Task Scheduling Algorithm (FLTSA) is proposed in [53] aimed to optimize VFC task scheduling. FLTSA aimed to decrease the energy consumption and time for task completion of the VFC system by scheduling the task in an optimized and effective manner across diversified fog nodes. It considers parameters such as network latency, availability of resources, and task priority to make scheduling decisions. The algorithm is based on a fuzzy interference system to map inputs such as network latency, availability of resources, and priority of tasks for effective decision-making in scheduling the tasks. FLTSA is evaluated via simulations, and the results examined depicted that FLTSA can improve time for task completion and consumption of energy in the VFC system compared to other task scheduling algorithms. It improves the time for task completion by 31+% and by 38+%, minimizing the energy consumption time compared to FCFS scheduling algorithms. The optimizing approach for task scheduling presented by [53] is considered to be effective for VFC frameworks. FLTSA can also support the process of improving the VFC system efficiency. In [54], the authors consider the advantages of both fuzzy logic and deep reinforcement learning to propose a unique algorithm for dealing with offloading schemes in VFC delay constrained. The algorithm is titled Fuzzy Deep Q-learning base Offloading scheme (FDQO). It is aimed to expand the quality of experience that addresses how the tasks meet its delay constraint, or it can be said that FDQO aimed to reduce the completion time of tasks while meeting the VFC system delay constraints. Using fuzzy logic, the algorithm depicts the vagueness and uncertainty of VFC input parameters such as channel capacity, task data size, delay constraints, and others. In addition, FDQO is evaluated via simulations, and the results depict that FDQO is effective compared to other approaches available for task offloading in terms of meeting the delay constraints and task completion time in VFC systems. FDQO improves the average quality of experience by 37+% compared to using Deep Q-Learning and 7.4+% compared to using only fuzzy Logic and 19% in comparison to the ∊-greedy strategy that is used for multi-armed bandits.

6) Deep Reinforcement Learning Scheduling Algorithms and VFC: For task allocation, a federated deep reinforcement learning (FDRL) algorithm is proposed for VFC environments [55]. In addition, FDRL plans to optimize the computing task allocation in the VFC environment considering the computation as well as communication resources available in vehicles when they are in vehicle-to-vehicle networks such as in a real-time environment. FDRL uses a deep neural network for estimating the allocation of the task for each vehicle, which is afterward used to update the allocation of task policy. Moreover, the proposed algorithm is evaluated using a real-world traffic data simulation. The results obtained address that the algorithm is comparatively effective in terms of baseline algorithms, specifically in the rate of task completion and resource utilization. Therefore, in [55], a novel algorithm FDRL is proposed for VFC environment task allocation using DRL. Hence, FDRL can support improving the effectiveness and efficiency of VFC systems. In [56], a PPO-based intelligent, deadline, and priority-aware distributed and online task scheduling and resource allocation algorithm entitled IRATS in VFC networks has been proposed. IRATS allocates resource problems through a Markov decision process to reduce the task delay and minimize the time for waiting. For sharing the vehicle's idle resources, the authors design a scheduler for the received task's orderly execution in accordance with their priorities by focusing on their multi-level queues. Simulative results via veins-gym, OMNeT++, SUMO, and Veins have been conducted for the effective validation of IRATS. The obtained results depicted that IRATS can help in improving the percentage of packet loss and in-time task completion alongside end-to-end delay and waiting time as compared to DQN and random A2C algorithms considering link duration and task priority of the vehicles.

TABLE III SUMMARY OF THE ALGORITHM ANALYSIS

VFC Scheduling Algorithms	TS	RS	JS	WS	RA
Traditional Scheduling Algorithms in VFC					
PRSA	●	●	●	-	-
RTFRS	●	-	-	-	●
FCFS	-	●	●	-	●
Integer Linear Programming in VFC					
ILP	●	-	-	-	●
Heuristic Scheduling Algorithms in VFC					
ASP	●	●	-	●	-
IH	●	-	-	-	●
Improved Heuristic	●	-	-	-	●
Meta-Heuristic Scheduling Algorithms in VFC					
SONG	●	●	-	-	●
TCaTNM	●	-	-	●	●
ESGA	●	●	-	●	●
Fuzzy Logic Scheduling Algorithms in VFC					
FLTSA	●	●	-	-	●
FDQO	●	●	●	-	●
Deep Reinforcement Learning Scheduling in VFC					
FDRL	●	●	-	-	●
IRATS	●	●	-	-	●

TS: Task Scheduling, RS: Resource Scheduling, JS: Job Scheduling, WS: Workforce Scheduling, RA: Resource Allocation.

V. Limitations, Assumptions and Critical Analysis

After conducting a detailed analysis of VFC algorithms focused on traditional, meta-heuristic, deep reinforcement learning, fuzzy logic, heuristic, and integer linear programming approaches where RA, TS, RS, WS, and JS were considered, it is found that algorithms work on some specific areas as per there nature and the target they are planned for. However, the authors of the projected paper deem that in terms of scalability and feasibility, it could become a challenge and there must be some middle way to go for such a task where more ease and reliability exists. This is required as the traditional dynamics of the vehicles have been changed and with the passage of time, it will be more, more and more users will have access to smart vehicles. In addition, working on or proposing solutions that are more scalable and flexible as well as easy would increase the accessibility of IoVs for the users more easily by mitigating the huge maintenance and FC services cost. Therefore, it is still a topic that, for the moment has not been discussed and explored to the extent it should have been. Hence, it is an open area for research where contributions on a significant scale can be made. It can be argued that the traditional algorithms are less flexible, and complex, and may not be suitable for changes as well as for dynamic environments. They failed to achieve the optimal solution in complex and large problem spaces. Furthermore, AI-aided algorithms require significant resources for training and reasonable memory. They primarily depend on the quality and quantity of data, and their performance varies if considerable operating and computational resources are not available. The traditional scheduling algorithms are preferred in less complex RSU-based Fog Computing environments where predictability and real-time performance are targeted. Whereas AI-based scheduling algorithms are more suitable in large, complex, and dynamic scheduling problems which change frequently, and require continuous adapting and optimizing decisions. Therefore, in the proposed work, the authors used and tuned the traditional less complex, and computationally feasible algorithms with respect to the environment constraints. In addition, the authors have set the IFogSim and testing environment for simulating four selected algorithms in Table 4, and simulation environment constraints are listed in Table 5. Each algorithm is tuned and simulated with 10 heterogeneous vFogNodes, where each node has been randomly allotted a few parameters like RAM, MIPS, and Bandwidth, but a fixed length of the task. Hence, the randomly allocated parameters have predefined an upper and lower bound value.

TABLE IV SELECTED ALGORITHMS

S. N^{O}	Ref. N^{O}	Acronym	Expansion
01	42	PRSA	Priority-based RSA Algorithm
02	43	FCFS	First Come First Serve
03	44	RTFRS	Real-Time Flexi Forwarded Cluster Refreshing System
04	42	ILP	Real-Time Flexi Forwarded Cluster Refreshing System

TABLE V SIMULATION ENVIRONMENT CONSTRAINTS

Parameters	Description
Machine Type	General Consumer Laptop – HP 640 G4
Processor	Intel(R) Core (TM) i5-8350U ~1.9GHz
Generation	8th
Cores	4
Threads	8
RAM	16GB
OS	Windows 11 Pro (Build 21996.1)
IFogSim Version	3.0

For results collection four performance matrices were selected TA, RS, JS, Bandwidth, and Latency. The units of matrices are mentioned in Fig 4.

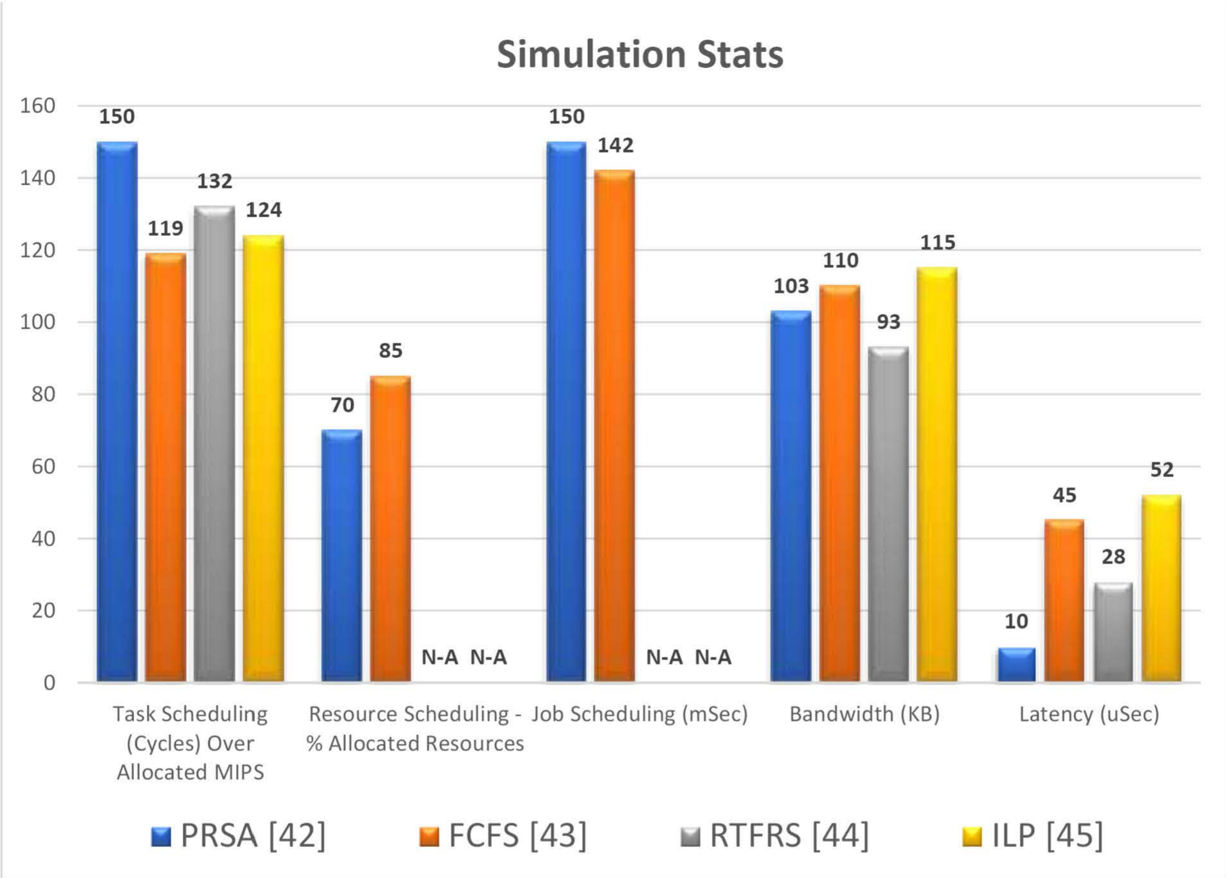

Figure 4 Simulation Stats and Analysis

To make the simulation more useful for future work, the authors have also concluded make span of each algorithm as shown in Fig 5.

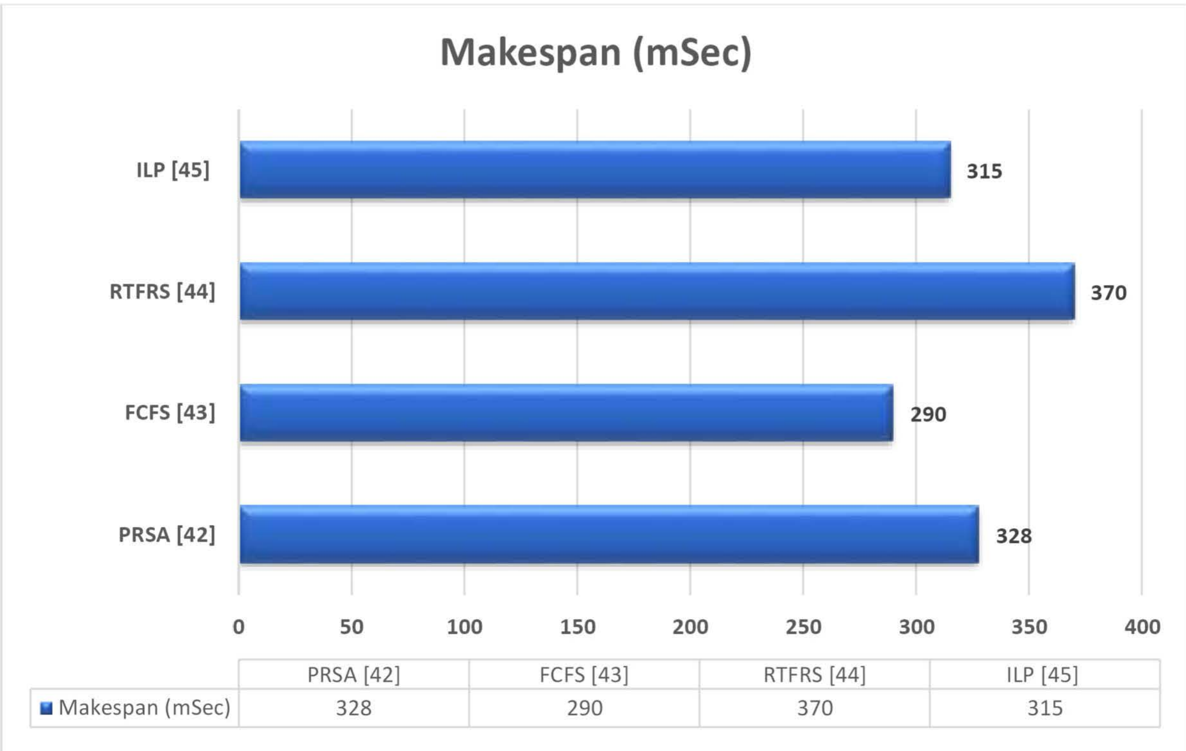

Figure 5 Make Span of Each Algorithm

VI. Conclusion

To conclude, the proposed paper aims to do a comparative and comprehensive analysis of scheduling algorithms that exist in the VFC domain. To limit the scope, algorithms available in the last three years, which are from 2019-23, are examined. Algorithms that were more suited to the aim of the proposed paper are analyzed where further limitations with respect to minimum 1 and maximum 3 are set. The paper first covers the introduction, where some basics are addressed. Afterward, the methodology is discussed briefly, which is used to complete the projected paper. In the third section, in line with five categories; resource allocation, task scheduling, workflow scheduling, resource scheduling, and job scheduling the existing algorithms are discussed; nonetheless, these algorithms were not directly linked to VFC, and the issues exist in such algorithms with respect to VFC are highlighted to strengthen up the future direction of the projected paper. This is necessary to do so as the authors aim to address that in today's modern era, where the concept of smart vehicles is increasing, the need to offer the best and most effective solutions is still a gap that has to be covered. In addition, these five categories are later on discussed specifically with respect to VFC, and the available algorithms are highlighted. Thus, a summary of those algorithms has been demonstrated in terms of the table.

VII. Future Directions

VFC is an emerging trend, and researchers have proposed various solutions to address problems mentioned or highlighted in multiple areas of VFC. The constraint of computing resources, availability time of nodes, network latency, and decision time for various scheduling algorithms remains an active area of research. These constraints vary between ad-hoc vehicular Fog Computing and infrastructure-based Vehicular Fog Computing, depending on the availability of working nodes with computing resources along with the processing overhead of cluster/node management.

The mentioned constraints vary between AI-driven and non-AI-driven algorithms. The computations load to process an AI-driven solution may increase; in any case, an algorithm is executed over the cloud, then the latency of the underlying communicating network will increase, which might degrade the performance of a working algorithm, whereas, in non-AI-based algorithms, the optimized performance may not be delivered to get efficient throughput from VFC. As discussed broadly, categories mentioned in section III have openings for researchers to propose the best viable solutions depending upon the scenario of VFC deployment.

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