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RESOURCE MANAGEMENT AND ALLOCATION IN FOG COMPUTING

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Abstract: Smart objects are increasingly playing a crucial role in the daily operations of both industries and individuals. These devices collect data through various apps and sensors, leading to a significant accumulation of information across various sectors. The use of smart objects has grown exponentially with the advent of the Internet of Things (IoT). This has led to a significant increase in the amount of data being generated, including both structured and unstructured data. However, there are currently no effective ways to manage this data. Despite the significant advancements made in the field of IoT, incorporating cloud computing is still facing challenges such as latency, performance, network and security concerns of computing can address the challenges faced by cloud computing in the context of the Internet of Things (IoT) by bringing the cloud closer to the edge. The primary objective of fog computing is to process and store data collected by IoT devices locally on a fog node, rather than transmitting it to a remote cloud server. This approach results in faster response times and better quality of services compared to cloud computing. Fog computing is an effective solution to enable the IoT to provide reliable and secure services to a large number of IoT customers. Fog computing allows for the management of service and resource provisioning from outside of cloud computing, closer to devices, at the edge networks, or at locations specified by Service Level Agreements (SLAs). It is not intended to replace cloud computing, but rather to enhance it by enabling computation at the edge while still providing access to cloud data centers. It covers various computing frameworks, fog computing features, a comprehensive reference architectural style of fog with its multiple levels, a comprehensive study of fog with IoT, various fog system methodologies, and a thorough evaluation of the challenges in fog computing, which also serves as a middle layer between IoT sensors or devices and cloud data centers.
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Keywords: Cloud Computing; SLA; IoT; Fog Computing; Resource Management

I. INTRODUCTION

The ability to pay for usage, scalability, and accessibility are some of the reasons why many companies are choosing modern cloud-based architecture today. The three main cloud services in cloud computing are Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). These services are driving the trend of Everything as a Service (XaaS).[3] Despite the large amount of data generated by sensors, or "Big Data," it takes a long time to analyze and send it to the cloud. Additionally, only a small number of IoT applications require processing speeds faster than what cloud computing can currently provide. To address this issue, fog computing with IoT capabilities is used to reduce the amount of data sent to the cloud for storage, analysis, and editing, thereby increasing efficiency. Sensor data is instead sent to edge devices for temporary storage and processing rather than being sent to the cloud. Fog as a Service (FaaS), a new service made possible by the combination of IoT and fog computing, involves the deployment of multiple fog nodes in different geographic regions to serve various clients from different industries. Each fog node is responsible for networking, computation, and storage[6] Unlike cloud computing, fog computing is a distributed computing approach that does not rely solely on a single component.[7,8] By utilizing the underutilized

resources of many nearby devices, fog can decrease the latency associated with cloud computing. However, for large-scale tasks, cloud computing is still necessary

Fog Computing, unlike Cloud Computing, is a decentralized computational approach in which many devices located near users utilize processing power with limited functionality but high computing capacity with multiple cores. As a result, a variety of smart devices, such as switches, base stations, routers, smartphones, and network devices, now have the ability to store and process data and can act as fog computing devices. Many research challenges have emerged as a result of the various organizations and global connectivity. The scalable environment and its requirements are at the core of the fog computing concept. This is why there are so many different computing strategies in the field of fog computing. The question that arises as a result is:

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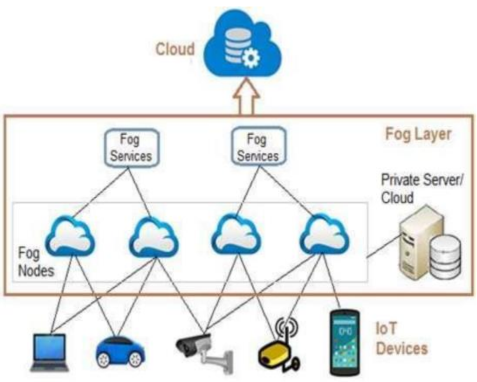
How can fog computing handle the specific challenges of resource planning and failure handling in a wide range of domains? Therefore, it is essential to carefully consider all other related aspects, including services, simulations, hosting issues, fault tolerance, and resource management. Fog computing has been the subject of numerous studies. [9-15]

II. LITERATURE SURVEY

The advent of IoT has introduced various challenges for integrating cloud computing, such as performance issues, security concerns, latency, and network problems. However, these challenges have been addressed by the development of fog computing, which brings cloud computing and IoT closer together. The main goal of fog computing is to manage data generated at the edge by IoT devices. This data is processed locally at a fog node rather than being sent to a remote cloud server. This approach results in faster response times and higher quality of services compared to traditional cloud computing. Additionally, fog computing allows for service and resource provisioning to be managed more locally, at the edge of the network, or at locations specified by Service Level Agreements, rather than centrally controlled by the cloud. Fog computing is not meant to replace cloud computing but to complement it by enabling both edge processing of data and access to the data center. This paper covers various computing models, key fog computing characteristics, a comprehensive reference fog architecture with multiple levels, a thorough examination of the connection between fog and IoT, various fog system methodologies, and a detailed analysis of fog challenges. [1]

A. The Architecture of Fog Computing

Fog computing is a technique that moves some data center operations to the edge of the network, by providing a limited set of storage, computing, and network capabilities as a framework for implementing between Cloud Computing data centers and end devices. The main objective of fog computing is to reduce unexpected latency for time-critical IoT tasks. [16]Muntjir et al. [17] and Mukherjee et al. [18] A benchmark framework for fog computing has been designed with seven levels, including Levels 1 and 2 for virtualized and physical systems, Level 3 for surveillance, Levels 4 and 5 for both pre- and post-processing, Level 6 for safety, and Level 7 for applications.



Fog Computing Architecture

III. STORAGE AND RESOURCE MANAGEMENT

Data storage via storage virtualization is the responsibility of the storage module. Data backup is the component in charge of preventing data loss and ensuring data availability. The idea of storage virtualization involves a collection of hardware that manages storage across a network and functions as a single storage device. This personal storage unit is simple to operate and maintain. The key advantage of storage virtualization is that it improves enterprise functionality while keeping hardware and storage costs low. Additionally, it reduces storage complexity. The data backup module is in charge of regularly customizing data backup plans. The components at the resource management level deal with concerns related to energy conservation as well as resource allocation and scheduling. Reliability is an essential aspect that guarantees the smooth functioning of an application by ensuring that scheduling and resource allocation are dependable. The scalability of the fog resources is guaranteed at times of heavy resource demand. The cloud platform succeeds in achieving horizontal scalability, while the fog platform concentrates on achieving both vertical and horizontal scalability. [19] When it comes to storing data in a system that utilizes distributed resources, the process of allocating those resources can be a significant challenge. All connected problems are allocated, de-allocated, and reallocated via the resource allocation component. Another significant challenge is that numerous programmers use the fog environment at the same time, necessitating proper application scheduling. The component called application scheduling is in charge of carrying out the application's numerous goals. The energy-saving element needed to effectively manage all the resources is present on this level. By doing this, operational costs are reduced. The reliability component, which focuses on various reliability indicators and measures, is responsible for managing the system's reliability. The following criteria could be used to analyze the metrics: redundant data in the data centers, redundant fog nodes, redundant mean time between fog node failures, and redundant mean time between major IoT application failures. The IoT devices, fog nodes, fog servers, and clouds are all maintained by the fog system, which has a complex design.

A. Fog Computing with the Internet of Things (IoT)

Different problems are being encountered with the current integrated CC framework for Internet of Things applications. For instance, it is not possible to implement time-sensitive requirements like augmented reality, audiovisual streaming, and gaming [20]. In addition, because it is an integrated prototype, it lacks position responsiveness. Fog Computing addresses these problems. Fog computing is the solution to the challenges facing IoT and cloud computing today. It acts as a bridge between cloud computing, storage, and the Internet of Things, providing a secure and organized way to manage IoT devices by bringing processing, storage, and cloud networking to the edge of the network. Numerous applications and services are provided by fog computing with widely scattered placement. The fog can effectively supply immediate transmission for a variety of IoT requests, such as connected autos, etc. Fog computing is the ideal

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solution for applications that require low latency, such as augmented reality, streaming, gaming, and more. Integrating IoT with fog computing brings a wide range of benefits to various IoT demands. One of the key advantages of fog computing is that it allows for instantaneous communication among IoT devices, reducing waiting time and making it perfect for time-sensitive IoT requests. Additionally, fog computing has the capability to support large-scale sensor networks, which is crucial for IoT applications that require monitoring and collecting data from a large number of devices.

IV. FOG SYSTEM ALGORITHMS

In this section, we will delve into the importance of classifying fog algorithms according to their scope of application. Specifically, we will discuss the benefits of separating fog algorithms into three distinct categories: job planning, resource allocation and loading, and fog node and device unloading.

A. Resource Allocation

The main aspects of fog system computing that have been studied are partnership between fog nodes and evaluating resource sharing. These features have been handled in the fog layer to fulfill the computing requirements.

B. Fog Computing : Research Challenges

Fog computing has emerged as a practical and commercially viable alternative to cloud computing, providing clients with computational resources. The Recent developments in the IoT have resulted in devices such as sensors and smartphones at low hardware costs. By performing computation closer to the edge, not only do we significantly reduce the costs of offloading data and computation to the cloud, but we also increase the security and privacy of the data being used. Fog computing is a revolutionary approach, however, it also poses several obstacles related to security, device integration, and the integration of fog and IoT. Despite these challenges, research is ongoing to overcome them and make fog computing even more powerful and efficient.

C. Challenges in the Device and Network

Decentralized framework, networking resources, and device heterogeneity are three of the various device and network problems that are discussed below.

*1) Decentralized framework :*Fog computing is an innovative, decentralized approach that allows for increased redundancy. However, this also means that the same code is often replicated across multiple devices at the network's edge [31,32]. To truly maximize the potential of fog computing, it is essential to focus on reducing this redundancy and streamlining the decentralized architecture.

*2) Networking resources :*In a fog computing architecture, network resources are dispersed randomly, which can make it difficult to establish and maintain connections. However, by implementing a proper network with middleware, it is possible to manage and allocate resources effectively to the necessary applications. Middleware in a fog computing architecture is responsible for organizing and centralizing network resources at the edge, making them easily accessible and manageable.

3) Device Heterogeneity : The fog architecture's end devices are diverse. The structure is more diverse due to the nature of heterogeneity [33]. This aspect of the diversity at the device and network should also be taken into consideration by the applications that are developed using fog.

4) Computational challenges : Fog computing presents difficulties in terms of distribution and management of computation resources across multiple levels of the network, as well as the need to perform computations at various levels, which can make it challenging to optimize the network infrastructure.

5) Computations at different levels : Fog systems and cloud servers should maintain constant communication to ensure optimal performance. The primary goal of the fog system should be to quickly respond to users at the lower levels of the network, while also sending any additional, more complex computations to the cloud. Determining which computations should be performed in the cloud and which should be performed in the fog can be difficult, as some computations can be executed close to the edge with low computation costs, while others require more computational power and fewer restrictions on response time.

6) Distribute computation resources : The necessary resources might not be available for computation at the edge. Other fog nodes are a source to acquire these resources. Due to this demand, it is now more important to distribute resource computations among different fog nodes. This calls for an approach that creates a common pool by combining the memory, computations, and networking resources. Different applications can access the resource pool and reserve the resources they require based on their specific needs [34,35]. Instead of using edge computing devices, the current research emphasizes the need to create a common pool that contains resources.

7) Utilization of Resource Challenge : Due to the variety and accessibility of the devices, resource utilization is particularly vibrant and unique in an environment like a fog. Each of these fog devices is responsible for carrying out the application on its own.

8) Request provision handling challenge : Fog computing is created to effectively handle a significant number of IoT devices, both responsive and unresponsive applications are included in this.The level of service and flexibility attainable with this approach is unique and different from traditional methods. However, one of the major challenges in the fog computing domain is making these services accessible to users and devices. Further research is needed to determine the possibility of fog-centered solutions to overcome this challenge. But, this challenge also presents an opportunity for organizations to invest in research and development of fog-centered solutions

The IoT has currently caught the attention of both industry and researchers. This attraction has transformed the way we live and is now necessary for today's society. Anything in our environment could be associated with it. IoT devices have a strong capability but are restricted in terms of processing and storage capabilities. Nevertheless, there are several issues with the conventional integrated CC, which

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include network failure and increased latency. Fog computing has emerged as an answer to these issues. It is an improvement to cloud computing (CC), but close to IoT devices. By utilizing fog computing, we can significantly decrease latency and increase efficiency in the processing of data. This is particularly beneficial for time-sensitive and mission-critical applications. Fog computing and IoT together provide significant benefits for various IoT applications. In this work, we delve into various computing paradigms, examine the characteristics of fog computing, provide a detailed description of the fog computing architecture with its multiple layers, and conduct a thorough analysis of the integration of fog and IoT. Additionally, the discussion also delves into different algorithms used in fog computing systems and the challenges that are currently being researched in fog computing. The purpose of this research was to investigate the latest advancements in the field of fog computing and IoT and to identify potential areas of future study. By conducting a thorough examination of current research, we aim to gain a deeper understanding of how these technologies can be integrated to create more efficient and effective systems.

V.

A. Resource Management and Resource Allocation in Fog Computing

Fog computing is a new emerging technology that was invented recently [21]. The growing number of devices and user data makes it very difficult to provide the requested cloud resources. Fog computing can be used as a supplement and extension of cloud computing. It serves as a link between the cloud and the users. Thus, it provides numerous perks by reducing the load on the cloud and resolving cloud-related problems such as latency, distribution, mobility, and so on. Two resource management techniques, known as FRR and FRL, have been developed by [22] Jun Li [23] These techniques focus on managing and allocating resources effectively within fog computing environments. FRR stands for "Fog Resource Reallocation" and FRL stands for "Fog Resource Reservation". It was suggested that using traffic flow prediction methods for reserving resources in fog computing environments is a valuable approach. This paper focused on exchanging resources from vehicles with a low priority and reallocating them to vehicles with a high priority. Researchers have presented a new model called [24] Zenith model, which aims to optimize the allocation of computing resources in edge computing environments. One of its key characteristics is that it allows organizations to manage their edge infrastructure independently, without the need for service providers. By implementing the Zenith model, organizations can gain a competitive edge and fully harness the potential of edge computing. Researchers suggested a framework for governing edge nodes in their paper.[26] The authors suggested a game framework for resource management with three levels of hierarchy in their paper.[27] The authors created a model for resource utilization that included Relinquish Probability and resource estimation.

B. Intelligent Distributed Dynamic Fog Computing Framework

Recently, 5G networks have emerged as a revolutionary technology that combines the best of mobile and fixed communication networks. By utilizing cloud computing structures such as fog and edge, they provide ultra-high data speeds and open up a wide range of new services. The integration of fog and edge computing with 5G networks, allows for even greater performance and flexibility.

Despite the many advantages of 5G networks, fog, and edge computing, the complexity of the system can make communication between these technologies challenging. This complexity arises from varying network conditions and the wide range of possible mechanisms, hardware, and protocols. However, this should not discourage organizations from investing in this technology as the benefits outweigh the challenges. Our proposed DD-fog framework for software development represents a significant advancement in the field, as it seamlessly integrates the latest technologies such as fog computing, mobile edge computing (MEC), and microservices approach to create a highly efficient and effective solution. Our DD-fog framework is a revolutionary solution for IoT-based application development and deployment, as it incorporates the latest technologies such as fog computing and mobile edge computing (MEC) and the microservices approach. This framework is unique in its ability to migrate microservices between fog structures and elements based on computational and network capabilities, and also takes into account user query statistics. This allows the framework to adapt to changing demands and network constraints, enabling the development of new time-constrained services such as tactile internet and autonomous vehicles. Our DD-fog framework is equipped with two cutting-edge algorithms that are designed to tackle the issue of user congestion, which is a common problem in IoT-based applications. These algorithms are specifically crafted to select the load points and find the fog migration node in order to ensure the highest quality of service delivery. Our proposed DD-fog framework has been put to the test and the results are astounding. Simulation results show that by employing rational resource allocation[49], the execution time of the microservices function can be reduced by a staggering 70%.

The union of MEC, SDN, and NFV technologies in the fog system creates a powerful synergy, elevating its capabilities and performance to new heights [28-30]. Taking user equipment dynamics and new quality challenges into account, the required characteristics can be ensured in the new ICT infrastructure. Software (platforms, large servers, etc.) is an essential part of service, As previously stated, the key to providing new services with high loads is to adopt the microservices approach. For implementing fog computing micro-services are therefore a more effective architectural approach. On the other hand, the development and deployment of microservices in MEC and fog architecture is currently challenging. As a result, the deployment strategy must be carefully taken into account. As a result of taking into account various factors such as MEC, fog infrastructure, and user dynamics, we have proposed a new framework for deploying services that is highly efficient, effective, and persuasive. Tran et al. in their study [36] focused on MEC technology and analyzed the advancements made in creating MEC networks, while also highlighting the

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main challenges that arise during the deployment of MEC networks such as security, resource management, support for mobility, load and resource distribution, service availability, and interoperability. This research emphasizes the importance of addressing these challenges in order to create a highly efficient, effective MEC network infrastructure.

Li et al. [37] proposed a fog computing network architecture that is not only efficient but also highly adaptable to changing demands. This architecture includes end-user equipment, a fog server that effectively manages a set of devices, a remote cloud server, and a dynamic policy for mobile cloud computing clusters (DMCCP) that can adapt to changing demands. The fog server is designed to create a cluster of cloudlet mobile devices, which will help to reduce the workload on the user. It is equipped with the capability of closely monitoring the resources available on each device, including aspects such as the CPU status, memory, battery power, network capacity, and the ability of other devices to complete a task using MRM (mobile resource monitoring) technology. This allows for efficient and effective management of the devices in the cluster. By doing so, it can make informed and strategic decisions when allocating resources. The fog server uses a heuristic approach to form clusters of devices by creating a list of available devices that are ranked based on the resources they provide and the amount of resources needed to complete a task. The devices are arranged in descending order. The fog server follows a systematic method for forming clusters by first calculating the total number of resources required to complete a task, then it starts eliminating devices with the best characteristics from the list of available devices until the required resources R are less than zero, at this point the process of cloudlet formation begins as per reference [50].

As of the start of 2020, there is a clear trend towards the implementation of advanced network and computing infrastructure technologies, coupled with the emergence of new services.

At the same time, the idea of networks for 2030 has replaced the concept of IMT-2020. Alongside networking (SDN/NFV), we are also seeing a shift in the way computing infrastructure is built. These new approaches will reduce the delay caused by the network when transmitting data packets to the data center. Two of the technologies that are being implemented are MEC (multi-access edge computing) and fog computing. By utilizing cutting-edge cloud computing structures and organizational strategies, data processing can be revolutionized. By moving data processing to the network's edge and utilizing distributed fog structures, such as devices. The following solution for combining the above technologies is proposed to gain a positive synergistic effect from their combined use (Intelligent Framework of Distributed Dynamic fog Computing System). By utilizing this new technology, we have the opportunity to revolutionize the way we provide custom services through the integration of the Internet of Things and microservices architecture. Not only will this allow for greater flexibility and efficiency, but it will also enable us to meet and exceed even the most demanding requirements.

As the usage of IoT applications continues to expand, the need for advanced computation and long-term data storage has become increasingly crucial. This has resulted in a strong dependence on cloud computing to meet these demands. The heavy reliance on cloud computing for IoT applications can lead to network congestion, which when coupled with the distance between cloud data centers and IoT devices, can result in an inconsistent and unreliable end-to-end response time. This not only diminishes the performance and user experience. Fog computing, an alternative to traditional cloud computing, has been introduced as a solution to the problem of high latency and unreliable response time. By bringing computation and storage resources closer to the network edge, fog computing can provide low-latency services, making it a more efficient and reliable option for IoT applications. This survey provides a comprehensive guide on the steps needed to effectively implement and execute fog computing systems: (a) the design and dimensioning of a fog infrastructure; (b) making fog resources available for use in IoT applications and assigning IoT resources to specific fog nodes; (c) installing frameworks to manage fog resources; (d) evaluating the fog infrastructure through simulations and emulation in order to determine the necessary requirements for building a practical and large-scale fog computing infrastructure that can support the Internet of Things (IoT) landscape. IoT technology has become increasingly popular due to its numerous benefits and versatility in a variety of use cases. This has led to a significant rise in the number of IoT devices and applications as well as data volume uploaded to cloud systems. The growing adoption of IoT technology is a clear indication of its value and potential for organizations. The International Data Corporation (IDC) has forecasted that by 2025, the number of IoT devices connected to the internet will be more than 41 billion and produce an enormous amount of data, over 79 Zettabytes [51]. This prediction is a clear indication of the rapid growth and potential of IoT technology. The current cloud systems are inadequate to handle the large amounts of data generated by IoT devices [52], this issue affects all IoT systems and is a major obstacle that needs to be addressed. Latency-sensitive IoT applications such as healthcare [53], multimedia [54], and vehicular/drone applications [55] require low latency and real-time processing. However, using cloud systems that are located far away can result in relatively large delays due to congested networks [56]. Additionally, centralization of cloud systems may also compromise the privacy of data that is uploaded by IoT devices [57]. Organizations that rely on these types of applications should not overlook these issues, as they can greatly impact their performance and security. Fog computing is a game-changing technology that is revolutionizing the way we connect and utilize IoT devices. It acts as a bridge between the IoT and the cloud, providing a powerful network of geographically distributed servers with computing, memory, and network capabilities. Fog computing offers a significant advantage over traditional cloud computing when it comes to servicing IoT devices. By having servers located closer to the devices, fog computing greatly reduces response time latency, making it ideal for applications that require low-latency responses [58]. Despite the fact that fog servers processing and storage capacities are substantially lower than those of cloud servers [59], By maintaining a high volume of IoT applications, their greater quantity and geographic diversity enable fog to reduce cloud

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network congestion [58]. Fog computing eliminates the need for data from IoT devices to be transmitted long distances to remote servers. With fog servers located close to the devices, all the necessary processing, data storage and management can be done locally, without having to send the data to remote servers. Fog computing systems go through three main stages of implementation and development. The first stage is the creation of a fog infrastructure, taking into consideration the specific requirements of IoT services. This is crucial as high traffic volume from IoT devices can lead to network congestion in the cloud. By building a localized fog infrastructure close to areas with high traffic, both Internet and cloud service providers can benefit from improved network performance and reduced congestion. The second stage in the implementation and development of a fog system is defining the interaction between the fog infrastructure and IoT devices, as well as managing the resources of the fog infrastructure. This is achieved by using specific algorithms or protocols that are integrated within the individual fog nodes or a centralized fog layer controller. The goal of these management techniques is to select the most appropriate fog nodes to process IoT data. To ensure optimal selection, certain hardware or software structures (such as fog orchestration controllers or APIs) may need to be implemented within the fog infrastructure. By properly managing fog resources, businesses can ensure that their IoT data is being processed by the most suitable nodes, resulting in improved performance and cost savings. The implementation of a robust resource management system in fog infrastructure is crucial for ensuring efficient and cost-effective IoT services. By examining the different algorithms, protocols and structures used in resource management separately, we can identify and implement the most effective solutions. The organization responsible for overseeing the fog infrastructure and IoT interactions, known as a fog service provider (FSP), plays a vital role in this process. By implementing resource management approaches that reduce costs and latency for IoT users, FSPs can not only improve the overall quality of IoT services, but also incentivize their use, leading to increased adoption and growth of the IoT industry. Effective resource management is a top priority for FSPs as it not only improves the quality of IoT services but also lowers operating costs by increasing energy efficiency. Thus, implementing strategies to improve resource management can have a significant impact on the overall success and profitability of the FSP. Third, utilizing established resource management techniques, the created fog infrastructure is assessed for its influence on various IoT applications. Developers of IoT applications can use evaluation tools to determine if local, fog-based, or cloud-based processing should be used for their applications.

VI.

A. Fog Computing Applications

The ability of fog computing to handle data processing of IoT with latency-sensitive or real-time needs is a significant benefit as it has applications in many industries such as healthcare, multimedia and it also can be used in self-driving vehicles.

1) Healthcare: Gill et al.[60] Had suggested using fog and sensors to aid heart disease diagnosis. Fog, in combination with sensors and apparel[61], [62] has been proposed to be used to offer patients at hospitals or healthcare facilities with real time services.

2) Autonomous Vehicles: For autonomous drone technology Loke [63] proposed a concept of asset management. Given a visible horizon amidst a drone and the fog server, for drone navigation control signals can be provided by a fog server. Traffic condition data from smart vehicles can be relayed by fog servers [64], [65] enabling real-time, area-wide traffic sharing and, as a result, reducing road accidents. Route navigation is enhanced when fog is paired with smart traffic lights[66].

3) Multimedia: As fog consists of real-time and per-instance processing its use in multimedia such as augmented reality, streaming videos and gaming. In applications where surveillance is done via a video, it can be used to detect faces, shortening the amount of time it takes for the appropriate authorities to respond in the event of an incident. Bursty data can be generated by surveillance cameras at the location of an event; Different data can be processed in various fog nodes by decentralized fog infrastructure, resulting in a faster overall emergency feedback. In IoT applications such as multimedia, smart cars or healthcare the outcome of an event can be significantly impacted even with minimal change in time for feedback. At the network edge, where IoT applications are present, fog computing can help.

B. Fog Resource Provisioning and IOT Resource Allocation

Fog resource provisioning refers to reserving memory and computing resources in fog nodes so that IoT applications can use them. In IoT resource allocation, the resources needed for an IoT request are assigned to fog. We can say that the allocation and provisioning of resources are similar, as a fog node needs to provide its resources to respond to IoT queries. Several consistent infrastructure assumptions apply to schemes involving the provisioning and allocation of resources: First, there is a presence of a fog infrastructure that is predefined. Then any IoT device can access fog nodes, and latency and static network congestion can be experienced by any two IoT devices or fog nodes. Finally, the feedback and the data which has been uploaded should be consistent

The allocation methods [59], [69] expects that each and every IoT consists of a single job. However, it was suggested by Agarwal et al. [70] that each request should be handled by a particular fog node, which can be split into many tasks if there are limited resources. A single fog node is adequate in both scenarios to process all data from IoT devices. Yousefpour et al.[48] took a step further by assembling IoT devices that perform that service and mapping them to fog node modules instead of IoT requests.

Because an IoT application's computation is performed entirely on a single fog server, more latency and an enormous processing queue can result from many requests. Each Internet of Things (IoT) request, according to Taneja and Davy [71], is made up of a number of complex tasks that are excessively taxing to be performed by a single fog node, and these tasks come from multiple sensors and actuators. As a result, the various functions of an IoT application are shared among one or more fog nodes. A single IoT request's multiple tasks are frequently represented

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as a directed acyclic graph, where each directed connection represents a task reliance[71], [72]. As a result, fog task processing may necessitate the usage of workflow order of the same task. Allocating application tasks to various fog nodes using algorithms[47], [71], [72] policies [73], [74], [75], or optimization models is a similar approach.

In our examination of the existing research in this field, it was noticed that the recommended models had fallen into one of three groups depending on precise or optimum service towards an IoT application. Based on realistic IoT traffic projections, the fog layer may reserve resources for future IoT usage. When an IoT appeal is received, it is presumed that the resources are available, the processing begins immediately. This strategy is used in schemes such as prompt allocation and prior provisioning.

Because IoT traffic forecasting necessitates additional computational work and it can be inaccurate, primarily plans would allocate resources only after requests for IoT have arrived. When using on-demand provisioning, there are generally two ways for resource allocation: There are two types of allocation: prompt allotment and small-batch allotment. When an allotment for IoT is quickly serviced, for processing it gets routed to the closest fog, irrespective of its cost such models are referred to as prompt allocation schemes and on-demand provisioning, and are perfect for supporting IoT which is dynamic. A fog resource manager might also gather a limited number of IoT requests and determine the optimum distribution of IoT work based on some measure such as resource cost and latency.

Whenever there is a module available for an IoT request, it immediately serves all subsequent requests from the equivalent IoT application, and the small-batch allocation ensures that for the provisioned module's lifespan, the IoT processing is efficient. Some schemes which use this approach are small-batch allotment schemes and On-demand provisioning but they are slower than prompt allocation methods in execution even though it gives support to IoT for a long time. In conclusion , small-batch allocation schemes are better for IoT applications that are static.

*1) Provisioning and Prompt Allocation :*IoT device usage data can be analyzed to predict when a new service request will be deserted, as proposed by Aazam and Huh [77], [78]. Devices that are likely to continue using fog for an extended period of time are given discounted prices and more resources. This allows for efficient resource allocation and immediate processing of new requests. It is assumed that new devices have a low probability of relinquishing resources and real-time calculations are used to determine pricing and resource allocation.

*2) On-Demand Provisioning and Prompt Allocation :*The algorithm proposed by Agarwal et al. [70] does not use any data from IoT or fog, whether old or recent; the plan for providing resources starts with the IoT application which sends a request to a fog node which is generally the closest one otherwise it can be one which is within its communication range. If the node has sufficient resources, then its request will be processed; otherwise, it will be divided into smaller tasks and processed with limited fog resources. In this worst-case scenario, High latency and poor IoT quality of service(QoS) could be caused by cloud propagation. Reducing latency by allowing the initial fog node to move, knowing how many additional fog nodes have sufficient resources [79], could be achieved through intermittent sharing of fog resources among fog nodes. Bittencourt et al.[80] expanded on this concept by proposing three different processing guidelines for fog. The order of processing for IoT applications may differ, but the first fog node that an IoT application connects to is always assigned to it. Cloud propagation is used If there are no resources at the fog node. Considering that in a node the applications are handled in parallel without regard to the resources that are currently available, the concurrent strategy could result in high processing latency. Fog processing is performed on IoT data in spite of the resources that are currently available. The first-come-first-serve (FCFS) strategy handles Internet of Things (IoT) requests in the order in which the fog node receives them. The delay-priority strategy starts with the IoT application as new requests comein, it reorders the next IoT application to process with the lowest QoS latency required. The delay-priority techniques and FCFS result in the least latency, whereas the least amount of data is transported to the cloud in the concurrent strategy, according to simulations. In vehicular fog circumstances where mobile cars demand compute from slow-moving or static vehicles, a multi-attribute double auction approach was developed by Peng et al[81], so that the base stations can link and match their vehicular IoT users to their vehicular fog nodes.The method, which is fulfilled by announcements by the IoT of its latency and resource needs as well as its bidding price, allows the fog nodes of a vehicle to declare the asking price, reputation and characteristics of its resource.Within 8ms, the one-to-one assignment approach matches resources for up to 100 vehicular IoT devices and fog nodes. Thus, the scalable matching process does not contribute much to the allocated vehicular fog node's near-instant processing. Likewise, even Zhou et al. [67] presented a framework that is contract-based, to shift Internet of Things queries to adjacent intelligent automobiles. In exchange for a reward based on the time and number of resources, a contract is generated and supplied to a vehicle; IoT customers needing fog computing are coupled with vehicles by using a pricing-based stable matching mechanism. For dealing with massive volumes of IoV data, fog computing architecture which is cooperative, was presented by Zhang et al. [44].It allows data transmission across fog nodes in mobile smart automobiles. Consequently, two distinct resource allocation strategies are investigated depending on the resource's proximity to the fog server. In this approach, a set number of virtual machines (VMs) on each fog node divide the fog resources for IoT use. An incoming IoT application will be assigned to VMs that use convex optimization to minimize fog energy consumption if sufficient VMs are present in a fog server to handle it. If data migration is required to reduce the possibility of transfer rejection, the decision to transmit fog node data is made using a min-max optimization model . For data transfer delay amongst fog nodes, fog computing offers IoT applications lower latency and more privacy as an alternative to cloud processing. Fog infrastructure implementations are becoming increasingly important as IoT applications increase in number. We identified four phases for setting up a fog infrastructure and discussing their restrictions and pending problems. First, the latest dimensioning and design models were compared, which produce a fog infrastructure blueprint for IoT application support. We categorized resource provisioning and allocation strategies according to how well they

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supported both static and dynamic IoT applications. Then, we found each scheme's optimal modeling strategies and objectives, then we looked at the fog framework's overhead and the primary contributions. At last, the restrictions of the emulation and simulation tools to evaluate the designed fog infrastructure were recognized and examined.

VII. OPEN ISSUES AND RESEARCH OPPORTUNITIES

A. Fog Design and Dimensioning

Here [55] [82], assume a reliable fog infrastructure that is based on data traffic provided by IoT devices that are static. There can be spikes in incoming IoT traffic as these devices are dynamic with respect to request frequency and location. Similarly, if fog node failures occur, there will be an increase in IoT traffic entering fog nodes that are operational. The stochastic fog and edge node failures can assist in comprehending the fog's influence on latency when the changing network congestion models are updated. A design and dimensioning solution for fog might be sensitive to fog's network traffic, depending on its modeling characteristics, such as the amount and placement of the candidate resource. As a result, when there are failures in fog nodes and volatile IoT traffic up to a certain level of confidence, the solution needs to give IoT adequate QoS conditions. Wherever there is a failure in a node, its IoT requests should be reallocated. In fog infrastructure, fault tolerance can be improved by including repository nodes in its design to back up the data of the fog node. [82] assumes that by adding more fog nodes, there can be a static rise in IoT requests; however, if the geographical area of the fog infrastructure is increased due to the addition of fog nodes, the devices that were inaccessible before might be accessible now. In the extended fog infrastructure, the total IoT traffic might be higher than expected. The traffic patterns of IoT may change over time, and it might decrease in some areas while increasing in others.

B. Fog Resource Provisioning and IoT Resource Allocation

Across several situations, fog resources are considered to be previously known to IoT devices [46], [44], [48], [71], [83], [84], and are frequently given by a FOC which has connections to all fog nodes [59], [85]. Some techniques require that a fog server within IoT range fulfills latency requirements [82], [98], and the present fog infrastructure adheres to architectural attributes [77], [44] which are specific. The conventional practice with rapid allocation methods is to upload IoT data to the fog server that is closest, and it is not affected by the availability of fog resources and their price. This information is believed to be unknown before the IoT-fog connection. In a multi-price fog environment, this might lead to suboptimal processing costs. If the nearby server is overloaded, response latency's rise might depend on whether the request of IoT is queued for processing [75], distributed to different fog nodes [44], or transferred to the cloud [70], [75]. An incoming IoT request is assigned by the node to the resource it has been allotted which reduces latency; nevertheless, this assumes that resources which are reserved are sufficient for it to be used by IoT all the time. Redistribution can be decreased with a complete awareness of the systems fog resources [44], [48], although it may result in increased software and/or hardware overhead.

VIII.CURRENT SCENARIOS AND RESOURCE MANAGEMENT IN FOG COMPUTING RESOURCE OPTIMIZATION

It is recognized that a significant quantity of information is produced by smart devices such as Actuators, Sensors, and Wi-Fi routers, making it challenging to handle and process in real-time using a centralized cloud platform. To overcome these challenges, Cisco has suggested using fog computing as a replacement for traditional cloud computing. This new technology is believed to elevate the computing experience by providing an expansion of centralized cloud computing. The limitations of cloud computing are acknowledged in this article, and a detailed analysis of Fog computing is provided, with its benefits, use cases in various industries, key characteristics, challenges and optimization techniques being highlighted. Furthermore, it has been highlighted that fog computing results in a more effective utilization of energy resources, cost reductions, and energy consumption.

1) Obstacles Associated With Fog Computing : Fog computing is an advancement of cloud computing with significant benefits, but it also has its own set of obstacles to overcome in terms of adoption, implementation, security, and privacy. Because it is decentralized, each end-user participating in the IoT environment can create various problems for fog computing, such as service availability in public cloud-fog storage. The energy consumption and battery life of end-user devices are major concerns for smooth streaming and operation. Inactivity of edge devices can lead to fog becoming inaccessible in some cases. Although fog computing is considered a secure platform, it is not immune to security concerns. A review of various studies in the field of fog computing shows that many authors have identified limitations, problems, and challenges with fog computing as follows. [87, 88, 89, 90]

*2) Privacy Issues :*Privacy has become a difficult task to manage in the Cloud of Things. Closer to end users, micro-data servers or cloudlets are continuously collecting and generating sensitive data. Thus, protecting user privacy at the edge network became a top priority. To improve the trustworthiness of communication in the fog domain, it is also vital to mask the locations of different fog nodes.

3) Access Control: Attempting to access the various tagged entities in an Internet of Things environment is an arduous task to manage. However, as edge devices become continuously connected and access computing resources, it becomes an essential component of fog computation. Putting the secured accessing protocols into practice ensures a valid authentication and performs the necessary checks to determine which connected component in the fog computing platform is active.

4) Authentication: Numerous smart gateways provide services at the front node in an IoT environment. However, fog platforms frequently fall victim to man-in-the-middle attacks without a proper authentication mechanism. By incorporating various encryption and decryption techniques in different face recognition, biometric, image processing, and fingerprint authentication methods, the issue can be effectively eliminated.

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5) Data Protection: The number of nodes increases immediately with IoT-based computing in fog. Maintaining the data created by communicating nodes to protect the end-user data is crucial. The integrity of data in fog computing is constantly at risk due to the challenge of monitoring the vast amount of data being generated. To protect and secure the data from malicious interference by unauthorized individuals, the use of masking and decoy techniques is essent.

6) Malicious Activities: Fog computing is a distributed and decentralized paradigm which results in lower latency, improved communication, and increased difficulty in detecting malicious nodes. However, malicious activities can still have an impact on service quality, service interruption (DoS), and man-in-the-middle attacks. To mitigate these risks, an Intrusion Detection System (IDS) is necessary to detect and address these issues in fog systems, providing timely notifications and updates about any potential dangerous activities.

The authors of this study have examined the Fog computing paradigm, its characteristics and its various applications. They conducted an extensive analysis of the various security risks associated with both decentralized and centralized computing paradigms. In the future, Fog computing's computational capabilities and data storage could be used to handle data-intensive applications and services .It necessitates less power for transmission and storage of analytical data over a longer period, and has been effectively executed in domains such as urban areas, healthcare and geospatial information systems. Prospective studies will center on enhancing the utilization, administration, and expense of resources for enhanced data storage proficiency and safety features. The utilization of fog computing is becoming more widespread in systems such as intelligent traffic lights, connected vehicles, the Smart Grid, the Internet of Things, cyber-physical systems, wireless sensor and actuator networks, and software-defined networks (SDN). However, it must be combined with cloud computing to handle complex tasks and provide the best optimization and services for resource management.

IX. CLASSIFYING AND ASSESSING STRATEGIES FOR MANAGING RESOURCES IN CLOUD/FOG AND EDGE COMPUTING

It is recognized that utilizing the cloud to process IoT applications may not always be the optimal solution, particularly for applications that require time-criticality. Alternative options, such as Edge and fog computing, are considered to be viable options for handling the high data bandwidth demanded by end devices, due to the fact that it entails handling large quantities of data in close proximity to the data origin as compared to cloud. Effective resource management is crucial in cloud-based IoT environments, and is the key to optimize performance by allocating resources efficiently, balancing workloads, provisioning resources, scheduling tasks, and ensuring Quality of Service (QoS). Ignoring these challenges can lead to poor performance, inefficiency and lower ROI, thus resource management is an essential aspect that should not be overlooked. This study examines various strategies for managing resources in cloud, fog, and edge computing, with a focus on evaluating their efficacy.

This paper aims to establish a framework for evaluating metrics for edge and fog/cloud resource management methods by examining the research issues surrounding resource management. To assist in the development of an evaluation system, existing research contributions are classified. A thorough review and analysis of research publications on resource management approaches is presented as a key contribution. Additionally, the benefits of utilizing resource management approaches within the context of the cloud/fog/edge paradigm are highlighted. It is acknowledged that this field is still in its early stages and challenges must be overcome. In cloud/fog/edge systems, the task of allocating available resources to system users falls on resource allocation algorithms, which can pose difficulty in efficiently assigning resources to applications and their end users/consumers. [91]

*A. **Obstacles in Assigning Resources for Cloud,Fog, and Edge Computing***

It is acknowledged that fog, cloud, and edge architectures are faced with a variety of challenges, including 5G deployment, allocating resources, improving performance, serverless computing, managing energy consumption, managing data, adapting federal concepts to fog computing, establishing trust models, developing service and business models, increasing flexibility, and implementing industrial IoT [92]. In particular, the implementation of the concept of network shredding to support a service collection with specific performance requirements in 5G is recognized as a difficult task. Some of these challenges include global resource management, wireless, optical packets, fog nodes, and cloud domains [92]. Despite recent developments in network virtualization providing guidelines for network shredding, a general and unified collection of resources across multiple areas is yet to be established. These challenges, if not addressed properly, can hinder the full potential of fog, cloud and edge computing, and it is crucial to overcome them to fully leverage the benefits of these architectures.

*B. **Evaluation Framework for Resource Management Algorithm in Cloud/Fog and Edge Scenarios***

A summary of the resource management algorithms is provided in the table, and they are evaluated using multiple metrics, which will be further discussed. The aim of resource management is to achieve resource coordination, which is demonstrated by the management actions taken by service providers and consumers. It examines how resources are allocated from resource providers to consumers. The algorithms discussed in the following sections implement a variety of resource management metrics, which are also evaluated and can be used for further analysis.

1) Resource Allocation : Resource allocation is a technique employed to enhance resource utilization and minimize processing costs. The duration of a job is a crucial factor as it can influence the allocation of resources. Balancing workloads is essential in enhancing energy efficiency and avoiding low-load resource management, overload and congestion. Effective resource allocation is a critical challenge for the processing nodes placed in the fog

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environment. For example, a workload balancing algorithm for fog computing is proposed to decrease data flow latency during transmission procedures by connecting IoT devices to appropriate base stations (BSs). The workload balancing algorithms discussed in this article, such as SJF, RR, ERA, ESCE, PBSA, DRAM, GPRFCA FOFSA, Hill Climbing algorithm (HCLB), Tabu Search algorithm, and Efficient Load Balancing algorithm (ELBA min-min) are powerful tools that can help optimize resource utilization, improve performance and minimize costs.

2) Resource Provisioning : Resource provisioning is a powerful technique that involves managing requests for tasks and data among fog nodes. It is the crucial next step after resource allocation. As previously discussed, resource allocation is simply assigning a set of resources to a task, whereas resource provisioning is activating the allocated resources. The algorithms that deal with the provisioning of resources include Fog Sync Differential Algorithm (FSYNC), Remote Sync Differential Algorithm (RSYNC), ERA, Energy-aware Cloud Offloading (ECFO) and Reed-Solomon Fog Sync (RS-FSYNC).

3) Task Scheduling : Task scheduling methods have been suggested to construct a blueprint for executing tasks to avoid problems like deadlocks while managing a great deal of activities that interconnect and rely on a confined set of resources.

C. Discussions and Limitations

This paper presents a significant contribution by providing a comprehensive categorization and assessment of the algorithms used for resource management in fog/cloud and edge environments. To ensure a successful evaluation and analysis process, it is crucial to understand the concept of edge/fog/cloud architecture and the challenges that may arise. The challenges of allocating resources in an edge/fog/cloud network are acknowledged and addressed. Processing and storing data in the cloud can take longer when devices are located far from data centers. It is imperative to distribute the workload to fully utilize all devices within a fog computing infrastructure. By focusing on a single network area, it would mimic a conventional cloud computing architecture, which is not an optimal choice. The distributed task allocation not only reduces average service latency but also minimizes overall quality loss.

In our upcoming research, we intend to create an innovative forecasting model for user mobility and service dynamics that incorporates existing data. For instance, the following objectives can be achieved: observing the burden on services and their subparts (micro-services); observing consumer demand (AI) while taking into account their trajectories; forecasting paths for microservices migration (via edge network and D2D) and forecasting user paths and demand (AI) based on observation.

X. CONCLUSION

The objective of this research is to develop a comprehensive framework for evaluating and classifying different resource management techniques used in fog/cloud and edge scenarios. This understanding of the different resource management concerns will be extremely beneficial for cloud/fog/edge architects. By utilizing a paradigm that combines fog, edge, and cloud computing, it is possible to find solutions for time-sensitive IoT applications. Furthermore, fog nodes often have more data processing and storage capacity capabilities, which can be leveraged to enhance performance while minimizing communication costs and latency. By evaluating state-of-the-art algorithms used in various research publications, this work analyzes algorithms that can be divided into six groups, as well as examines how resources can be shared between fog, edge, and cloud devices. Future studies should focus on comparing and simulating these algorithms instead of simply providing an evaluative summary. Additionally, some of the techniques studied can be used to mimic a fog/cloud/edge architecture suitable for a particular application area (example, smart logistics). This research also recommends conducting case study research in various topics. Furthermore, future research may investigate new algorithms that address resource management and other issues in fog/cloud/edge computing environments. Additionally, more work can be done to validate and improve the assessment framework and categorization approach, such as through an extensive literature review.

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