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A Comprehensive Study of Caching Effects on Fog Computing Performance

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The rapid advancement in the Internet of things applications generates a considerable amount of data and requires additional computing power. These are serious challenges that directly impact the performance, latency, and network breakdown of cloud computing. Fog Computing can be depended on as an excellent solution to overcome some related problems in cloud computing. Fog computing supports cloud computing to become nearer to the Internet of Things. The fog's main task is to access the data generated by the IoT devices near the edge. The data storage and data processing are performed locally at the fog nodes instead of achieving that at cloud servers. Fog computing presents high-quality services and fast response time. Therefore, Fog computing can be the best solution for the Internet of things to present a practical and secure service for various clients. Fog computing enables sufficient management for the services and resources by keeping the devices closer to the network edge. In this paper, we review various computing paradigms, features of fog computing, an in-depth reference architecture of fog with its various levels, a

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detailed analysis of fog with different applications, various fog system algorithms, and also systematically examines the challenges in Fog Computing which act as a middle layer between IoT sensors or devices and data centers of the cloud.

Keywords: Caching; fog computing; performance measurement; edge computing; IoT; IoE.

1. INTRODUCTION

The 5G mobile network's primary goal is to offer people cloud computing access to all applications and services anytime and from any location [1,2]. By far, the most recent offspring of the physical separation of functional units is fog. It's a computational layer that delivers processing, networking, and storage services near the perception layer, which houses the sensors and actuator [3,4]. Latency-critical applications in mobile networks have recently received a lot of attention and have seen progress. Such applications often demand a lot of processing power or a large dataset to work. Fog technology is a new 5G network architecture aiming to provide ultra-low latency and ultra-high capacity [5,6].

The Edge device development and deployment is increasingly strongly tied to the large-scale multimedia and other services with high dataflow development and deployment transfer rates [7,8]. The idea of developing a revolutionary content-centric People's interest in a computer system in a fog computing environment has aroused [9,10]. Fog computing is a promising technology that can deeply exploit huge devices' idle communication, caching, computational, and regulatory assets and reduce cloud computing's burden on link congestion, latency, and power consumption. It is a network edge extension of cloud computing services in the future Internet of Everything (IoE) paradigm [11,12].

Fog computing is a network design that creates a virtualized network at the network's edge to enable caching and processing using a large number of low-cost, often dispersed fog nodes [13,14]. Fog computing, also known as mobile edge computing (MEC), provides processing and storage capabilities to edge access points (APs), allowing low-power wireless devices to locate APs with integrated edge servers for task offloading and real-time energy-saving calculation [15,16]. Many initiatives were planned to deal with cloud RAN to meet the rising demand for quality of service (QoS) in the IoT context. Fog increases radio bandwidth and delays from start to finish [17,18]. A possible addition to the mix was considered as computing [19,20]. Applications and services closer to the edge could be hosted in the cloud [21,22]. The Internet of Things (IoT) is a system in which we are surrounded by billions of intelligent objects that affect numerous aspects of our lives [23]. Using the fog computing paradigm, data processing for a resource-hungry mobile application can be transferred from resource-constrained terminal devices to a powerful mobile cloud-assisted platform [24,25].

This study seeks to introduce FOG, a developed technology that can assist us in coping in Today's environment, which is increasingly digital [26].

The rest of the paper is structured as follows: section 2 is the Theoretical Background, including Fog Computing Compositions. Section 3 summarizes the previous works as a piece of literature review—section 4 is related to analyzing, discussing, and comparing the previous works of the related works. Finally, the conclusion about the article is provided in Section 5.

2. THEORETICAL BACKGROUND

In this section, the related theory of the addressed subject will be presented. The Caching Effects on Fog Computing Performance will be explained in terms of latency, efficiency, generality, Choice of Virtualization Technology, Fighting with Latency, Network Management, and Security and Privacy [27]. This will also deal with the Fog Computing Compositions, including Authentication and Authorization, Offloading Management, Location Services, Physical Network, System Monitor, Resource Management, and VM Scheduling [28].

Fog computing is a complicated extension of cloud computing that spans the core and edge networks [29,30]. It offers a complete definition of fog computing, based on the issues and technologies that define the fog, focusing on a few essential characteristics such as geographical dispersion, heterogeneity, and interoperability [31]. The preponderance of wireless connectivity and sandboxed many nodes and a flexible interoperability environment [32,33].

On the other hand, current definitions of cloud computing are all based on different perspectives and so are not universal [34,35]. For example, just because mobility is essential in edge computing doesn't mean it has to be mobile [36,37]. The term "fog computing" should be used for a broader set of always-on devices [38,39]. Although the description offers a complete picture of fog computing, it ignores the cloud's unique role [40,41]. A universal description that incorporates all of these linked concepts is required [42,43]. The following is how we define it: Pool comprises of one or more ubiquitously connected heterogeneous devices (including edge devices) at the network's edge, not exclusively smoothly powered by cloud services, fog computing is a resource-constrained, geographically distributed computing system to deliver elastic compute, storage, and communication (along with a slew of other new services and jobs) to a considerable number of clients in remote locations [44]. Creating Objectives, A good fog computing platform should have various design goals.

- Latency: Fog computing platforms must ensure that end users have access to apps and services with minimal latency is affected by the execution time of a task, the offloading time of a task, the time for cyber foraging, and the pace with which judgments are made [45,46].
- Efficiency: While efficiency may appear to affect latency at first glance, it is more directly linked to resource and energy usage [47]. The reasons are self-evident, and they differ from cloud computing scenarios [45,48].
- Generality: Due to many fog nodes and clients, fog clients want the same abstract top layer apps and services. General application programming interfaces (APIs) should be provided to deal with current protocols and APIs (e.g., Machine-2-machine protocols, intelligent vehicle/smart appliance APIs, etc.). Fog Computing's Challenges It's not straightforward to design fog computing platforms that meet the following goals. We were able to detect several potential roadblocks ahead of us at the very least [32,49].
- Choice of Virtualization Technology: In fog computing, virtualization is the most common way to create isolated environments and the essential component affecting fog node performance [50]. So, a natural question here is, "should we use a container or a hypervisor?" Cloudlet, as we know, employs hypervisor virtualization techniques, but Paradrop employs a more lightweight solution: Virtualization at the OS level, i.e., containers [51,52]. Because their hardware has varied capabilities, they make different design decisions. One downside of container-based virtualization is the lack of flexibility. On a single infrastructure node, it cannot, for example, host various types of guest operating systems. As a result, hypervisor virtualization solutions are preferred over container-based virtualization solutions [53,54].
- Fight with Latency: Many reasons contribute to excessive application or service performance delay on fog computing devices [55]. There are various approaches to reduce latency in fog computing because it is designed for delay-sensitive applications and services [56]. Because the fog computing paradigm is geo-distributed, there will be delays if data collection is not completed before data processing [57]. There are, however, a variety of solutions to this problem, including data partitioning/filtering and using hierarchy locality to lower the size of the data set. Provisioning resources for certain operations will take longer, especially for fog nodes with limited resources [58,59]. It's possible that a well-planned schedule, based on priority and mobility models, will be required [60,61].
- Network Management: If we don't take advantage of SDN and NFV approaches, network administration will be a barrier to fog computing [62]. Integration of SDN and NFV with fog computing, on the other hand, is complex and will surely be a significant issue [63]. The challenges stem primarily from the need to re-design the south-bound, north-bound, and east-west-bound APIs to include fog computing primitives [64]. The design goals for latency and efficiency may not be met with an essential integration [24,64].
- Security and Privacy: At every level of the fog computing platform design, security and privacy should be considered [65]. It's

one of the most challenging problems that fog computing has to deal with [66]. To deal with this, we'll need to design an access control and intrusion detection system, which will require help from all layers of the platform [9,67].

2.1 Fog Computing Compositions

The following components should be included in a fog computing platform:

- Authentication and Authorization: Authentication and permission are essential for fog computing services and resources [68]. In a similar article, an access control mechanism for the authorization of heterogeneous resources was developed. Because fog computing is close to end-users and can identify them using access patterns, mobility patterns, and trusted secure devices, it provides novel authentication and authorization approaches [45].
- Offloading Management: Offloading is a crucial component that affects all design objectives. As examined in, there is a lot of existing study on this topic. In fog computing, offloading must deal with a variety of issues [69]. Establishing what types of data are required in offloading decisions, splitting applications for offloading, and devising the optimum offloading technique are among the challenges[70].
- Location Services: Mobile end users must be tracked, a list of nearby nodes (both mobile and non-mobile) must be kept, and location information must be shared among fog nodes. It links network locations to physical locations and, if possible, adopts or learns mobility models specified by end-users [71]. Communal Cloud Infrastructure Platform Services are a type of service that allows you to track and track the network management system and keep track of VM scheduling. Load Balancer Authentication Authorization Location Service Readings from sensors (GPS, Acc, Gyro, Video, Audio) for controlling message offloading Management API Service Management [72].
- Physical (ultrasound, wireless signal, and signature, GPS, IMU sensor) network (IP address), and application (social activities) information are required for mapping on mobile nodes, demanding a novel component design[73].

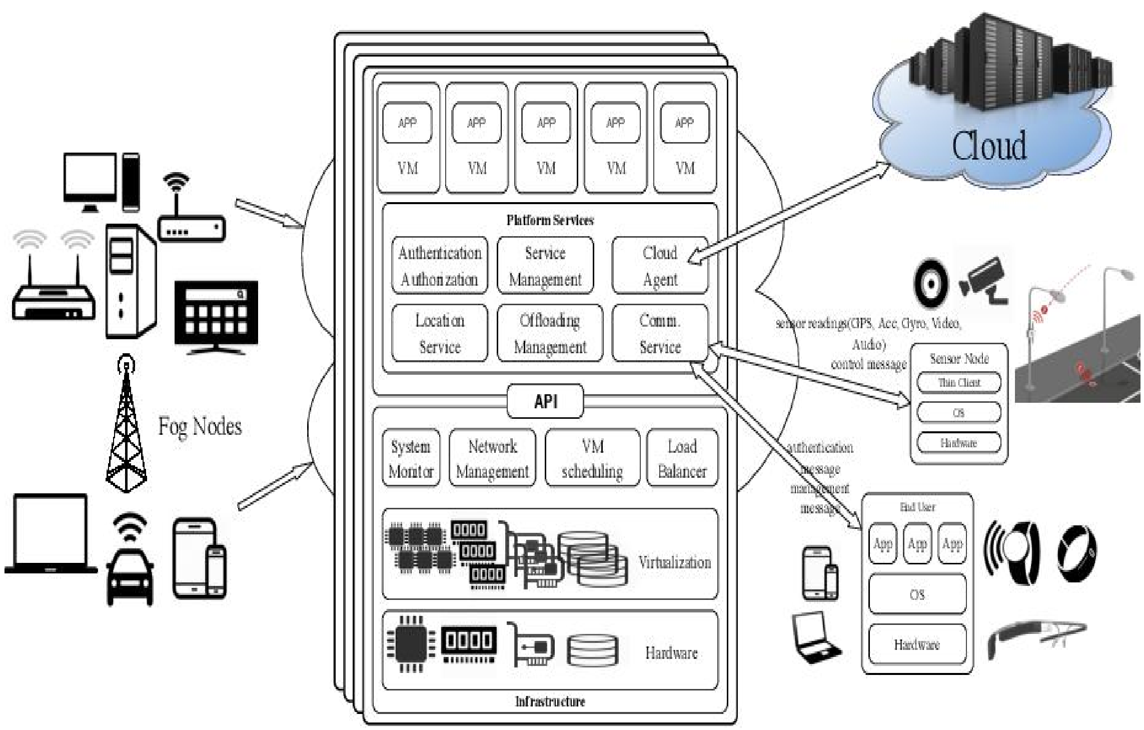

Fig. 1. Components for fog computing platform [72]

- System Monitor: System monitors are an essential part of cloud infrastructures because they may provide helpful information like workload, usage, and energy consumption, which can help with decision-making and pricing [74]. This component is featured in fog computing systems because it provides crucial information for other components [75-77].
- Resource Management: The majority of duties related to resource discovery, resource allocation, dynamic joining and leaving of fog nodes, and delivering and administering the resource pool in a distributed manner will be handled by resource management [78,79].
- VM Scheduling: Because of the combined input of system usage, job load data, location information, and mobility model, the VM scheduling needs to be wholly overhauled [80]. To provide an effective solution for scheduling virtual machines, new scheduling algorithms are necessary [81].

3. LITERATURE REVIEW

In this section, the closest previous works will be addressed and analyzed to review the Caching Effects on Fog Computing Performance comprehensively. There are 29 previous works been selected to be studied and analyzed that will help the researchers working in this field have a broad scope of the subject.

B.Assila et al. [11] investigated how to use Fog Computing's characteristics and caching capabilities to increase 5G IoT (Internet of Things) device transmission latency and performance. The paper proposes a many-to-one matching game between the sets of devices and the set of devices to tackle the ever-increasing number of IoT devices and the limited computational resources in fog computing. To manage the ever-increasing number of IoT devices and fog computing's limited CPU resources for device allocation, according to simulation results in the research, when combined with caching capabilities on distributed fog computing, the suggested matching approach outperforms traditional caching methods in terms of the cache hit ratio, average latency, and backhaul traffic load.

B.Assila et al. [32] The need for a disruptive, high-efficiency, scalable, and flexible communication network that can handle growing demands and the number of connected devices, as well as application requirements The "Special Issue on Emerging Trends and Challenges in Fog Computing for the Internet of Things" seeks to learn three things: 1) new administration mechanisms for fog computing-enabled device-to-device and M2M connection, allowing for more straightforward extensive data analysis on the Internet 2) new fog and cloud administration methods for edge devices, such as new APIs and web services, to improve IoT and cloud connectivity . 3) novel microservices-based strategies for handling big data in IoT and fog environments, encompassing all scenarios (confidentiality/privacy, integrity, authenticity, etc....) for ensuring IoT security.

F.Shen et al. [82], Based on the Stackelberg game, provided a unique incentive structure to encourage FNs to regularly send their resource sensing data to the FC. It is shown that the global optimum of both FC and FN utilities exists. Closed-form solutions are used to find the FNs' optimal sensing frequencies. The article presents various simulations, supporting the theoretical research and underlining the importance of the suggested resource sensing incentive framework in the fog computing network.

Z.Ennya et al. [60], Edge computing and offloading issues in fog computing networks were investigated. The computing capabilities of edge devices have permanently been restricted. The study investigates the issues of spreading computational jobs across fogs in the context of a given number of fogs servicing various consumers. The proposed system is built on a coalition game that encourages fogs to collaborate and work together, allowing them to quickly analyze large volumes of data. The paper's simulation findings show that the suggested approach provides better latency and load balancing of fogs resources.

X.Cui et al. [15], in fog radio access networks, researchers looked into the cooperative caching problem (F-RAN). An effective graph-based technique is proposed to maximize incremental offloaded traffic. Compared to the brute force strategy, which has exponential complexity, the graph-based strategy suggested in the research appears to have low complexity. After performing simulations and analyzing the findings, the research concludes that utilizing the technique provided in the research and the findings indicate significant gains in terms of offloading gain.

R.Wang et al. [83], in fog radio access networks, caching has been presented as a possible option for reducing backhaul traffic congestion and enhancing performance. This research investigates a proactive probabilistic approach in a wireless fog radio access network where several users request varied files from several base stations. Improvement of caching (BSs). When SNR = 10dB, user density u = 0.09, base station density b = 0.1, and file number N = 100, test results demonstrate that the suggested methodology improves caching location by approximately 18% over the best existing caching distribution.

Luiz Angelo Steffenel [84] P2P-based platforms are solid candidates for hosting Fog computing. Still, the difficulty is that they frequently lack essential components like control over where the data is stored and who is in charge of processing the computing duties. As a result, determining where data is stored is as critical as determining who will handle it. The research presents various strategies for enhancing data locality in P2P-based middleware and investigates how these strategies might be implemented. The results of the trials show that data proximity has an impact on data access performance.

Y.Niu et al. [85] centered on the difficulty of mobility-aware transmission scheduling for caching at edge nodes near hotspots and how to increase performance via multihop relaying and concurrent transmissions. The best scheduling problem is thus expressed as a stochastic nonlinear mixed-integer program, and It is advised that a cache scheduling strategy that is mobile-aware be employed. Extensive performance testing demonstrates that MHRC produces a more than 1x larger anticipated cached data capacity than state-of-the-art approaches.

J.Li et al. [86] Because of the limited caching space, it is thought that on-demand cache design is a critical issue for optimizing redundant cache, reducing time delays, and lowering traffic overhead. To address the issue mentioned above, the study introduces Fog Cache, an on-demand fog caching solution for ICN that is implemented by analyzing synthetical content popularity, traffic and time costs, and node impact. Fog Cache produces a coherent multi-dimensional synthesis of awareness by dividing the target layer, the criteria layer, the indicator layer, and the observation layer into four layers. Simulation results reveal that the proposed Fog Cache outperforms related techniques in terms of caching performance.

I.Althamary et al. [87] In fog networks, cache placement is a crucial issue. It is critical to evaluate network connection quality, content demand, and user behaviors simultaneously. The study suggests that files be placed within a fog node cluster based on popular categories for more efficient cache placement. Requested files are divided into three categories of popularity and carefully cached at fog nodes with varying activity levels. The algorithm's performance was confirmed through simulations on energy efficiency.

Yi-Hsuan Hung and Chih-Yu Wang [88] Fog Micro Service Market Game (FMG) is a game-theoretic framework that uses free-market processes to promote fog computing in fog-enabled cellular systems on mobile devices. Customers that rent microservices (renting technique) have complete control over the services they rent and the price they pay for them (pricing approach). The results of the tests indicate that the proposed method can significantly improve overall system usefulness.

X.He et al. [89] In a fog computing environment, data flow and new user expectations are increasing, as is the promise of content-centric computing systems. As a result, achieving QoE satisfaction becomes a considerable task. In this research, QoE models are proposed to evaluate the fog computing service quality environment, both for the system and the users, to improve QoE satisfaction. The simulation results show that employing the dynamic allocation (DA) strategy to allocate resources can better QoE performance.

Y.Jiang et al. [9]The topic of edge caching was investigated in a fog radio access network (F-RAN). The study suggested an algorithm for predicting online content popularity based on user preferences and content qualities, as well as an offline user preference learning algorithm based on the online The (proximally) regularized leader (FTRL-Proximal) methodology and the algorithm gradient descent (OGD) method The simulation results show that the proposed policy's overall cache hit rate is higher than standard policies and approaches optimum performance asymptotically.

V.Veillon et al. [90] Dedicated to providing a consistent streaming experience with low latency and no interruptions. The paper proposes a Fog

Delivery Network (FDN) architecture and federation methods (named F-FDN) to reduce video streaming latency. Experiments comparing FDNs to other streaming technologies demonstrate that on-demand processing and the use of cached video sections on neighboring FDNs can significantly reduce streaming latency (on average 52%).

J. Wu et al. [13] Users must be able to configure and control computational and storage resources on-demand and based on their understanding of the material. This paper offers a fog-computing-enabled cognitive network functions virtualization method for an information-centric future Internet to overcome these difficulties. The results of the tests suggest that the proposed method is beneficial and efficient.

J.Ahmed Khan et al. [91] Today's mobile network infrastructure is straining to keep up with the increased demand for content from an increasing number of smart devices in terms of bandwidth and cost. The following are the main obstacles: 1. Who and how can fogs be produced for local content caching? 2. How might be interacting with the fog aid in the caching and retrieval of content? IS-Fog, a socially conscious fog network where content is treated as a first-class citizen, is built to address these concerns via information-centric networking. The ability of a gadget to distribute material in novel content-based ways is critical first and foremost. Users are encouraged to self-organize and share the resources and cache of their devices in the fog. According to simulations, IS-Fog is the most scalable and efficient content caching and delivery technology compared to existing systems.

H. Ali Khattak et al. [92] Emerging vehicle ad hoc network (VANET) Significantly more communication and computing power will be required by apps. This article includes a scenario for an infotainment app as well as the design of a VANET based on fog computing. In the studies, the cache size of fog nodes was used as a parameter to observe how it affected various performance indicators in a fog-enabled VANET. The paper concludes with a discussion of the numerous advantages of a fog-enabled VANET, as well as a look at future obstacles and possible solutions.

SH. Yan et al. [93] For automotive networks, the rapid proliferation of data, combined with the necessity for high reliability and low latency, has created considerable challenges. This study looks into the topic of access mode selection and spectrum allocation in fog computing-based car networks. The original high-complexity optimization problem is divided into two more minor problems to make it easier to tackle. The analytical findings of the recommended algorithm and the usual baseline approaches are compared using different weight factors, validating the researchers' theoretical analysis and demonstrating that the recommended methodology can achieve significant performance gains.

Y.Wei et al. [94] The performance of the fog-enabled system Because the Internet of Things relies on the intelligent and efficient management of numerous network resources, caching, processing, and communications synergy becomes a key challenge. computation offloading policy, content caching approach. This paper discusses radio resource allocation and presents a fog-enabled IoT joint optimization approach. Numerical simulations are used in the study to demonstrate the proposed algorithm's learning capabilities and to investigate the end-to-end service latency.

Tian Dang and Mugen Peng [1] Ultra-high transmission rates and ultra-low latency delivery are required for the ever-evolving virtual reality (VR) experience, which is difficult to achieve with Today's cellular networks. The paper provides an F-RAN-based mobile VR delivery architecture, with the core idea of caching parts of VR films in advance and performing processing at the F-RANs' edge. In both mobile VR devices and F-APs, the tradeoff between communications, caching, and computation is shown. The numerical findings show that local caching and processing capabilities significantly impact the average tolerable delay. The paper's proposed mobile VR distribution infrastructure promises to increase spectral efficiency while maintaining high-quality requirements by maximizing average acceptable latency.

Z.LI et al. [1,3,5] Due to advantages in both communication and computing, the fog radio access network (F-RAN) is a potential architecture for future networks that can effectively boost network performance. In a device-to-device (D2D) enabled F-RAN, the data caching mechanism is examined from a social aspect. In the end, the simulation proves the usefulness of the planned method.

Y.LAN et al. [73] This study looks at resource allocation in a D2D-assisted Fog computing system with a large number of mobile user equipment's (MUEs). Each MUE is considered to have received a task request from a task library and must select one of three processing modes to perform the task: manner on a local level, Fog offloading mode, and cloud offloading mode are also available. The study looks at two scenarios: task caching and offloading during off-peak hours and task caching and offloading during peak hours. The simulation results show that the proposed system is effective when compared to various baseline systems.

Wesam A. Almobaideen and Ola M. Malkawi [51]. ABC FOX is a new caching method presented in this paper (Application Based Caching for Fog Computing). "Caching for fog computing" is abbreviated as ABCFOG. The type of application is the essential caching prediction criterion in the methods provided here. ABC FOX has been put to the test in three different settings. The three assessment parameters that are measured are hit ratio, reaction time, and bandwidth. According to the findings, ABCFOG has improved caching by at least 30% in response time and hit ratio. However, this improvement comes at the cost of additional bandwidth.

Q.Li et al. [53] This research investigates fog computing network edge caching and provides a capacity-aware edge caching solution that takes into account both fog cache capacity and base station connectivity capacity (BSs) . According to the results of the testing, to effectively profit from edge caching, the allocation of fog cache capacity and BS connectivity capacity must be balanced. When the BS connectivity capacity is sufficient, maximizing the edge-cache-hit-ratio (ECHR) by utilizing all available fog cache capacity is excellent, but the BS connectivity capacity is low. Retaining a lower ECHR and allocating more traffic to the cloud is superior.

N.JASIM et al. [24] This research provides a freestanding heterogeneous fog architecture comprised of high-capacity and low-capacity fog nodes near the terminal. As a result, without having to relay to cloud nodes, a substrate network with low latency and enormous resources can be established. Predicting the following incoming function and prefetching it on the node is the goal. The deep learning network produces a loss model with a low failure rate and a high success rate.

K.Liu et al. [95] This research is the first to propose a fog computing-enabled architecture with a specialized data dissemination scheduling mechanism for software-defined heterogeneous vehicular ad-hoc networks (VANETs). The proposed algorithm's practicality is demonstrated by the complexity analysis. Finally, the simulation model is created, and the researchers provide a detailed performance evaluation based on accurate vehicular trajectories retrieved at various times and locations. According to the simulation findings, the offered option is the best.

C.Mavromoustakis et al. [96] The wide range of IoT services accessible, as well as the need for a disruptive, highly efficient, scalable, and flexible communication network that can handle increased demand and the expanding number of connected devices, as well as application needs, are discussed in this article. The "Special Issue on Emerging Trends and Challenges in Fog Computing for IoT" has three objectives: 1) new management techniques for fog computing-enabled device-to-device and M2M connections, enabling for significant data analysis on the Internet 2) new administration methods for edge devices in the fog and cloud paradigms, such as new APIs and web services, to increase IoT and cloud connectivity 3) novel ways for processing large amounts of data in IoT and fog environments using microservices, embracing all aspects of IoT security (confidentiality/privacy, integrity, authenticity, and so on).

L.Hu et al. [5] This study recommends using intelligent traffic prediction and cognitive caching in IF-RANs. First, an attention mechanism is added to an LSTM-based traffic flow prediction system. The program can accurately forecast real-time data traffic in a variety of formats. Then, as a caching policy, cognitive caching based on LSTM and collaborative filtering is advocated to lower the total communication delay. The experiment's findings suggest that the proposed IF-RANs effectively improve real-time prediction accuracy while also reducing communication latency.

J. Chen et al. [78] In this study, fog computing, also known as mobile edge computing (MEC), is offered as a potential method for cutting wireless network expenses. The study analyzes a multi-user caching-enabled MEC system under the concept of reusable caching, and Users can get the results they need right away without having to wait for compute offloading since their task requests are proactively saved and handled at the edge server. Task caching's excellent speed has also been aided by experiments verifying the impact of poor caching options.

Table 1. Summary of the reviewed researches

Reference	Year	Tools	Objectives	Significant Results
B.Assila et al. [11]	2018	Matching Game (Many-to-One)	To boost low-latency and throughput transmission for 5G IoT devices, Fog Computing characteristics and caching capabilities are being used.	Simulation results show that the recommended matching methodology paired with caching capabilities on distributed fog computing outperforms typical caching strategies in the cache hit ratio, average latency, and backhaul traffic load.
B.Assila et al. [32]	2018	Matching Game	Propose a green approach for improving the efficiency and performance of fog computing environments and IoE devices.	In terms of a cache hit ratio, energy consumption, and backhaul traffic load, the results of this research show that combining a matching approach with distributed Fog computing caching capabilities beats traditional caching solutions.
F.Shen et al. [75]	2018	Incentive Framework based on Stackelberg game	Minimize the cost of sensing at Fog Controllers (FN).	The article presents various simulations, supporting the theoretical research and underlining the importance of the suggested resource sensing incentive framework in the fog computing network.
Z.Ennya et al. [60]	2018	Coalition Game Model	Motivate fogs to collaborate and work together, allowing them to handle large volumes of data quickly.	The suggested approach provides better latency and load balancing of the fogs resources, according to simulation results.
X.Cui et al. [15]	2018	Graph-based Cooperative Caching	Researchers investigate the cooperative caching problem in fog radio access networks to maximize incremental offloaded traffic (F-RAN).	The results demonstrate that utilizing the methodology presented in the research improves offloading gain significantly.
Luiz Angelo Steffenel [84]	2018	Data Locality	For P2P-based middleware, reinforce data locality and investigate how those strategies may be implemented.	The results of the trials show that data proximity has an impact on data access performance.
Y.Niu et al. [85]	2018	MHRC (Ministry of Health and Human Services Research (Multi-Hop Relaying based Caching)	To improve performance, multihop relaying and concurrent broadcasts are used.	Compared to state-of-the-art techniques, extensive testing shows that MHRC achieves a more than 1x greater predicted cached data volume.
J.Li et al. [86]	2018	FogCache	To optimize redundant cache, decrease traffic overhead, and	The suggested FogCache achieves superior caching performance than related techniques, according to the

Reference	Year	Tools	Objectives	Significant Results
			reduce time delay.	results.
I.Althamary et al. [87]	2018	Popularity-Based Cache Placement	Propose a more efficient cache placement.	The algorithm's usefulness was confirmed through simulations on energy efficiency.
Yi-Hsuan Hung and Chih-Yu Wang [88]	2018	Market Game for Microservices in the Fog (FMG)	Through a free market mechanism, promote fog computing in a fog-enabled cellular system on mobile devices.	The test results suggest that the proposed solution can significantly improve overall system utility.
X.He et al. [89]	2018	Joint Resource Allocation Based on Quality of Experience	Evaluate the quality of service in a fog computing environment, taking into account both the system and the users to increase QoE.	The simulation findings suggest that allocating resources using the dynamic allocation (DA) technique can improve QoE performance.
Y.Jiang et al. [9]	2018	Edge Caching Based on User Preference Learning	In a fog radio access network, solve the edge caching problem (F-RAN).	The results show that the suggested technique outperforms traditional policies in the cache hit rate and asymptotically reaches optimal performance.
R.Wang et al. [83]	2019	Caching	Solve the problem of backhaul traffic congestion and boost throughput in fog radio access networks.	According to test results, the cache location improved by the suggested methodology enhances the STP by roughly 18% over the best existing caching distribution.
V.Veillon et al. [90]	2019	Networks of Fog Delivery (FDN)	Fix the issue of reliable streaming in terms of low latency and no interruptions.	On-demand processing and leveraging cached video sections on neighboring FDNs have been demonstrated to considerably reduce streaming latency in tests (on average 52 percent).
J.Wu et al. [13]	2019	Fog-Computing-Enabled Cognitive Network	Configure and control computational and storage resources on-demand, based on user content cognition.	The results of the tests suggest that the proposed method is beneficial and efficient.
J.Ahmed Khan et al. [91]	2019	Information-centric networking	Solve the primary challenges of current mobile infrastructure	Simulations show that IS-Fog is the most scalable and efficient content caching and delivery technique than existing systems.
H.Ali Khattak et al. [92]	2019	VANET	Present a fog computing-based VANET architecture as well as a scenario for an infotainment application.	The article concludes with a discussion of the numerous advantages of a fog-enabled VANET, as well as future obstacles and potential solutions.
SH.YAN et al[93]	2019	Q-learning-	Solve the twin	The results of the analysis

Reference	Year	Tools	Objectives	Significant Results
		based algorithm	optimization problem of access mode selection and spectrum allocation in fog computing-based car networks.	show that the recommended strategy can result in significant performance improvements.
Y.Wei et al [94]	2019	Deep Reinforcement Learning with Natural Actors	Content caching, compute offloading, and radio resource allocation is just a few of the issues you'll face.	The research uses numerical simulations to demonstrate the proposed algorithm's learning capability and examine end-to-end service latency.
Tian Dang and Mugen Peng [1]	2019	Framework for mobile VR distribution based on F-RAN	Solve the challenge of ultra-high transmission rates and ultra-low latency in virtual reality (VR) experiences.	The mobile VR delivery architecture, according to reports, can improve spectral efficiency by optimizing average acceptable latency while meeting high transmission rate requirements.
Z.LI et al.[1,3,5]	2019	Socially Aware Caching	The fog radio access network (F-RAN) boosts network performance by leveraging communication and computational advantages.	The simulation results finally demonstrate the effectiveness of the proposed method.
Y.LAN et al. [73]	2019	D2D-aided Fog Radio Networking	Examine resource allocation in a D2D-assisted fog computing system that includes many mobile user devices (MUEs).	When compared to various baseline systems, the simulation results suggest that the suggested system is effective.
Wesam A. Almobaideen and Ola M. Malkawi [51]	2020	Fog computing application-based caching (ABCFOG)	Propose a new caching strategy called ABCFOG (Application Based Caching for Fog Computing).	According to the findings, ABCFOG has improved caching by at least 30% in response time and hit ratio. However, this improvement comes at the cost of additional bandwidth.
Q.Li et al. [53]	2020	Caching at the edges	Given the limited fog cache capacity as well as the base station connectivity capacity (BSs).	When the BS connectivity capacity is sufficient, use all available fog cache capacity to maximize the edge-cache-hit-ratio (ECHR); when the BS connection capacity is insufficient, keep the ECHR low and send more traffic to the cloud.
N.JASIM et al. [24]	2020	Deep Learning	Create a substrate network with low latency and significant resources that do not require relaying to cloud nodes.	The deep learning network produces a loss model with a low failure rate and a high success rate.

Reference	Year	Tools	Objectives	Significant Results
K.Liu et al. [95]	2020	Fog Computing Empowered Data Dissemination	Propose a fog computing-enabled architecture for software-defined heterogeneous vehicle ad-hoc networks with a specific data distribution strategy (VANETs).	Based on the simulation findings, the recommended solution is superior.
C.Mavromoustakis et al. [96]	2020	Special Issue on Emerging Trends and Challenges in Fog Computing for IoT	Satisfy the demand for a disruptive, high-performance, scalable, and flexible communication network that can cope with escalating demands, the number of connected devices, and application requirements.	All entries were carefully considered and assessed to address all of the issues as mentioned above, resulting in 15 articles being accepted.
L.Hu et al. [5]	2020	IF-RANs	In the case of IF-RANs, suggest using intelligent traffic prediction and cognitive caching.	The experiment results show that the proposed IF-RANs successfully enhance real-time prediction accuracy and reduce communication latency.
J.Chen et al. [78]	2020	Edge Computing on Mobile Devices (MEC)	Propose fog computing or mobile edge computing (MEC) as a wireless network cost-cutting solution.	Experiments validating the effectiveness of poor caching selections have also contributed to task caching's an impressive performance.

Files-Papadopoulos et al. [97] presented an improved simulation framework that (a) supports graph-based network topologies, (b) requests have been reconstituted for differentiation of requirements, and (c) statistics were computed per site and network metrics per link, improving the granularity and parallel performance. They also proposed a two-phase optimization scheme that used simulation outputs to guide the search for optimal cache placements. They simulated a CDN network based on real traces obtained from the BT CDN infrastructure and analyzed performance and scalability aspects to evaluate their proposal.

- They proposed a new, improved simulation framework for vCDNs.
- They combined a new two-phase cache placement optimization scheme with the framework.
- They parallelized the optimization scheme for a super-computing system with OpenMP, MPI.
- The two-phase cache placement scheme could be used by any other simulation framework.

4. COMPARISON AND DISCUSSION

This suction reflects the significant points of what has been explained in the literature review section. This style will help make a fair comparison among all 29 research explained in the previous section.

To begin, the study suggested using caching technology and fog computing to achieve low energy usage in IoT and Cloud contexts. To tackle the resource sensing problem in a fog computing network with several nodes and a single controller, the paper provides a unique incentive structure to drive Fog Nodes to send back their sensing data often to the Fog Controller. Article [82] Since edge devices have always been limited in computing capability, this paper addresses the subject of edge computing and offloading in fog computing networks. In F-RAN, study number proposes a graph-based cooperative caching technique [83]. Advanced solutions for implementing data locality in P2P-based fog computing platforms were the attention of researchers. They then showed various ways to promote data locality without changing the core of existing DHT overlays. In addition, paper [85] MHRC is a multihop D2D-relaying-based caching scheduling approach for fog computing systems in the mmWave band that is mobility-aware. FogCache, an on-demand fog caching service for ICN that adapts fog computing to ICN to analyze network status-aware information, is proposed by the study's authors. After that, there's paper. In research [24], the authors proposed an everyday utility for a fog computing situation. An optimal caching resource allocation technique integrating global and local decision-making is used. The placement of caching in fog nodes is proposed in the paper, which reduces energy usage. The results were achieved by dividing the nodes into three groups: active, moderately active, and less active. Fog Micro Service Market is a game-theoretic framework that promotes Fog computing in Fog-enabled cellular systems on mobile devices through free-market principles, according to the research. The purpose of this study was to investigate ways to increase QoE in a fog computing environment by collaborating on resource allocation. Researchers from the [83] Calculate the STP in the general SNR region to begin. Then, using a proposed projection gradient method, they optimize cache placement to maximize STP. The article's content [94] seeks to solve the problem of fog–enabled IOT service latency reduction by combining catching, computing, and radio resource allocation [1]. The caching prediction criterion should be established by the application being used, according to ABCFOG. The full text of the paper [53] proposes a CAEC framework for efficient content cache and provision in fog computing networks. Research [3] The issue of online content placement with undetermined content popularity was investigated. It suggested LACP, a multi-play Thompson sampling-based learning-aided content placement strategy.

5. CONCLUSION

In this paper, we look at the future Internet issues as it becomes more information-centric. Fog computing, which enables to overcome these issues, cache and network function virtualization technologies can be coupled. A new fog-enabled system based on fog computing has been reviewed that provides network caching and control virtualization using storage and computing resources. According to the reviewed concept, Fog nodes serve as small databases for routers as well as an activity and network monitor, delivering control and configuration information to the network for better data transport, caching, and security. To provide a cognitive resource configuration methodology, the fog-computing-enabled network functions virtualization architecture is deployed. This effort is critical for improving the Internet's future performance and adaptability.

The following trends can bound the outcomes of this research: To boost low-latency and throughput transmission for 5G IoT devices, Fog Computing characteristics and caching capabilities are being used. They minimized the cost of sensing at Fog Controllers (FN) and presented a fog computing-based VANET architecture. Given the limited fog cache capacity as well as the base station connectivity capacity (BSs). They were proposing fog computing or mobile edge computing (MEC) as a wireless network cost-cutting solution.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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