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A Review on Fog Computing: Research Challenges and Future Directions

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ABSTRACT

The traditional centralized cloud computing paradigm confronts several problems, including a lack of capacity, high latency, and network failure, due to the rapid expansion of IoT (Internet of Things) applications. Fog Computing brings cloud computing and IoT devices closer to addressing these issues. Instead of transferring IoT data to the cloud, the Fog allows local processing and storage of IoT data in IoT devices. Fog Computing offers services with a quicker response time and higher quality than the cloud. Therefore, Fog Computing may be considered the greatest option for enabling the IoT to provide efficient and secure services to many IoT users. In this paper, we define the term "Fog Computing," examine its architecture and list its features. We also talk about other related work and emphasize it.

Keywords:

Cloud, Fog Computing, Challenges, IoT Internet of Thing

1. INTRODUCTION

The creation of a wide range of IoT devices is a result of the introduction of the Internet of Things (IoT) technology. IoT devices are connected vehicles, smart TVs, smart speakers, smart mobiles, tablets, smartwatches, edge routers, smart fire alarms, medical sensors, smart home systems, smart security systems, etc.. These different network edge devices are becoming more prevalent; thus, this requires prompting rapid continuous data transmission. Processing and quick responses are required for this raw data[1].

IoT devices are used to store, process, gather, and exchange data created in massive amounts from new applications. This led to the production of huge amounts of data that must be processed by cloud computing. However, because data must first be sent from the node to the central server for processing, which often requires a lengthy period, processing this data can be slow. So, there is a requirement to approximate the cloud's characteristics to the source of demand. A cloud computing extension (Fog Computing) is used to get around these issues [2]. Through a cutting-edge architecture dubbed Fog Computing, which functions and is connected as a layer between the Internet of Things (IoT) and the cloud, Fog Computing offers services to the network edge[3].

Cisco Systems were the first to adopt the phrase "Fog Computing" to describe a new paradigm for minimizing data transfer in the Internet of Things (IoT) network architecture [4][6]. Fog Computing is defined as an extension of the cloud, but it is more closely related to IoT devices. In addition, it can be described as a distributed computing paradigm that extends from the cloud's services to the edge of the network [2]. Moreover, it can be described as a situation in which a large quantity of ubiquity and decentralized heterogeneous devices communicate and possibly cooperate with the network to accomplish processing and storage activities without the assistance of outside parties [5].

The sections of this review paper are organized as follows: Section 2 covers the Fog Computing architecture and features. Section 3 overviews Fog Computing's relationship to Internet of Things (IoT) issues. In Section 4, a review of the literature on Fog Computing is presented. In Section 5, Workload and load balancing. In Section 6, Research Challenges and Future Directions. At the end of Section 7, conclusions are presented.

Fig. 1 describes the complete organization of the review paper

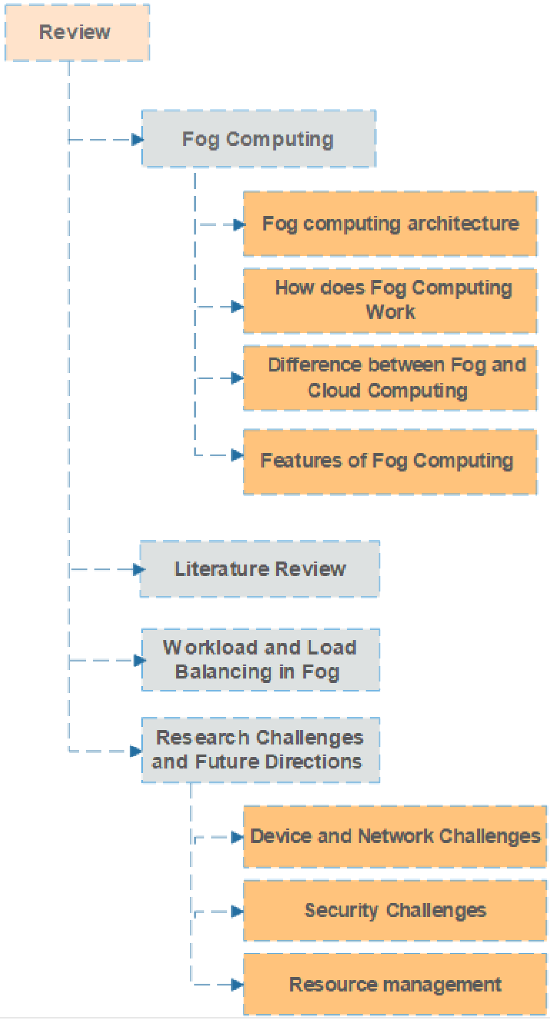

Fig.1 The Organization of Review

2. THE FOG COMPUTING

This section gives a general overview of the Fog Computing architecture and functionality:

2.1. Fog Computing architecture:

A collection of logical and physical software, network components, and hardware configurations called "Fog Computing architecture" are used to construct realistic networks, such as the Internet of Things. The topologies in which the Fog nodes are arranged, their placement, link capacity, the amount of accessible data bandwidth, and their consumption are all important architectural aspects. Another critical architectural choice is how the Fog nodes are used and controlled [6]. Fog Computing research frequently uses a variety of designs because there is no industry-standard architecture. The Fog Computing architecture is described in general terms in (Figure 2). the three main layers are the end devices layer, the Fog layer, and the cloud computing layer [3], [7]:

- **End devices layer:**

This foundational layer represents end devices such as mobile smartphones, sensors, actuators, tablets, aircraft, smart cars, and desktop and laptop computers with applications. Endpoints offer a variety of computing capabilities and can be thought of as human-operated resources. These components cooperate to create a communication network, and the data from all of these parts are sent to cloud computing through the Fog Computing layer [7]– [9].

- **Fog Computing layer:**

It is the layer directly above the layer for end devices. Any device that can store, process, and connect to a network is called a Fog processing device. In this sense, some gadgets, such as cell phones, can be categorized as IoT and Fog gadgets. A collection of processing units, gateways, and networked hardware (routers and switches) are arranged between network edges and clouds to form the Fog Computing layer. Resources from the Fog are connected and used to provide users with various services, including computing, storage, and network services. A distributed system of Fog Computing devices is being created that offers services to a certain set of end devices in a particular location and controls data transfer by such devices [7]– [9].

- **Cloud Computing layer:**

The cloud layer contains actual data center nodes. Each node satisfies user requests for resources by having a CPU, main memory, and network bandwidth. Utilizing control techniques, cloud computing resources can be managed and scheduled by their load requirements. Wide Area Networks (WANs) are connected to clouds, which give users economic advantages, elastic services, data-intensive analysis, high-quality services, and high fault tolerance. However, because of present WAN connectivity, clouds experience significant latency and limited capacity. Additionally, because cloud computing is centralized, it cannot offer context-aware computing for IoT applications [7]–[9].

Fig.2 Three-layer architecture (end user/ Fog/cloud).

2.2. How does Fog Computing Work?

The bottom layer continuously gathers user-generated raw data and sends it to the edge node simultaneously. This edge node closest to the user is where you can find this unprocessed data. The Fog node processes this raw data and performs computations using it. These Fog Computing nodes are situated in the intermediate layer. Active Fog nodes assist in the analytics process at the Fog Computing network. These analytics are performed close to the end user, providing a quick response for further processing, reducing transmission latency, and providing an immediate response. The topmost layer of the cloud receives updates with the computation's results and necessary actions. As a result, Fog Computing aids in cutting down on the amount of data transmitted via the network between the Fog and the cloud. Better performance, increased bandwidth, and quicker packet delivery over the network are all benefits of this. Although cloud and Fog Computing are different technologies, they work together to deliver improved performance, more efficacy, and faster response times.

2.3. Difference between Fog and Cloud Computing

Fog Computing serves as a link between IoT devices and large-scale cloud computing and storage services. However, Fog computing is part of the cloud computing paradigm but is separate from each other. So, depending on various factors, comparing the properties of Fog Computing and cloud computing, the major differences are outlined [1] [10] in Table 1.

Table 1: Services of Fog Computing vs. cloud computing [11], [12]

Parameters	Fog Computing	Cloud Computing
Computing Model	Distributed	Centralized
Size	Smaller	Large
Latency	Very low	High
Distance between die and server	One hop	One or more hops
Delay jitter	Very low	High
Security	It can be defined, and it is good	Undefined
Support for mobility	More supported	Limited
Type of last-mile connectivity	Wireless	Leased/ wired
Real-time interactions	More supported	Very large
Location of server nodes	At every edge of the local network	Within Internet
Attack on data encounter	Less possibility	High possibility

2.4. Features of Fog Computing

Although cloud and Fog Computing are independent technologies, they complement one another to offer faster response times, greater efficiency, and superior performance. Fog is a valuable resource to support IoT requirements in mobile environments; it performs processing, communication, and storage functions on devices at the edge of the network that is close to users. Its proximity to end consumers is one of the advantages of its services [13].

According to [15]– [18], when Fog Computing is compared to other conventional computing models, the following qualities and benefits are found also shown in (figure 3):

- Low latency: Because the IoT devices and the Fog Computing nodes are close together, the data created by sensors and devices are processed and stored by Fog Computing nodes at the network edge, resulting in very little latency.

- Real-time interactions: Fog Computing provides rapid, high-quality, locally supported services through endpoints, and it considerably decreases data transit across the Internet. As a result, it addresses the need for real-time communications, especially for time- or latency-sensitive applications.
- Heterogeneity: There are many different edge devices or Fog Computing nodes that include edge routers, access points, high-performance servers, base stations, gateways, etc.. Fog Computing may adapt to diverse hardware platforms since these platforms run different operating systems, have different computing and storage capacities, and load various software programs.
- Geographical Distribution: Fog Computing delivers applications and services that are decentralized and can be hosted anywhere, as opposed to centralized cloud computing, which provides centralized cloud services. Better location-based services, faster big data processing, and more potent real-time decision-making capabilities can all be supported by this trait.
- Mobility Support: In the Fog Computing environment, there are a variety of mobile devices (such as cell phones) that maintain regular spatial mobility at the terminal layer, as well as some stationary end devices, like traffic cameras. Similar to this, a computing resource platform that is mobile or static can also be a Fog node in the Fog Computing layer.
- Compatibility: Fog modules can adapt to and work with various platforms and service providers since they are heterogeneous.
- Improved Security: Business places a high priority on data security. As opposed to one central location for all connections, risk and threat screening is slightly easier when many links are connected to a network. Identifying the danger or malwareacross several endpoints is preferable to doing so at a single endpoint or centralized network.
- Network Bandwidth Constraints: Fog Computing offers data processing based on application requirements, accessible networking, and computer resources. This reduces the amount of data that needs to be transferred to the cloud, preserving network capacity.

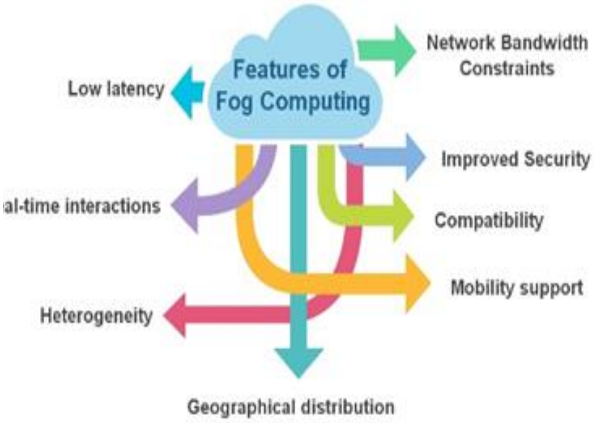

Fig. 3 Features of Fog Computing

3. FOG COMPUTING CHALLENGE WITH THE INTERNET OF THINGS (IOT)

The Internet of Things (IoT) allows all devices connectivity and data exchange (Figure 4). IoT is described as a network for device-to-device communication [19]– [21].

This communication has been categorized under home-based execution environments [21] and industry execution environments [22]in several Fog-based research publications. Additionally, wireless sensor and actuator networks [23], cyber-physical systems [24], embedded system networks [25], etc., were taken into account as various forms of IoT. For several IoT applications, the Fog Computing paradigm has several benefits and provides a workable solution to the problems. Real-time interactions, latency, mobility assistance resource limitations, decentralized data, service quality, energy consumption, scalability, interoperability, heterogeneity, and security congestion are some challenges in the IoT context.

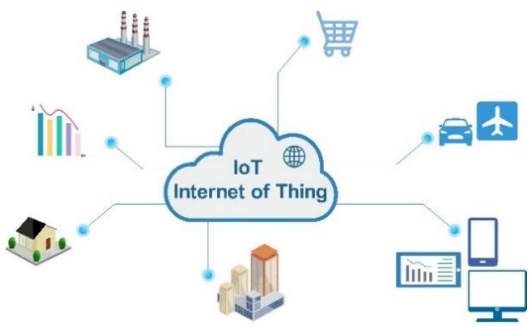

Fig. 4 IoT Internet of Thing

4. LITERATURE REVIEW:

The possibility of using Fog Computing in the Internet of Things (IoT), which is a separate domain, has been investigated by several researchers.

- M. Yannuzzi et al. (2014) highlighted the factors that make Fog Computing the ideal IoT platform, addressed how the cloud and Fog interact, and reviewed some of the technologies if Fog Computing is to support the applications that the IoT market expects. [26].
- K.P.Saharan and Kumar (2015) addressed the primary characteristics of the Fog, investigated the benefits and driving forces behind Fog Computing, and examined its use in IoT (Internet of Things) applications[27].
- Chiang and Zhang (2016) referred to Fog Computing as a provider of services closer to the user at the network's edge. They focused on how IoT networks might use Fog Computing platforms, and they mentioned potentials along with new difficulties of using Fog Computing and why this new architecture is necessary[28].
- Mahmud R et al. (2016) analyzed the difficulties in creating Fogs that serve as a layer of intermediary technology between IoT devices and cloud data centers and reviewed recent advancements in this area. They presented a taxonomy of Fog Computing based on the difficulties found and its distinguishing characteristics. [29].
- Varghese et al. (2017) focused on the viability and advantages of employing Fog Computing to enhance the Quality-of-Service and Experience. It was determined that using the edge of the network rather than a cloud-only method reduces a user's average response time for an online game by 20%. The use-case results in a traffic volume decrease between the edge and cloud server of over 90%.[30].
- Qiang Fan et al. (2018) suggested a workload balancing system in a Fog network by connecting IoT devices with compatible BSS to reduce data flow delay in communications and processing operations. They tested the suggested load balancing scheme's performance against competing methods to confirm its benefits for Fog networking [31].
- Mansoor Ahmad Rasheed et al. (2021) explained various Fog Computing designs, privacy and security-related problems, and potential solutions. This study discussed real-world IoT Fog Computing applications that can solve some of our everyday issues [32].
- Sabireen H. et al. (2021) examined the challenges of Fog Computing, which acts as a middle layer between IoT sensors or devices and cloud data centers. They proposed various computing models, features of Fog Computing, an extensive reference architecture for Fog Computing with multiple levels, a detailed analysis of Fog with IoT, and different Fog Computing system algorithms[33].
- Jagdeep Singh et al. (2021) analyzed the core attributes of Fog Computing frameworks, pointed out problems with their architectural design, quality of service metrics, implementation specifics, applications, and communication modes, and proposed a taxonomy for Fog Computing frameworks based on the literature that was already available. Based on the taxonomy, they contrasted the various research programs [34].

Table 2: Related Review on Fog Computing

Year	Author	Main Focus
2014	M. Yannuzzi et al. [26]	• pointed out the characteristics that make Fog Computing the ideal IoT platform. • Discussed the relationship between the cloud and Fog.
2015	K.P.Saharan and Kumar [27]	• addressed the primary. Characteristics of the Fog. • Analyzed the motivations and advantages of Fog Computing. • Looked at Fog in IoT (Internet of Things) application.
2016	Chiang and Zhang [28]	• Fog Computing is a provider of various services that are closer to the user at the network's edge. • How IoT networks might use Fog Computing platforms.
2016	Mahmud R et al. [29]	• analyzed the difficulties in creating Fog.

		• Reviewed recent advancements in this area. • Display a taxonomy of Fog Computing. Based on the challenges found.
2017	Varghese et al. [30]	• Using Fog Computing to enhance the Quality-of-Service. • Using the edge of the network reduces a user's average response time for an online game by 20% rather than a cloud method.
2018	Qiang Fan et al. [31]	• suggested a workload balancing system in a Fog network by connecting IoT devices with compatible BSS.
2021	Mansoor Ahmad Rasheed et al. [32]	• explained various Fog Computing designs. • Presented various Fog Computing privacy and security-related problems and potential solutions.
2021	Sabireen H. et al. [33]	• study challenges of Fog Computing. • Proposed various computing models and features of Fog Computing.
2021	Jagdeep Singh et al. [34]	• discussed the important characteristics of Fog Computing frameworks. • Identified various issues related to its architectural design, quality of service metrics, implementation details, and applications.

5. WORKLOAD AND LOAD BALANCE IN FOG

The workload term refers to the amount of work (or load) needed by the processor to complete the task and, in the computing environment, is known as the amount of time, it takes to accomplish a task or produce a product, as well as the number of computer resources required. As mentioned earlier, the basic goal of Fog Computing is to perform as much processing within the Fog layer itself as feasible rather than sending all the data to cloud servers, this can decrease response time, and reduce latency, and bandwidth but at the same time the Fog Computing includes possible challenges. For example, the use of incorrect scheduling results in increased power consumption in Fog devices and increases traffic overhead because all requests are sent to the main server which introduces delays that cannot be allowed in delay-sensitive applications. By using an efficient workload, these difficulties must be overcome.

Accordingly [35], they find appropriate workload allocation based on power and delay tradeoffs. Different scheduling methods, including FCFS (First Come, First Served), RR (Round Robin), and SJF (Shortest Job First), are implemented in Fog devices, and the Fog Computing subsystem analyses the power and delay tradeoffs of these algorithms.

Also, in [36], they looked into solutions to this issue to maintain Fog Computing with homogeneous load distribution even in heterogeneous environments. In order to do this, an algorithm model is shown that takes into account the changeability and diversity of Fog Computing's computing nodes. This model sends tasks to the most appropriate node based on policies set by the network administrator. The results show that in the proposed work, tasks were spread out evenly among the Fog nodes, and response times were shorter than in other proposed solutions.

Therefore, load balance is a method or technique for increasing network capacity, dependability, and efficiency and performs a variety of tasks, including sending a distributed client request across several networks, distributing the workload among several active servers, ensuring high availability, and allowing for server addition and removal flexibility. Between the server farm and the client, there is a load balancer that receives the incoming application traffic and distributes it through a connection and service using different methods. [37] Figure 4 shows the load balancer in Fog.

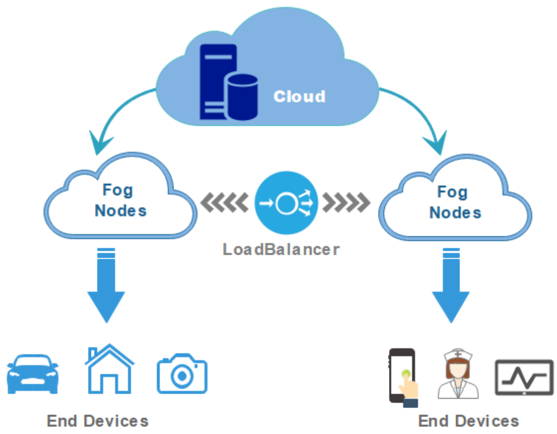

Fig.4 Load balance in Fog

Workload balancing can generally be defined as the ability to distribute the workload on all the working machines equitably. Load balancing is carried out in two types static and dynamic. With static load balancing, the traffic is split in half and distributed equally among the servers. Performance is assessed at the start of execution since the technique requires prior information on the resources employed in the system.

In dynamic load balancing, preference is given to the server that can handle the least load. Real-time networks are preferred in this scenario because they boost traffic in the technique and use the steady state to guide decision-making for load control. Dynamic load balancing gives input to the present methodology so that the processes can switch from an overly used computer to a least used machine in real-time.

6. RESEARCH CHALLENGES IN AND FUTURE DIRECTION FOG COMPUTING:

Fog computing is a distributed computing architecture that presents network-related difficulties, computing-related research objectives, security-related problems, and management-related difficulties. The system is more susceptible to incorrect computation because of its widely distributed nature. Therefore, we talk about these research challenges in the fog computing system :

6.1. Device and Network Challenges:

- **Distributed architecture:** A redundant system is more likely to exist in fog computing due to the distributed design. The edge devices in the network contain many copies of the same code [38]. The computing architecture should be sufficiently sophisticated to eliminate redundancy in the distributed environment.
- **Device heterogeneity**: The fog environment has several heterogeneous end devices. The system is now more diversified due to the heterogeneity of the apparatus [39]. The computing platform should consider this device and network heterogeneity when creating fog applications.
- **Distributed Resources:** In the fog architecture, the networking resources are dispersed among edge or near-edge devices. Because of this, the system becomes more complicated regarding network connectivity. It is necessary to provide a common network middleware that can manage a pool of resources across edge or near-edge devices and, in turn, assign resources to the workloads of applications.

6.2. Security Challenges:

Security issues: Because it comprises various heterogeneous devices, the fog computing system is open to multiple security threats. Security of data and networks are the key concerns in Fog. Furthermore, because the fog computing architecture also depends on cloud servers' services and it is more susceptible to problems with trust and authentication. Data privacy is another issue with this massively dispersed fog computing architecture [40]. Another security flaw is the placement of fog devices outside of highly secure data centers, where physical access by attackers may be simple [41]. So, it is possible that the system software can't be trusted. Consequently, it is necessary to securely implement the edge functionalities over the Fog.

6.3. Resource management:

The Fog computing domain distributes various networking and computation resources. Fog computing needs to be adaptable and flexible like cloud computing to handle problems like failures or lack of resources. Fog node failure brings a halt in the system because the resource is not accessible from that fog node.

Once more, the resources in the fog network are virtualized. Resources virtualization poses several challenges, like latency and virtual network device migration in a fog network. In these situations, managing the resources effectively is important to prevent downtime and maintain high availability. This is primarily due to the latency-sensitive applications that a fog computing system handles, such as smart homes and smart healthcare monitoring systems [42]. Resource management over fog nodes can be accomplished using contemporary technologies like software-defined networking SDN [43], which presents numerous research directions.

7. CONCLUSIONS:

We may infer from the review above that Fog computing is an extension of cloud computing that offers extra features for service providers and end users. Fog Computing is not a substitute for cloud computing even if it can manage vast amounts of data produced by the IoT (Internet of Things) near the network's edge. Fog Computing is considered the best IoT platform because of its low latency, heterogeneity, and mobility characteristics.

8. ACKNOWLEDGEMENTS:

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REFERENCES

[1] S. P. Singh, A. Nayyar, R. Kumar, and A. Sharma, "Fog Computing: from architecture to edge computing and big data processing," *Journal of Supercomputing*, Vol.75, No. 4, pp. 2070–2105, Apr. 2019, DOI: 10.1007/s11227-018-2701-2.

[2] P. Prakash, K. G. Darshaun, P. Yaazhlene, M. V. Ganesh, and B. Vasudha, "Fog Computing: Issues, challenges, and future directions," *International Journal of Electrical and Computer Engineering*, Vol.7, No. 6, pp. 3669–3673, Dec. 2017, DOI: 10.11591/ijece.v7i6.pp3669-3673.

[3] S. v. Margariti, V. v. Dimakopoulos, and G. Tsoumanis, "Modeling and simulation tools for Fog Computing-A comprehensive survey from a cost perspective," *Future Internet*, Vol.12, No. 5, May 2020, DOI: 10.3390/FI12050089.

[4] N. Peter, " Fog Computing and Its Real-Time Applications," *International Journal of Emerging Technology and Advanced Engineering* 2008.

[5] L. M. Vaquero and L. Rodero-Merino, "Finding your Way in the Fog: Towards a Comprehensive Definition of Fog Computing," 2014. [Online]. Available: http://blogs.cisco.com/ioe/cisco-iox-an-application

[6] T.Dimitrios, k. Helen, " Simulation Performance Evaluation of a Fog System". *In 2018 Third International Conference on Fog and Mobile Edge Computing (FMEC)*, pp. 26-33, IEEE, 2018.

[7] M. H. Kashani, A. Ahmadzadeh, and E. Mahdipour, "Load balancing mechanisms in Fog Computing: A systematic review.", *arXiv preprint arXiv:2011.14706* 2020.

[8] H. F. Atlam, R. J. Walters, and G. B. Wills, "Fog Computing and the internet of things: A review," *Big Data and Cognitive Computing*, Vol.2, No. 2. MDPI AG, pp. 1–18, June 01, 2018. DOI: 10.3390/bdcc2020010.

[9] S. Kunal, A. Saha, and R. Amin, "An overview of cloud-Fog Computing: Architectures, applications with security challenges," *Security and Privacy*, Vol.2, No. 4, Jul. 2019, DOI: 10.1002/spy2.72.

[10] M. A. Aleisa, A. Abuhussein, and F. T. Sheldon, "Access Control in Fog Computing: Challenges and Research Agenda," *IEEE Access*, Vol.8, pp. 83986–83999, 2020, DOI: 10.1109/ACCESS.2020.2992460.

[11] Deshmukh UA, More SA. "Fog computing: a new approach in the world of cloud computing.", *Instr Technol.* 2016 Sep;49. DOI:10.13140/RG.2.2.26749.51688

[12] M. Mukherjee, L. Shu, and D. Wang, "Survey of Fog Computing: Fundamental, network applications, and research challenges," *IEEE Communications Surveys and Tutorials*, Vol.20, No. 3, pp. 1826–1857, Jul. 2018, DOI: 10.1109/COMST.2018.2814571.

[13] P. Hu, S. Dhelim, H. Ning, and T. Qiu, "Survey on Fog Computing: architecture, key technologies, applications, and open issues," *Journal of Network and Computer Applications*, Vol.98. Academic Press, pp. 27–42, November 15, 2017. doi: 10.1016/j.jnca.2017.09.002.

[14] J. Carlos Ribeiro Vieira, A. Manuel Raminhos Cordeiro Grilo João Coelho Garcia, T. Maria Sá Ferreira Vazão Vasques Supervisor, and A. Manuel Raminhos Cordeiro Grilo, "Fogand Cloud Computing Optimization in Mobile IoT Environments Electrical and Computer Engineering Examination Committee," *PhD Thesis. Instituto Técnico de Lisboa* 2019.

[15] Y. Ai, M. Peng, and K. Zhang, "Edge computing technologies for Internet of Things: a primer," *Digital Communications and Networks*, Vol.4, No. 2, pp. 77–86, Apr. 2018, DOI: 10.1016/j.dcan.2017.07.001.

[16] S. Yi, Z. Hao, Z. Qin, and Q. Li, "Fog Computing: Platform and applications," *in Proceedings - 3rd Workshop on Hot Topics in Web Systems and Technologies*, HotWeb 2015, Jan. 2016, pp. 73–78. doi: 10.1109/HotWeb.2015.22.

[17] S. Rahul and R. Aron, "Fog Computing Architecture, Application and Resource Allocation: A Review," *CEUR Workshops*. Vol. 4638. 2021.

[18] F. Bonomi, R. Milito, J. Zhu, and S. Addepalli, “Fog computing and its role in the internet of things*," in Proceedings of the first edition of the MCC workshop on Mobile cloud computing*, Aug. 2012, pp. 13–16. doi: 10.1145/2342509.2342513.

[19] S. Cirani, G. Ferrari, N. Iotti, and M. Picone, "The IoT hub: A Fog node for seamless management of heterogeneous connected smart objects," *in 2015 12th Annual IEEE International Conference on Sensing, Communication, and Networking - Workshops*, SECON Workshops 2015, Nov. 2015, pp. 43–48. DOI: 10.1109/SECONW.2015.7328145.

[20] N. K. Giang, M. Blackstock, R. Lea, and V. C. M. Leung, "Developing IoT Applications in the Fog: A Distributed Dataflow Approach."

[21] M. Abdullah and A. Faruque, "Energy Management-as-a-Service Over Fog Computing Platform," *5th International Conference on the Internet of Things (IOT). IEEE*, 2015.

[22] V. Gazis, A. Leonardi, K. Mathioudakis, K. Sasloglou, P. Kikiras, and R. Sudhaakar, "Components of Fog Computing in an industrial internet of things context*," in 2015 12th Annual IEEE International Conference on Sensing, Communication, and Networking - Workshops, SECON Workshops* 2015, Nov. 2015, pp. 37–42. DOI: 10.1109/SECONW.2015.7328144.

[23] W. Lee, K. Nam, HG. Roh, SH. Kim. "A gateway-based Fog Computing architecture for wireless sensors and actuator networks". *In 2016 18th International Conference on Advanced Communication Technology (ICACT)* 2016 January 31 (pp. 210-213). IEEE.

[24] L. Gu, D. Zeng, S. Guo, S. Member, A. Barnawi, and Y. Xiang, "Cost-Efficient Resource Management in Fog Computing *Supported Medical Cyber-Physical System", IEEE Transactions on Emerging Topics in Computing* Vol. 5, Issue: 1 , 2015. DOI: 10.1109/TETC.2017.2508382.

[25] D. Zeng, L. Gu, S. Guo, Z. Cheng, and S. Yu, "Joint Optimization of Task Scheduling and Image Placement in Fog Computing Supported Software-Defined Embedded System," *IEEE Transactions on Computers*, Vol.65, No. 12, pp. 3702–3712, Dec. 2016, DOI: 10.1109/TC.2016.2536019.

[26] M. Yannuzzi, R. Milito, R. Serralgracì, D. Montero, and M. Nemirovsky, "Key ingredients in an IoT recipe: Fog Computing, Cloud Computing, and more Fog Computing*.", 2014 IEEE 19th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD).* IEEE, 2014.

[27] K. P.Saharan and A. Kumar, "Fog in Comparison to Cloud: A Survey," *International Journal of Computer Applications*, Vol.122, No. 3, pp. 10–12, Jul. 2015, doi: 10.5120/21679-4773.

[28] M. Chiang and T. Zhang, "Fog and IoT: An Overview of Research Opportunities," *IEEE Internet of Things Journal*, Vol.3, No. 6. Institute of Electrical and Electronics Engineers Inc., pp. 854–864, December 01, 2016. DOI: 10.1109/JIOT.2016.2584538.

[29] R. Mahmud, R. Kotagiri, and R. Buyya, "Fog Computing: A Taxonomy, Survey and Future Directions," *Internet of Everything: Algorithms, Methodologies, Technologies and Perspectives* Nov. 2016, DOI: 10.1007/978-981-10-5861-5_5.

[30] B. Varghese, N. Wang, D. S. Nikolopoulos, and R. Buyya, "Feasibility of Fog Computing," Jan. 2017, [Online]. Available: http://arxiv.org/abs/1701.05451

[31] Q. Fan and N. Ansari, "Towards Workload Balancing in Fog Computing Empowered IoT." *IEEE Transactions on Network Science and Engineering*, Vol.7, No. 1, 2018.

[32] R. , Jabar S., M. Hudabia, T. Hafiz Abdullah, R.Mannan Ahmad, and A. Mishaal. "A Survey on Fog Computing in IoT.", *VFAST Transactions on Software Engineering* Vol 9, No 4 (2021), DOI: 10.21015/vtse. v9i4.727.

[33] H. Sabireen and V. Neelanarayanan, "A Review on Fog Computing: Architecture, Fog with IoT, Algorithms and Research Challenges," *ICT Express*, Vol.7, No. 2, pp. 162–176, Jun. 2021, DOI: 10.1016/j.icte.2021.05.004.

[34] J. Singh, P. Singh, and S. S. Gill, "Fog Computing: A taxonomy, systematic review, current trends, and research challenges," *Journal of Parallel and Distributed Computing*, Vol.157. Academic Press Inc., pp. 56–85, November 01, 2021. doi: 10.1016/j.jpdc.2021.06.005.

[35] Rajadurgamani, R. and Muthubharathi, R. "Effective Workload Allocation in FogDevice based on Power Consumption and Delay Tradeoff". *Journal of Information Technology*, 3(4), 2021.

[36] Pereira, Eder, et al. "A load balancing algorithm for Fog Computing environments." *High Performance Computing: 6th Latin American Conference*. Springer, Cham, 2019.

[37] Singh, Simar Preet, et al. "Leveraging energy-efficient load balancing algorithms in Fog Computing." *Concurrency and Computation: Practice and Experience* 34.13,2022.

[38] M. Chiang, S. Ha, F. Risso, T. Zhang, and I. Chih-Lin, "Clarifying Fog Computing and Networking: 10 Questions and Answers,*" in IEEE Communications Magazine*, vol. 55, no. 4, pp. 18-20, April 2017, doi: 10.1109/MCOM.2017.7901470.

[39] F. Bonomi, R. Milito, P. Natarajan, and J. Zhu, "Fog computing: A platform for internet of things and analytics," *in Big Data and Internetof Things: A Roadmap for Smart Environments*. Springer, 2014, pp. 169–186.

[40] S. Yi, Z. Qin, and Q. Li, "Security and privacy issues of fog computing: A survey," *in Proceedings of the 2015 Springer International Conference on Wireless Algorithms, Systems, and Applications*. Springer, 2015, pp. 685–695.

[41] K. Bhardwaj, M.-W. Shih, P. Agarwal, A. Gavrilovska, T. Kim, and K. Schwan, "Fast, scalable and secure on loading of edge functions using airbox," *in Proceedings of the 2016 IEEE Symposium on Edge Computing (SEC)*. IEEE, 2016, pp. 14–27.

[42] T. N. Gia, M. Jiang, A.-M. Rahmani, T. Westerlund, P. Liljeberg, and H. Tenhunen, "Fog computing in healthcare internet of things: A case study on ECG feature extraction," *in Proceedings on the 2015 IEEE International Conference on Computer and Information Technology; Ubiquitous* Computing and Communications; Dependable, Autonomic and Secure Computing; Pervasive Intelligence and Computing. IEEE, 2015, pp. 356–363.

[43] N. B. Truong, G. M. Lee, and Y. Ghamri-Doudane, "Software-defined networking-based vehicular Adhoc network with fog computing," *in Proceedings of the 2015 IEEE International Symposium on Integrated Network Management (IM). IEEE*, 2015, pp. 1202–1207.

مراجعة حول الحوسبة الضبابية: تحديات البحث والاتجاهات المستقبلية

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**مطور برامج في سيتا ، الدرشوت ، إنجلترا ، المملكة المتحدة

تاريخ الاستلام:24-10-2022 استلم بصيغته المنقحة: 26-11-2022 تاريخ القبول:15-12-2022

الملخص

تواجه نموذج الحوسبة السحابية المركزية التقليدية العديد من المشكلات، من بينها نقص السعة وزمن انتقال عالٍ وفشل الشبكة، بسبب التوسع السريع في تطبيقات إنترنت الأشياء (إنترنت الأشياء). تعمل حوسبة الضباب على تقريب أجهزة الحوسبة السحابية وأجهزة إنترنت الأشياء من بعضها لمعالجة هذه المشكلات. بدلاً من نقل بيانات إنترنت الأشياء إلى السحابة، يسمح الضباب بمعالجة وتخزين بيانات إنترنت الأشياء محليًا في أجهزة إنترنت الأشياء. حيث تقدم حوسبة الضباب خدمات ذات وقت استجابة أسرع وجودة أعلى من الحوسبة السحابية. لذلك، يمكن اعتبار حوسبة الضباب هي الخيار الأفضل لتمكين إنترنت الأشياء من توفير خدمات فعالة وآمنة لعدد كبير من مستخدمي إنترنت الأشياء. في هذا البحث، نحدد مصطلح "الحوسبة الضبابية"، ندرس بنيتها، ونسرد ميزاتها. نتحدث أيضًا عن الأعمال الأخرى ذات الصلة.

الكلمات الدالة:

الحوسبة السحابية، الحوسبة الضبابية، التحديات، انترنت الأشياء.