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Fog Computing

A Review on Characteristics, Challenges, and Opportunities

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Abstract

By providing high-quality services, reducing latency, enabling mobility, allowing multi-tenancy, and many other aspects, the fog computing paradigm leverages the advantages of using both cloud and edge devices to serve modern computing systems. In addition to reviewing and discussing cloud computing, this study also briefly highlights the prior to fog computing applied paradigms. Cloud, mobile edge computing, and mobile cloud computing are some of these paradigms. The objective of each model was to improve the quality of service between end devices and the cloud. The research reveals that among the contributions from scholars, security, privacy, application, and communication concerns are frequently mentioned. There are additional identified potential uses for fog computing, such as smart city applications, healthcare applications, and farm applications.

Keywords: Fog computing, Internet of Things (IoT),Edge computing, Cloud computing

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الحوسبة الضبابية: مراجعة للخصائص، التحديات والفرص

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الخلاصة

نموذج الحوسبة الضبابية (Fog Computing) يوفر العديد من المزايا والتي تتمثل في توفير خدمات عالية الجودة مع تقليل زمن الوصول اليها، وقابلية الاتصال أثناء التنقل (Mobility) والسماح للعديد من مستخدمي الحوسبة السحابية باستخدام نفس موارد الحوسبة في نفس الوقت مع الحفاظ على الأمان والخصوصية، والعديد من الجوانب الأخرى. في هذه الدراسة حاولنا بالإضافة إلى مراجعة ومناقشة الحوسبة السحابية تسليط الضوء أيضًا بإيجاز على النماذج التطبيقية السابقة للحوسبة الضبابية. تعد الحوسبة السحابية(Cloud) والحوسبة الطرفية المتنقلة (Mobile edge Computing) والحوسبة السحابية المتنقلة(Cloud Edge Computing) بعضًا من هذه النماذج. حيث كان الهدف من كل نموذج هو تحسين جودة الخدمة بين العملاء (المستخدمين طالبي الخدمات) والخدمات السحابية. كما يكشف هذا البحث أن بعض من الأبحاث السابقة أشارت إلى المخاوف المتعلقة بالأمن والخصوصية والتطبيقات المتعلقة بالحوسبة الضبابية كما أنها تطرقت الى التحديات التي تواجه الاتصال والربط بين أجهزة هذه الشبكات. كما أن هذه الابحاث قامت بدراسة مجالات استخدام الحوسبة الضبابية (Fog Computing) مثل تطبيقات المدن الذكية وتطبيقات الرعاية الصحية وأخيرا التطبيقات في مجال الزراعة.

الكلمات المفتاحية: الحوسبة الضبابية، إنترنت الأشياء (IoT)، الحوسبة الطرفية الحوسبة السحابية

1. Introduction

Fog computing is now being pointed to by the trending paradigm pointer. Security is a priority in the field of computing, just as efficiency and quality of service remain crucial goals. Because of its scalability and flexibility, cloud computing was seen as a promising application prior to the fog. Large companies, such as IBM,

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Microsoft, Google, Amazon, and others, made it possible for various cloud-based services to simultaneously manage enterprise and educational computations. Platform as a Service (PaaS), Infrastructure as a Service (IaaS), and Software as a Service (SaaS) are a few of these services. However, the centralized nature of the cloud created a barrier to calculations that require low latency (Mahmud et al., 2018). Certain fundamental computing and communication needs, such as location awareness, mobility support, and low latency, are becoming less effective due to the growing demand for cloud computing services from IoT devices (Stojmenovic et al., 2016). The main issues that now hinder the quality of service provided by IoT devices are processing power, battery life, storage capacity, and bandwidth. The gigantic became the solution—that is, using the services of the strong, able to handle the limitations—to offset the strain of IoT devices' limited resources. It is believed that cloud computing holds the key to affordable, flexible resource delivery for services (Yi, Li, et al., 2015). However, a few disruptive factors that prompted the resorting touse fog computing were latency, location awareness, geo-distribution, and security. The Open Fog Consortium ("OpenFog," n.d.) states that Edge devices encounter two major obstacles from all cloud services. These include: 1) The exponential growth of data being produced by IoT devices will lead to network congestion and performance issues at the periphery of infrastructure. 2) For many tasks, a cloud-only solution is insufficient due to problems with dependability, performance, security, and bandwidth, among other problems. Fog computing's main focus is performance control; efficiency and latency have helped make it successful.

Considerable effort has been spent into defining and characterizing fog computing by several researchers, each of whom has contributed to a distinct aspect of the paradigm. Numerous review and survey papers covering both general and categorized fog computing concerns have been published. The goal of this study is to present an in-depth understanding of fog computing and the issues that are plaguing the paradigm. The paper will also give academics a general grasp of the problems that are currently plaguing the paradigm because it acts as a bridge between the cloud and the edge. To be more precise, this work makes the following contributions:

1. A basic but comprehensive overview of fog computing.
2. A summary of the most important problems and difficulties in fog computing.
3. The study highlighted a few possible uses for fog computing.

2. Literature Review

A possible paradigm for the Internet's future is fog computing, which offers computational functions at the network edge and opens up new applications and services (Zhang et al., 2018). Since fog computing is placed closer to IoT nodes than other paradigms like cloudlets, mobile cloud computing (MCC), and mobile edge computing (MEC), it has a better deployment position. It further facilitates the expansion of cloud-based services. As a result, it aids in delivering effective services, such as a notable reduction in latency (Mahmud et al., 2018).

In computation technology, a number of computing paradigms have already been developed that take the ideas of edge and cloud computing into consideration. Future breakthroughs in cloud and edge computing include Mobile Edge Computing (MEC) and Mobile Cloud Computing (MCC). Most people agree that MEC is essential to the current state of development of cellular base stations. Simultaneously, MCC provides the processing power needed to enable the remote run of decommissioned mobile apps in closer proximity to end users. Similar to MEC and MCC, fog computing can facilitate edge computation. Fog computing might reach the core network as well as the edge network. More precisely, fog computing may use edge and core networking components as processing infrastructure (Mahmud et al., 2018). Figure 1 shows a comparison graph that gives a brief overview of the distinctions and purposes of the mentioned paradigms.

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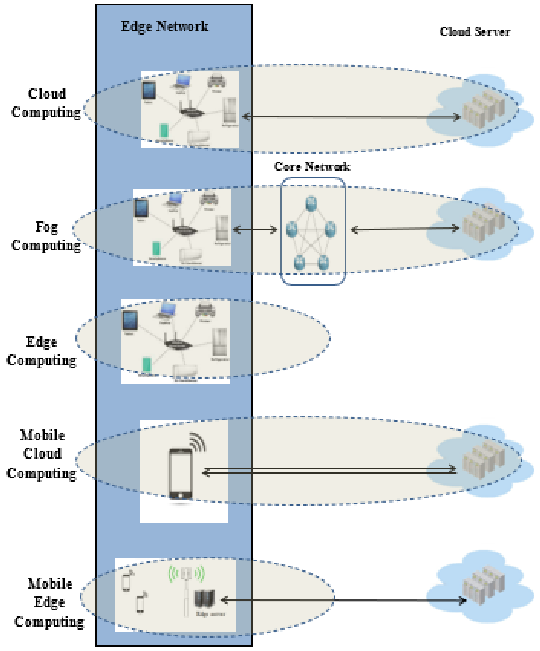

Figure1 Computation domain of cloud, fog, edge, mobile cloud and mobile edge computing(Mahmud et al., 2018)

2.1 Cloudlet

In order to facilitate the use of an appropriate application, cloudlets are often small box data centers that are placed in public spaces like malls, office buildings, and hospitals at a wireless hop's distance from mobile devices (Abbas et al., 2018). The internal architecture of a cloudlet consists of a collection of potent multicore computers with fast internet connection and a high-bandwidth wireless LAN that is accessible to nearby mobile devices. For safety concerns, the cloudlets are kept in a tamper-resistant box to ensure security in unattended areas (Bilal et al., 2018). Because cloud computing has enough storage and strong processing capability, it has processed data efficiently. Despite being a centralized system, cloud computing requires sending all requests and data to the cloud for processing. The cloudlet was suggested as a way to move resources closer to edge devices, enabling local processing and storage. It

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would also lower latency and the rate of network transmission (Hu et al., 2017).

2.2 Mobile cloud computing

Another technique called Mobile Cloud Computing (MCC) aims to maximize cloud computing resources to offer mobile customers a new framework of services. While coordination and data preservation are done in the cloud, some operations and analytical tasks are completed on the edge device (Hu et al., 2017). The limitations of mobile devices in terms of energy, storage, and computational power drove the development of MCC. Known as "cloudlets," MCC commonly places tiny, light cloud servers at the perimeter of the network. Rich mobile applications are produced using cloudlets in conjunction with mobile devices and cloud data centers, resulting in a three-tier hierarchical application deployment architecture (Mahmud et al., 2018).

2.3 Mobile-edge computing

A system known as Mobile-Edge Computing (MEC) was developed to give mobile users access to other IT services and the cloud while they are in close proximity to a radio access network (RAN). By moving storage and processing power from the core network to the edge network, MEC's main goal is to reduce latency. A paradigm called "Mobile Edge Computing" allows a business-focused cloud computing platform to be placed in the radio access network close to mobile customers, allowing it to provide context-aware and delay-sensitive applications (Abbas et al., 2018; Li et al., 2017; Mahmud et al., 2018).

2.4 The architecture and the environment of fog computing

Fog computing is an outpost of cloud services, not a stand-alone paradigm. The architecture is made up of combinations of fog nodes, and the fog environment is made up of three layers: the cloud layer, the fog layer, and the terminal layer (Hu et al., 2017). Furthermore, data can be processed locally by the fog with a desired latency (Caiza et al., 2020).

2.5 Characteristics of fog computing

The huge size of geo-distributed nodes, position awareness, mobility support requirements, variety of fog nodes and fog networks, low latency, and mobility support are some of the highlighted characteristics of fog computing (Yi, Qin, et al., 2015).

2.5.1 Low latency

This is the shortest amount of time needed to process, evaluate, and fulfill the computational request. The close proximity of the fog nodes to the edge devices facilitates faster analytical replies and calculation jobs.

2.5.2 Heterogeneous end-user support

Because the asking IoT device is nearer the processing node, end-user assistance is maximized (Anawar et al., 2018).

2.5.3 Multi-tenancy

Refers to a system's capacity to allow numerous instances to access and share a single instance of the program. (Nguyen Gia et al., 2018)refer to these systems as shared systems. This was welcomed by the highly virtualized and distributed fog platform.

2.5.4 Mobility support

It is a feature that makes it possible to register and deregister Internet of Things devices between access points. Mobility support is a critical need for mobile IoT systems since missing or delayed data when the device is in motion could be harmful (Nguyen Gia et al., 2018). Hence, unmediated transmission between the IoT device and the fog node is necessary (Mahmood & Ramachandran, 2018).

2.5.5 Context-awareness

By retrieving data, this feature enables fog nodes to gain knowledge about their networks and make better decisions.

2.5.6 Wide geographical distribution

Fog computing's architectural design gave the paradigm the capacity to distribute widely geographically while guaranteeing the provision of QoS (Mahmood & Ramachandran, 2018).

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2.5.7 Wireless access network

This relates to wireless sensing devices that use the Wireless Access Protocol (WAP) to access network services.

2.5.8 Interoperability and federation

Enhancing open standards and giving third-party systems the capacity to run models and processes through web service calls while allowing the output to be shared for use with other services are two ways to make fog computing systems more open and interoperable (Yi, Li, et al., 2015).

2.5.9 Real-time analytic

Real-time analytics in fog computing is the process of collecting, analyzing, and acting upon data as it is generated, instead of waiting for it to be transmitted to a central location for processing(Bonomi et al., 2012).

3. Security threats of fog computing

The majority of fog computing applications are driven by the user's demands and/or their desire for functioning services, either neglecting or giving security considerations second attention (Khan et al., 2017). Fog computing security issues have not received enough attention (Gope, 2019). Fog computing may be open to abuse due of the security issues associated with cloud computing (Aljumah & Ahanger, 2018). The OpenFog RA's security architecture is not one-size-fits-all. Instead, it outlines every technique that can be used to secure a fog node from software to silicon (Alli & Alam, 2020). Numerous academics have been attempting to offer solutions in various fog computing domains. Nonetheless, fog computing security remains a crippling issue in both academic and industrial settings (Kayes et al., 2020). Furthermore, as fog computing and cloud computing operate on distinct tiers and have different architectures, the security solution designed for cloud computing might not work for fog computing (Hu et al., 2017).

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3.1. Forgery

This type of attack involves the attacker trying to mimic a specific node in order to trick the end users into performing actions that the attacker chooses. Unfortunately, that may slow down the network's performance due to excessive usage of bandwidth, storage, and energy, which could negatively impact the quality of service (Aljumah & Ahanger, 2018).

3.2. Tampering

This kind of assault involves the attackers dropping the data, delaying its transmission, or even altering it. Owing to the mobile nature of fog computing, it can be more challenging to identify this type of assault right once because the network can impede or induce delays in data transfer (Dang & Hoang, 2017).

3.3. Spam

Unwanted, junk mail sent to an Internet user's mailbox is sometimes referred to as spam (Faris et al., 2019). In order to take advantage of the victim's network resource and compromise privacy, the attacker deceives them with undesired data in this assault.

3.4. Data privacy

They also go by the name "information privacy." It is in charge of specifying the proper handling of the information. Insufficient data privacy in fog networks might make a user's beliefs and preferences visible to unreliable nodes.

3.5. Usage privacy

This is the configuration or model that the user employs to access fog services, protecting their privacy regarding their status and transactions on the network.

4. Application areas of fog computing

4.1. Healthcare management

Delivering better healthcare services became the benefit of having numerous servers in a fog environment, each capable of running a certain application. A healthcare system can benefit greatly from fog

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computing, which lowers energy consumption, delays, and data traffic. Additionally, since the fog's layer saves sensitive and important information inside the company, evaluating and keeping data locally there improves security (Vilela et al., 2019).

4.2. Traffic light systems

Virtual traffic light systems, which are more economical, have taken the place of traditional physical traffic signal systems in fog computing and vehicular networks. Furthermore, fog computing offers a simple method of reducing traffic congestion by directing vehicles to less congested routes via vehicular communications or by adjusting traffic signals in response to changing traffic conditions (Banikhalaf et al., 2005).

4.3. Medical wearables:

Healthcare professionals are increasingly using these gadgets. It is employed in the provision of telemedicine, patient condition monitoring, and on-site staff guidance during surgical procedures (Mahmood & Ramachandran, 2018). In addition to lowering medical costs, fog computing is becoming a mainstay of contemporary healthcare systems (Wu et al., 2018).

4.4. Connected vehicles:

Fog computing facilitates safe and effective real-time communication between vehicles, traffic signals, and access points with the aid of context awareness. As a result, because the fog nodes are close to the IoT devices, they can facilitate vehicle-to-vehicle communication (Mahmood & Ramachandran, 2018). Fog computing is used to provide short-distance domestic connections and low-latency services to the automobiles in VANET environments (Pereira et al., 2019).

4.5. Smart homes and cities

Smart-city applications aim to improve the way the city functions and provide users with immediate feedback on issues that may arise during their daily operations. Although the cloud-based solutions for smart cities meet many of the requirements, they have numerous drawbacks, such as issues with localization, scalability, mobility support, and latency. While fog computing reduces latency and enhances quality of service, context awareness, load balancing, and data distribution efficiency by bringing cloud computing services closer to edge devices (Pereira et al., 2019).

5. Issues and challengesface fog computing

Because fog computing is heterogeneous, it has structural issues. Since either the edge or the core network can function as a fog node, some nodes may not be intended to provide computations for general-purpose use. As a result, it could be difficult to integrate the general-purpose function from its usual duty. Furthermore, because some fog nodes have limited resources, the expansion of large-scale applications may encounter difficulties in the face of service orientation. Thus, a programming environment that facilitates the creation of distributed applications is required. The fog's quality of service can be greatly impacted by the implementation of a data-centric integrity security system. Furthermore, it may be challenging to maintain the privacy of such a large distribution network and to authenticate access to services (Mahmud et al., 2018). Fog computing still has a problem with device-to-device (D2D) connections despite its abundance of functionalities (Gope, 2019). Numerous studies on fog computing, according to (Alli & Alam, 2020), focused on solutions from IoT to fog and fog to cloud. Nonetheless, as fog computing is still in its early stages, research on fog-to-fog communication is vital. Fog-to-fog selection, job prediction from past data, fog-to-fog resource use, and the fog nodes' mobility, scalability, and robustness were a few instances. The performance of fog ecosystems, robustness, storage, energy savings, utilization of distributed fog through a combination of D2D and cellular network, mobility and node selection, trust and security issues at all levels of the fog paradigm are other topics that have been found but still require understanding. For a very long time, experts have studied new technology.

The quality of services in the health industries has begun to improve with the integration of fog and IoT services. These reduce operating costs, maximize electricity usage, and increase operational efficiency. Applications for fog e-Health can enhance the standard of care provided to patients and reduce certain medical issues that may even result in the patient's death. Additionally, the applications' generated data can be used to study and stop pandemics and/or epidemics (Vilela et al., 2019). It is being emphasized that the healthcare sector will see the use of strong fog computing technologies to ensure high-quality service delivery. Securing sensitive data, managing system failures, configuring different systems, and managing various systems with various dimensions are some of the difficulties it encounters (Alli & Alam, 2020). In order to fulfill its role as a provider of application awareness for crowdsourcing and sensing applications, FC must make certain measures to set aside resources that may be used to supply mobility services. The problem here is that variations in compute, storage, bandwidth, and latency may cause problems for the mobile node (Hu et al., 2017).

6. Future research directions

A platform called fog computing serves as a conduit for network, computation, and storage services between edge nodes and the cloud (Zhang et al., 2018). As a result, numerous vital application services are created to fulfill a specific or general purpose. The most important issues in cloud and edge computing are those of transportation, location, storage, and efficient and effective computation of massive amounts of data (Karatas & Korpeoglu, 2019). so, providing a route for further research.

6.1. Healthcare applications

Healthcare administration had previously found success with cloud computing prior to the advent of fog computing. However, a cloud-based architecture's long reaction time is caused by any network outage or insufficient bandwidth. It impairs the patient's quality of life and may possibly cause death, making it inappropriate for usage in medical settings. One could argue that cloud computing does not always provide healthcare applications with a high enough level of service quality(Akrivopoulos et al., 2017; Pourkiani et al., 2019, 2019). According to WHO projections, there will be a worrisome

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global shortage of 12.9 million healthcare workers by 2035. Energy-efficient, affordable, and scalable healthcare technologies are required to support illness prevention and treatment in order to alleviate the scarcity of healthcare professionals (Asif-Ur-Rahman et al., 2019).
By enhancing response times, access controls, privacy, and other aspects of traditional services, as well as by bringing devices closer to users and patients, fog technology is now being utilized to improve them (Mahmood, 2018). Improved decision-making can be facilitated by using the newest characteristics of fog computing to expedite the identification of early warning signs of emergencies in time-sensitive healthcare applications. Fog computing performs better than cloud computing in time-sensitive applications by offering convenient data access and making wise decisions during emergencies (Chakraborty et al., 2016). It is possible to reduce the patient data retrieval time by utilizing fog computing functionalities (Wang et al., 2020).

6.2. Smart city applications

Better real-time reaction is provided by fog computing as compared to cloud-based models. Transmission from intelligent devices (such as sensors) to the cloud becomes a bottleneck due to Wireless Sensor Networks' (WSNs') poor communication capabilities. This is especially true for cloud-based IoT applications that are latency-sensitive. Future expansion could be hindered and application efficiency compromised by this constraint. In sustainable smart cities, fog computing solutions optimize resource use, save expenses, boost system performance, and more successfully connect IoT devices. Numerous potential for consumer service management, growth, and governance arise from the integration of numerous IoT technologies. Cities are important places that symbolize the standard of living for people.

6.3. Farm applications

In order to improve the services, they offer to customers, the agriculture industry is progressively implementing the Internet and specific networking technologies. The Internet is known to have

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shortcomings, particularly when it comes to handling big networked devices (IoT) or stakeholders (Trilles et al., 2020). It isn't lagging behind in fog computing, either, as fog is finding its way into production control, maintaining farm productivity standards, monitoring the health of livestock and crops in real time, and expanding the market. Crop management, animal management, and climatic condition prediction are further agricultural applications of fog computing (Alli & Alam, 2020). By employing picture alignment analysis, it can also be utilized to enhance pest detection systems (Hsu et al., 2020). Smart agriculture can be used to help farmers monitor their farm remotely and determine the best time to cure a disease (Trilles et al., 2020).

It's critical to keep in mind that fog computing is still in its infancy and that further study is necessary. All things considered, there are many fascinating study areas in fog computing, and there may be much more to learn in the years to come.

7. Conclusion

A novel paradigm that has gained widespread recognition and appreciation for its substantial contribution to contemporary computing technology is fog computing. In addition to reviewing and discussing cloud computing, this study also briefly highlights the prior to fog computing applied paradigms. Cloudlet, mobile cloud computing, and mobile edge computing are some of these paradigms. Enhancing the quality of service between end devices and the cloud itself was the goal of all the models. Based on recent research on fog computing security challenges, service issues, operational issues, and data management is offered.

Potential applications and challenges are noted. The research demonstrates that among the contributions from the scholars, security, privacy, application, and communication concerns are significant. There are additional identified potential uses for fog computing, such as creative city applications, healthcare applications, and agricultural applications.

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