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Integration Of Edge And Fog Computing In Iot-Based Healthcare Applications - A Review

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Abstract

The use of the Internet of Things (IoT) in the healthcare industry has the potential to improve healthcare services and outcomes through the use of connected devices and technology. By collecting and analyzing a large amount of data from various sensors and devices, the combination of IoT and centralized cloud computing can enable healthcare professionals to remotely monitor patients in near real-time, accurately diagnose conditions, and provide more personalized and efficient treatment through the use of artificial intelligence. However, high latency, low storage, lack of geographical location awareness, network failure, and security and privacy issues remain challenges in the adoption of IoT and cloud computing in the healthcare industry. To address these weaknesses, there is increasing interest in using edge and fog computing, which brings cloud computing capabilities closer to IoT devices through the use of intermediary nodes or gateways to process and transmit data, rather than sending all data to a central cloud server. This can reduce latency, improve data security and privacy, and allow for more efficient use of resources. This paper provides a review of state-of-the-art of edge and fog computing, its integration with the IoT, and the benefits and challenges of implementing the fog model in healthcare applications. It also covers various edge and fog computing architectures and how they can be used to improve emerging IoT applications, including potential future research directions related to fog computing, and AI in edge/fog layer in the IoT-based healthcare applications.

Keywords: Internet of Things; Fog computing; Edge computing; Artificial Intelligence; Healthcare; Computing technology

1. Introduction

The Internet of Things (IoT) refers to the interconnected network of physical devices, such as sensors, actuators, and other devices, that are embedded with electronics, software, and network connectivity, allowing them to collect and exchange data. These devices are able to communicate and interact with each other and with other systems and devices over the Internet, enabling the creation of smart environments and systems. IoT has the potential to transform a wide range of industries, including healthcare, transportation, manufacturing, energy, and agriculture, by enabling the development of smart systems that can improve efficiency, reduce costs, and enhance customer experience [41]-[45]. The concept of "smart healthcare" originated from IBM's idea of a "Smart Planet" in 2009. This involves using sensors to gather information, transmitting that information through the Internet of Things (IoT), and using supercomputers and cloud computing to process the information. The goal is to use this intelligent infrastructure to coordinate and integrate social systems in order to achieve efficient management of society. Smart healthcare utilizes technology like wearable devices, the Internet of Things (IoT), and mobile internet to access and connect with information, people, materials, and institutions related to healthcare [1]. The Internet of Things (IoT) is improving the quality of treatments for both patients and healthcare professionals, allowing for the analysis, management, and delivery of real-time results. Real-time results include monitoring of various vital signs, such as blood pressure, heart rate, oxygen level, and blood temperature, without the need for healthcare professionals. AI is used to run machine learning tasks on IoT networks, which analyze all the data to identify trends, detect early signs of disease, and alert for potential threats [2].

Cloud computing refers to the delivery of computing resources, such as storage, processing, and networking, as a service over the Internet, enabling users to access and use these resources on demand, without the need to own or manage the underlying infrastructure. The Cloud provides various types of services, including Platform as a Service (PaaS), Software as a Service (SaaS), and Infrastructure as a Service (IaaS), which are all moving towards offering "Anything" as a Service [3]. However, certain large amounts of data generated by sensors cannot be transferred to and processed by the cloud. In addition, some healthcare IoT applications require faster processing than what the cloud is currently capable of due to the critical nature of this industry. Edge and Fog computing addresses this issue by bringing processing capabilities closer to the devices generating the data, allowing for faster processing times for IoT applications [4]. Fog computing, also known as fog networking or edge computing, is a decentralized computing paradigm that brings computation and data storage closer to the edge of the network, where IoT devices and sensors are located. Fog computing enables real-time processing and analysis of data generated by IoT devices, without the need for the data to be transmitted to a central server or cloud for processing [5]. This reduces the latency of the system, as well as the burden on the network and the central server. Additionally, the edge/fog layer provides privacy, security & data storage capability. Overall it improves the system's performance [6]. Fog and Edge computing does not replace cloud computing but rather work alongside it to provide additional capabilities and support. While cloud, Edge, and fog computing can be used together to create hybrid systems, fog computing is particularly well-suited for applications that require low latency, high bandwidth, and real-time processing, such as in the healthcare, transportation, and manufacturing industries [6].
In the healthcare industry, fog and edge computing can be used to enable the development of smart healthcare systems that can improve the delivery of care, enhance patient outcomes, and reduce costs. Some examples of the application of edge/fog computing in IoT for smart healthcare include Remote monitoring, Clinical decision support, Telemedicine, Disease surveillance, Supply chain management. Overall, the use of IoT and edge/fog computing in healthcare can improve patient outcomes, reduce costs, and provide data privacy and increase efficiency in the healthcare system.

In this review paper, we attempt to contribute to the concept and application of edge and fog computing in the smart healthcare industry. The rest of the paper is organized as follows: Section 2 presents a Cloud computing overview, Section 3 discusses Edge computing and its architecture, followed by section 4 which introduces Fog computing, its architecture, and various services provided by this layer. Section 5 provides a comparison of edge and fog layers. Section 6 presents the characteristics of the edge and fog layer. Section 7 provides examples of IoT healthcare applications where researchers have used edge/fog for real-time processing. Section 8-10 includes advantages, challenges, and discussion on future research on the use of fog/edge with AI. Section 11 gives a conclusion and finally, the reference paper used in this review paper has been listed under the reference section.

2. Overview of Cloud computing

Cloud computing is a technology that has been widely used in the tech industry for over a decade. It involves moving computation and storage to a centralized server called the cloud, which is located in a data center and accessed by end-user devices using a client-server protocol over a wired or wireless network. The cloud is divided into two layers: the upper layer consists of centralized servers with powerful processing and storage capabilities, while the lower layer consists of end-user devices with network connectivity. However, it has some disadvantages, such as high latency and heavy bandwidth usage, which can affect the performance of real-time applications. The Internet of Things (IoT) generates a large amount of data that needs to be processed in real-time. The centralized server handling large amounts of data can lead to congestion in the cloud servers and backhaul links. Another variant of cloud computing, called multi-cloud computing (MCC), involves distributing services across multiple clouds. While MCC can improve data redundancy and recovery, it also introduces complexity and portability issues [7]. The conventional structure of cloud computing involves data producers generating raw data and sending it to the cloud, and data consumers sending requests for data to the cloud, as indicated by the solid blue line in the figure 1 [5]. The cloud then sends the requested data back to the data consumers, as indicated by the dotted green line. However, this structure is not suitable for the Internet of Things (IoT) due to several issues. First, the large volume of data generated at the edge of the network can lead to excessive bandwidth and computing resource usage. Second, the need for privacy protection can be a challenge for cloud computing in IoT. Lastly, many IoT end nodes are energy constrained and rely on wireless communication modules that are energy intensive, so offloading some computing tasks to the edge can be more energy efficient [5].

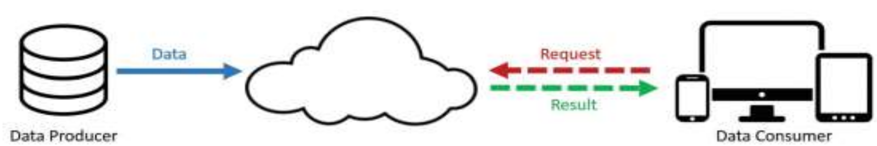

Figure 1: Cloud computing paradigm [5]

3. Overview of Edge computing

Satyanarayanan, a professor at Carnegie Mellon University in the United States, defines edge computing as a new computing model that involves placing computing and storage resources, such as cloudlets, micro data centers, or fog nodes, at the edge of the network near mobile devices or sensors [8]. Another definition provided by the author in this reference [9] as - "Edge computing is a distributed computing paradigm which brings data center services closer to the last hop of the network, where end devices reside. Edge computing aims to shift the processing and computation power partially or completely from a centralized data center toward distributed edge devices." In other words, Edge computing refers to technologies that allow computation to be performed at the edge of the network, between data sources and cloud data centers. This can include IoT devices like sensors, smartphones, vehicles, and wearables, which serve as the edge between the body and the cloud, or gateways in smart healthcare, which serve as the edge between devices and the cloud. The goal of edge computing is to perform computation as close as possible to the data sources, in order to improve efficiency and reduce latency. Edge computing is similar to fog computing, but tends to focus more on the things side of the network, while fog computing focuses more on the infrastructure side. Edge computing is located at the edge of the network, near IoT devices. However, it is not located directly on the IoT devices, but rather one hop away from them. It is important to note that the edge can be more than one hop away from IoT devices in a local IoT network [10]. Edge computing uses the close proximity of servers to physical objects to help support and improve the functionality of the low-powered IoT layer while reducing network latency and transportation costs [9].

3.1 Overview of Edge computing Architecture

Different architectures have been proposed by the authors to realize edge computing platforms. A detailed review of this architecture and their advantage can be found in reference [11]. In this case study, the author has classified edge computing architecture based on common features of deployment. However, the most commonly used architecture is general architecture. Below is a brief overview of the components and functions of each layer in general edge computing architecture:

The bottom layer - of this system also known as an IoT access layer is made up of many IoT devices, such as sensors, smartphones, and wearable devices, among others. Some of these devices are mobile, while others are stationary. These devices are able to generate or gather raw data, which is then transmitted to a higher-level device for further processing.

The middle layer - the Edge Computing layer consists of edge nodes, which are devices that have some computing capabilities, such as base stations, routers, set-top boxes, and switches. These devices can provide services to users, including offloading computational tasks, storing transient data, caching content, and delivering services from the cloud to users. They can also work together to provide collaborative services to users, such as in the connected health use case described by Shi et al. [5], where hospitals, pharmacies, logistics companies, governments, and insurance companies form a collaborative edge to provide healthcare services. In addition, edge nodes can help to alleviate the burden on the cloud by taking on some computational tasks. User devices with some computational power act as edge nodes to preprocess raw data before sending it to a cloud server for further processing. However, if the computation task is too large for the user device to handle, the task can be offloaded to an adjacent edge node. For example, in a case study proposed by Shi et al. [5], video analysis can be used to find a lost child. The cloud sends a request to search for the child to all cameras in a targeted area, and the cameras perform the search mission and return the results to the cloud. In this case, the cameras act as edge nodes to execute the search request, which can alleviate the burden on the cloud and save search time compared to a method that relies on the cloud to perform the search analysis.

In the second type where computation is too large to handle by the edge node, user devices offload some computational tasks to adjacent edge nodes for preprocessing (such as data compression and data fusion), and then the cloud performs the final analysis. In this situation, hybrid communication technologies, including wired communication technologies (such as Ethernet and optical fiber) and wireless communication technologies (such as ZigBee, WiFi, and LTE) are applied to facilitate communication between the different layers of the system (i.e., IoT device layer, edge computing layer, and cloud server layer). It is worth noting that the communication between the cloud server and edge nodes, as well as the communication among edge nodes, is usually supported by wired communication technologies, while edge nodes and IoT devices communicate with each other using wireless communication technologies [12].

The last layer - is the cloud computing layer, which performs further processing on data that has already been pre-processed by the edge nodes. In some cases, the cloud server may delegate computational tasks to the edge nodes. There are two situations where the cloud server needs to perform additional processing after the edge nodes have finished processing the data. The first is when coordination between edge nodes is required, and the cloud server can help to facilitate communication between them. The second is when the data analysis requires a large-scale or long-term approach, such as when analyzing data from an entire city over a period of several years. In these cases, the edge nodes typically send the data to the cloud server for analysis [13] [12].

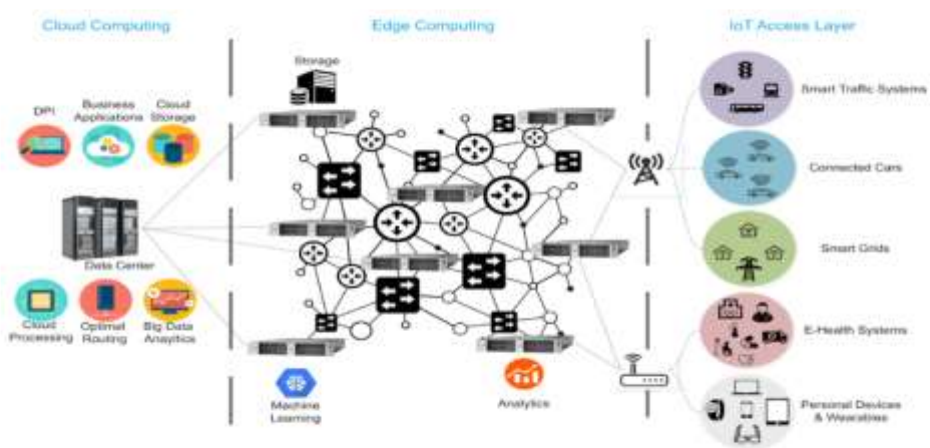

Figure 2: Edge Computing architecture

4. Overview of Fog computing

According to Cisco [14], "the fog extends the cloud to be closer to the things that produce and act on IoT data. Fog applications are as diverse as the Internet of Things itself. What they have in common is monitoring or analyzing real-time data from network-connected things and then initiating an action." The author Yi et al. in [15] has provided a more general definition of fog computing where he defines it as follows - fog computing is a distributed computing architecture that utilizes a network of connected devices at the edge of the network, including edge devices, to provide flexible computation, storage, communication, and other services to many clients in proximity. These devices can work together and be supported by cloud services to enable the delivery of services in isolated environments. In other words, Fog computing adds a decentralized layer of enterprise computing between the source of data and a central cloud platform. Like edge computing, fog computing brings the processing power closer to where the data is generated. This helps to improve efficiency, but fog computing can also be used for cybersecurity and regulatory compliance. Fog computing is also defined by the OpenFog Consortium [16] as; "a system-level horizontal architecture that

Distributes resources and services of computing, storage, control, and networking anywhere along the continuum from Cloud to Things". Similar to edge computing, Fog computing is not intended to replace cloud computing, but rather to work alongside it and complement it by handling less intensive analytics and processing tasks at the edge of the network. This helps to reduce the workload on the cloud and allows it to focus on more resource-intensive tasks. Fog computers process data in real-time and create analytical summaries, which are then shared with a central cloud platform for further analysis. Edge devices that generate or collect data may not have the storage and computing power needed for advanced processing tasks, such as those related to machine learning and analytics. In these cases, the cloud can provide the necessary resources but may be too far away to be efficient for certain applications. Fog computing fills this gap by providing a more efficient and effective way to perform these tasks. Additionally, transmitting raw data to a remote cloud server over the internet may not be compliant with certain regulations, and fog computing can address this concern by providing a more private, secure, and compliant environment for processing sensitive information. Fog computing has a wide range of applications, including in smart cities, smart grids, smart homes, and software-defined networking (SDN) [6]

4.1 Overview of Fog computing Architecture

Fog computing is based on cloud computing concepts such as virtualization, hypervisors, and encryption. It is a modern system that provides minimal processing, memory, and networking capabilities at the edge of the user's endpoint. The IoT-fog computing-based healthcare architecture consists of three layers: the device layer, the fog layer, and the cloud data center layer, as shown in Figure 2 [17].

1. Device layer: Patients use sensors and monitors to track their health, and these devices are able to sense and transmit data in real-time. These devices, located on the device layer, are responsible for selecting healthcare data and transmitting it to the fog layer for access via Wi-Fi or mobile network. Sensors, wearables, and smartphones are a few examples of device layers.
2. Fog computing layer: Fog computing is a virtual platform that provides processing, storage, and networking services between a device and a cloud computing data center. It is not limited to being located at the edge of the network, and the resources it provides for processing, storing, and networking are building blocks for both cloud and fog computing [18]. This layer collects and analyzes medical data from various IoT health-tracking devices in real-time.
3. Cloud computing layer: The cloud computing layer is responsible for storing, preparing, and carrying out tasks that the fog layer is unable to handle. The core of fog computing, the cloud layer, performs data virtualization, analysis, and machine learning, and updates rules and patterns in the fog layer's proxy servers. These proxy servers act as simpler

cloud servers, and centralized data storage provides easy access to data for computing resources in the cloud. This data storage, located at the center of the fog computing structure, can be accessed by both the device layer and the fog layer [18].

A detailed survey of various types of architecture used by other researchers can be found in the reference [19].

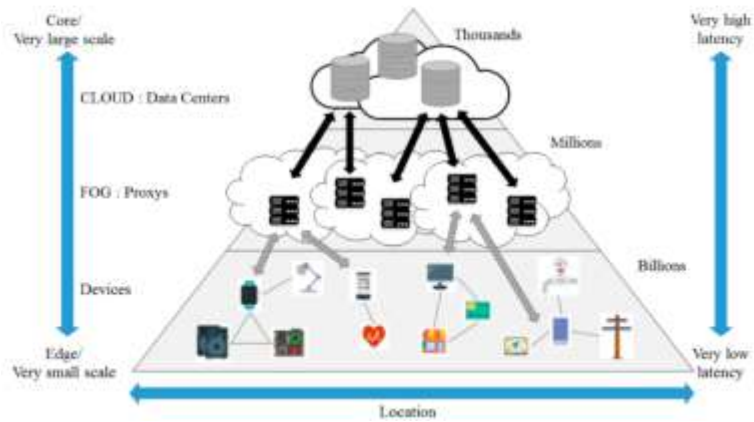

Figure 3: The architecture of Fog computing

4.2 Service provided by the fog layers

Data management: It is critical because sensory data is locally used to extract important information that can be used to respond to users and adjust the system's plans. The fog layer dynamically receives a large amount of data from the sensor network in a short period of time, and its main focus is to control this incoming data in order to provide a fast response based on the number of users and system conditions. This task is especially important in healthcare settings, as delays or errors in decision-making can lead to serious harm to patients. To manage data effectively, the researchers have identified five different components that are necessary for an intelligent e-health gateway: local repository, data analysis, data filtering, data compression, and data integration [20].

1. Local Repository - Data from sensors such as temperature sensors, ECG sensors, EMG, and blood pressure sensors connected to a wearable device is gathered, stored in local repository and analyzed to inform decision-making processes.
2. Data filtration: There is a high chance of getting noise with all the bio-signals which are collected from the sensors. The fog layer performs data filtering to boost the signal-to-noise ratio before performing data analysis.
3. Data Compression: Data compression is used to reduce the amount of data that is transmitted through a communication network. In healthcare IoT applications, it is important to use lossless compression methods to avoid incomplete or inaccurate disease diagnoses due to lost data. Additionally, by compressing the data from sensors connected to wearable devices worn by patients, it is possible to reduce the amount of data transferred over the network and reduce the amount of storage space needed in the cloud. This can be helpful for

disease prediction, risk analysis, and long-term use for researchers [21].

4. Data Integration: At this stage, Sensory data from various sources is combined to gain more valuable and robust insights. By combining data from different sources, such as an ECG signal and a respiration signal, more accurate and reliable information can be obtained.
5. Data analysis - After data integration, they are analyzed for the emergency situation. If there is any high-risk event obtained from the analysis then notifications would be sent to the patients using edge devices and data further would be transmitted to the cloud.

Handling Event: There can be several significant occurrences, such as changes in vital signs,

5. Comparison of Cloud, Edge, and Fog computing

1. Comparison between cloud and edge computing:

Table 1: Comparison of edge and cloud computing

	Edge Computing	Cloud Computing
Location Awareness	Yes	No
Geographic position	Fixed position	Various position
Latency	Low	High
Large-scale IoT support	Yes	No
Mobility	Yes	No
Hardware	Heterogeneous Devices	General Devices

activities, or surroundings of the patient, during the monitoring of a patient's condition. Fog computing can quickly provide low-latency notifications to healthcare professionals, caregivers, and patients in case of critical conditions.

Privacy and security: Fog computing can be used to enhance efficiency and improve cybersecurity and regulatory compliance [22]. Security in healthcare is very important to avoid patient data breaches or getting healthcare devices hacked which can put human life at risk. In reference [23], the author has conducted a detailed survey on security and privacy issues and their solution in fog computing.

A summarized comparison of cloud computing and edge computing has been proposed by the author Dan Liu et al. in reference [12].

Network architecture	Decentralized	Centralized

2. Comparison of edge and fog computing:

Edge computing involves performing data processing and analysis at the edge of a network, close to where the data is being generated. On the other hand, fog computing acts as an intermediary between the edge and the cloud, providing additional processing and storage capabilities for applications such as data filtering. While fog computing can enhance edge computing and cannot work without edge computing, edge computing can exist without fog computing in many cases.

According to the OpenFog Consortium, fog computing is a broad IT architecture that creates connections between various components, including edge devices, the cloud, shared local computing and storage resources, and other edge devices such as IoT gateways. It standardizes the extension of the cloud out to the edge, covering all the space and activity in between.

Edge computing, on the other hand, is more specific and refers to instances of computational processing that occur at or near the endpoints of a network. Fog computing always involves edge computing, but edge computing may or may not involve fog computing. Additionally, fog computing includes the cloud, while edge computing does not.

Fog computing is a way to bridge the gap between edge devices and the cloud. It involves the use of computing and storage resources located between edge devices and the cloud, allowing for the processing and storage of data closer to the source. This helps to reduce the amount of unnecessary data being transmitted to the cloud, improving the efficiency and speed of data transfer. Fog computing also allows for real-time data processing and decision-making, making it particularly useful for time-sensitive applications such as autonomous vehicles and healthcare.

Fog computing can also improve security by encrypting data before it reaches the cloud and providing decentralized data storage and processing. Overall, fog computing helps to improve the performance and efficiency of data transfer between edge devices and the cloud, while also addressing security and privacy concerns [24].

Table 2: Comparison of Edge and Fog computing

	Edge Computing	Fog Computing
Computing service	Response time is usually milliseconds	Response time ranges from seconds to minutes based on application architecture
Bandwidth utilization	Very low	low
Communication protocol	Wireless LAN, 3G, 4G, IP	Wireless LAN

Server overhead	Very low	low
Storage and processing service	Data can be stored for hours up to days and with high processing feature. Collects data from multiple endpoints.	Data can be stored for hours up to days and with high processing feature. Collects data from multiple endpoints.

6. Characteristics of Edge/Fog Computing

1. Location awareness: Edge/Fog computing allows for the deployment of fog nodes in different locations, which enables it to be aware of the location of end devices. This proximity to the end devices helps to reduce latency when processing their data. Edge/Fog computing allows data to be collected and processed based on its location, rather than being transported to the cloud for processing [5].
2. Geographically distributed: The Edge/Fog computing platform offers services and applications that can be deployed and used in any location, rather than being restricted to a centralized location such as a cloud server. Collaborative edge computing involves the use of multiple, geographically distributed edge computing nodes to share data and resources, allowing for collaboration among stakeholders who may have privacy concerns or face high costs for data transportation. This concept expands upon traditional edge computing by connecting the edges of multiple stakeholders and facilitating collaboration in spite of their physical location and network structure.
3. Low Latency: Edge/Fog computing is well-suited for applications that demand quick responses with low latency, such as emergency health or public safety situations. This is because edge/fog computing can reduce data transmission time and simplify network structure by processing data locally at the edge of the network rather than transmitting it to a central cloud for processing. This can also improve efficiency by allowing for quicker decision-making at the edge of the network instead of having to collect and process information at the central cloud.
4. Real-time interactions: Fog computing applications provide real-time interactions between fog nodes, rather than the batch processing that is typically used in cloud computing.
5. Heterogeneity: The fog is able to accommodate different types of hardware and software, and can be deployed in a variety of environments
6. Interoperability and federation: The fog can support the interoperability of different types of devices and services from multiple providers, allowing them to work together seamlessly especially for services that require real-time interaction like streaming.
7. Online analytics and interplay with the cloud: Fog computing act as a bridge between cloud and end devices, allowing for the processing and analysis of data at the edge of the network. This helps to improve efficiency and reduce the burden on the cloud.

7. Application of Edge/Fog computing in healthcare

The increasing population has made it difficult to provide healthcare services to everyone. In the past, online healthcare applications were not accessible to the general public due to the lack of suitable and affordable handheld devices. The introduction of the Internet of Things (IoT) with a clear architecture and the widespread use of smartphones has led to significant growth in IoT technology. While IoT has various applications such as smart cities, smart farming, and smart parking, the healthcare domain has become one of the most popular areas of IoT technology. IoT, along with cloud computing, fog computing, and edge computing, is a promising technology for creating a digital and advanced healthcare system [25]. Fog/Edge computing is essential for healthcare real-time processing.

Author Sujata Dash et al. in [20] have proposed a detailed smart e-health monitoring system using fog computing with the smart gateway. Gateways are typically used to connect a sensor layer to cloud services. When considering the role of gateways in a smart home or hospital where users and devices are stationary within the building, it becomes clear that these stationary gateways have the advantage of being able to handle large amounts of processing power, power consumption, and communication bandwidth without any constraints. This can be leveraged by giving gateways more processing power, intelligence, and networking capabilities, turning them into smart e-Health gateways [26]. In research [27] author T. N Gia et al. aim to improve a health monitoring system by utilizing the capabilities of fog computing at smart gateways, which can provide advanced services such as data mining, distributed storage, and notification at the edge of the network. In particular, they focus on using fog computing to extract Electrocardiogram (ECG) features, which are important for detecting various cardiac diseases. The ECG signals are analyzed in smart gateways, and features such as heart rate, P wave, and T wave are extracted using a lightweight wavelet transform mechanism. Based on their experiments, fog computing can significantly improve bandwidth efficiency by more than 90% and provide low-latency real-time responses at the edge of the network.

As the aging population grows and more people develop chronic diseases, it is becoming more challenging to provide sufficient and effective healthcare services to meet the increasing demand [28]. In this article, the author has proposed a patient-centric e-healthcare system using the device, fog layer, and cloud to achieve speed and latency. Additionally, they have also implemented various healthcare applications like mobile health, assisted living, e-medicine, implants, and early warning systems, population monitoring in smart cities.

Apple acquired AI startup Xnor.ai, which specializes in low-power edge-based tools, for $200M in early 2020. Xnor.ai's remote monitoring capabilities could lead to added health features on the Apple Watch, such as monitoring blood oxygen levels. Wearable company Klue's gesture-sensing AI technology was purchased by Medtronic in 2019 to automate insulin delivery in the Medtronic Personalized Closed Loop (PCL) insulin pump system based on the wearer's current food intake [29]. Additionally, this article also mentions how edge computing can improve the transfer of patient information in healthcare, optimizing workflow and decision-making while saving time and increasing revenue. Oncora Medical, CloudMedX, and BioSigns are examples of companies developing edge-powered tools that incorporate AI and adaptive technology to streamline workflows, access patient data in real-time, and transfer patient data from ambulances to hospitals. These technologies can help decentralize medical administration systems and allow medical professionals to spend more time with patients.

A framework for fog-assisted healthcare was designed in developing countries to diagnose and prevent chikungunya, as the diagnostic test is not easily accessible. The proposed system in [30] aims to provide early diagnosis at home or in remote areas to minimize mortality rates by continuously monitoring users and collecting data in the cloud.

In the reference [31] author V. Jagadeeswari et al. has provided detailed fog computing-based healthcare monitoring architecture. This study also examines the use of emerging technologies, including cloud computing, fog computing, Big Data analytics, IoT, and mobile applications, in personalized healthcare systems.

Research article [32] discusses the development of fog-centric wireless, real-time, smart wearable and Internet of Things (IoT) based system for tracking and analyzing health and fitness in a smart gym setting. The system is designed to use data on body vitals, movement, and other health-related information to help athletes, trainers, and doctors interpret physical signs and identify potential health risks. The goal of the system is to support the health and fitness industry by providing a comprehensive, ubiquitously available framework for monitoring and analyzing health and fitness data. Their research was able to identify athletes' physical states with 97% accuracy.

Rahmani et al. [26] have proposed the use of fog computing in healthcare applications to improve various aspects of IoT architecture, including energy consumption, interoperability, performance, and trustworthiness. They demonstrated the effectiveness of their system through the use of an Early Warning Score (EWS) health monitoring case study.

8. Benefits of Edge/Fog computing

1. Enhanced Bandwidth: Networks with many connected devices can experience challenges due to limited bandwidth, which can easily become congested if there is a sudden increase in concurrent data transactions by multiple endpoints. While it is possible to increase network bandwidth to allow for more data throughput and connected devices, this can be costly. Edge and fog computing can help organizations overcome these challenges by allowing data to be processed at the edge, or setup box, routers, and access points instead of on the cloud, reducing bandwidth requirements and associated costs.

   This is especially useful in the IoT healthcare industry where quick response times are critical and there are a large number of devices. Time-sensitive healthcare applications cannot afford the high latency and network bandwidth requirements of sending data streams to the cloud for processing. To stream and process data in real-time at the edge, healthcare facilities and caregivers require efficient solutions. For example, author Elarbi Badidi et al. in [33] presents a five-tier architecture designed to handle the streaming and processing of data generated by devices and equipment in healthcare facilities and systems, enabling the development of smart healthcare applications using IoT, and edge/fog computing.
2. Optimized latency and congestion: Latency refers to the time it takes for data to be transmitted between two points in a network. While communication is generally fast, the distance between servers and clients can slow down data transfer speeds. Network congestion and service outages can further increase latency. Delays like these can impact time-sensitive business processes, such as device health monitoring, network analytics, and decision-making. Fast responses are crucial for certain applications, particularly in industries like autonomous vehicles and healthcare. Edge and fog computing reduce latency by processing data locally in almost real-time, enabling enterprises to experience almost instantaneous response times for time-

sensitive applications. For example, the author has presented the application of edge/fog computing in real-time healthcare for an emergency response systems as it often requires fast, efficient real-time actions, which can be hindered by latency on the cloud [34]. One way that fog computing can be used to improve the efficiency of a system is by acting as an alternative for sensor nodes to reduce the latency of a request for certain data, such as an electrocardiogram (ECG). By routing the feature extraction algorithm towards the fog layer, the total latency of the request can be minimized, improving the speed at which the data is available. This is particularly useful in healthcare applications where quick access to data is crucial [35].

3. Facilitating self-governed actions: While high latency and congestion can be a problem for many organizations, some organizations face an even more severe issue – no connectivity at all. Remote locations or any secure place may not have access to a functional internet connection. That's where edge and fog computing comes into play. These platforms work together to process data locally, even in situations where bandwidth is limited or connectivity is unreliable. Once the data is processed, it can be stored locally until a connection is established and the data can be sent to a central platform. One example of edge and fog computing enabling autonomous operations is using sensors on water purifiers to measure water quality in remote villages [6].
4. Improved security and privacy: Security is an essential concern in the healthcare industry, as any vulnerabilities in a system can potentially have serious consequences for patient safety. For example, a hackable insulin pump in an IoT glucose control machine could be a danger to patients if it was within 100 feet of the device. Ensuring the safety of every request in healthcare is, therefore, crucial [36] [20]. There are various security threats that can compromise the confidentiality and integrity of clinical data obtained from sensors and IoT devices in the healthcare industry. These threats include impersonation, data breaches, data integrity issues, eavesdropping, and collusion. It is important to protect this data from unauthorized access, as it is highly confidential and should only be accessed by authorized individuals. If the data is accessed by unauthorized individuals, it could be revealed and its confidentiality compromised [21]. Edge and fog computing offers enhanced data security and privacy by encrypting data before it is transmitted from the edge. This helps to protect the data from being accessed by unauthorized individuals and ensures that it remains confidential. For example, to prevent security breaches, this paper [38] proposes a user authentication method using identity management in a fog computing-based healthcare architecture. The architecture includes the use of the virtual machine (VM) partitioning in the fog node to securely run data from body sensor networks and medical IoT devices.

9. Challenges

Fog computing technology has advanced modern communication by addressing the technical issues of cloud computing, but it also poses security and privacy threats. The existing security techniques of cloud computing are not suitable for fog computing due to its characteristics such as mobility, heterogeneity, and geo-distribution, so new security mechanisms are needed. While fog computing has advantages over cloud computing, it has its own security issues that can hinder the deployment of modern systems using fog computing. Previous research has addressed various security concerns in fog computing, but some only focus on specific aspects of fog applications or architecture security. In the survey [39], the authors have discussed the main security and privacy challenges facing fog and edge computing and how they can impact the work and implementation of these technologies. They also provide countermeasures to mitigate the effects of these security issues.

There are several other challenges associated with storing data in an IoT-based fog computing environment. These challenges include

1. Limited storage capacity: IoT devices typically have limited storage capacity, which can be a challenge when storing large amounts of data.
2. Data security: Ensuring the security and privacy of stored data is a major challenge, as fog computing environments often involve the transmission of sensitive data over the internet.
3. Data integrity: Ensuring the integrity of stored data is important, as errors or corruption can impact the accuracy and reliability of the data.
4. Data management: Managing and organizing large amounts of data can be challenging, especially when data is being stored on multiple devices in a distributed environment.
5. Data accessibility: Ensuring that data is accessible to authorized users in a timely manner can be difficult, especially when data is being stored on multiple devices in a distributed environment.
6. Loss of data: IoT-based devices often face challenges in fog computing environments, including data discontinuity, coverage in unknown regions, and large amounts of data transmission. These challenges can lead to errors in data transmission, such as bit errors and packet dropping, which can impact the accuracy and reliability of the data. In the healthcare sector, where data generated by IoT devices is often critical for patient diagnosis and treatment, these errors can have serious consequences. To address these issues, it may be necessary to implement additional layers in the fog computing environment to control data loss and improve the quality of service [40]
7. High Energy consumption issue: IoT devices used in the healthcare industry often face challenges related to power and space constraints. Sensors and cameras, which are commonly used to gather information from the environment, can consume a significant amount of energy. Researchers are working to optimize energy consumption in these devices. To ensure that healthcare IoT devices can operate continuously and efficiently, it is important to develop an energy-efficient fog-oriented model that can support the monitoring and analysis of data without interruption due to power constraints [40].

10. Discussion

There have been numerous studies in the literature on the use of edge, fog, and cloud computing for addressing healthcare problems through the implementation of artificial intelligence (AI) and machine learning (ML) based approaches for tasks such as decision making, anomaly detection, predictive risk monitoring, and treatment support. While many of these applications still offload deep analysis tasks to the cloud due to the limited resources of edge devices, there is a trend towards solutions that utilize functional cooperation between edge, fog, and cloud services. In cases where high-demand ML inference tasks are required, fog architectures with GPU-enhanced local servers are often used. In dynamic monitoring situations, edge stream-computing techniques that involve parallelizing the inference process between multiple edge devices, or the adoption of lightweight deep learning models optimized for running on embedded devices, can be effective solutions. However, active learning systems that require training at the edge level may face challenges such as biased training samples and insufficient computational power, which can lead to the need for offloading the retraining stage to the cloud. To address these issues, some proposals have investigated peer-to-peer (P2P) approaches or decentralized edge training for distributed deep network training and collaborative machine learning at the edge level.

11. Conclusion

Edge and Fog computing has the potential to greatly enhance various Internet of Things (IoT) applications in healthcare by bringing computing and storage capabilities closer to the devices that generate and collect data. It improves the performance of real-time applications, such as early detection, risk prevention, remote monitoring, and activity recognition, by reducing response times and improving data storage and security.

In this review, we discussed the current state of edge/fog computing, including its characteristics, architecture, and benefits. We also examined the ways in which different IoT based healthcare applications can be improved through the use of edge/fog computing. We also discussed how artificial intelligence and machine learning techniques can be effectively used at the edge and fog layers for real-time decision making, anomaly detection, predictive risk monitoring, and treatment support. We also addressed the benefits and challenges of implementing the fog model in healthcare and highlighted the potential for future research in this field. Overall, this review aims to provide a comprehensive overview of edge and fog computing architecture, benefits, current research and developments, challenges in edge/fog computing and its integration with the IoT, as well as highlighting potential future research directions in the healthcare industry.

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