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Advancing Healthcare Data Management: IoT Edge-Fog-Cloud Architectures for Medical IoT Devices' Data Storage and Processing

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Abstract

The advent of the Internet of Things (IoT) has opened new horizons in the healthcare domain, enabling massive collection of medical data from connected devices. However, this rapid expansion of IoT devices has brought forth major challenges in terms of health data storage and processing, demanding innovative solutions to ensure efficient and secure management. For a considerable period, cloud computing has been the predominant paradigm for storing and analyzing data gathered from a plethora of connected medical objects. Nevertheless, with the rise of big data and considering the sensitivity and criticality of health data, this paradigm has started to face limitations, particularly in terms of latency, throughput, bandwidth, dependence on the internet, and cost, which escalates with the consumption of its resources, even when such processing can be performed at the client's end. To address these limitations, various other paradigms have emerged, notably edge computing and fog computing. As a result, research has witnessed a proliferation of hybrid solutions based

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on these three computing paradigms. This work aims to provide a holistic overview of a substantial number of these proposals, with the objective of offering a one-stop resource for researchers and professionals in the field. In summary, this scientific review contributes to enlightening researchers and practitioners about the emerging IoT Edge-Fog-Cloud architectures for healthcare applications. It underscores the significance of these integrated approaches in enhancing health data management.

1 Introduction

The rapid evolution of Internet of Things (IoT) technologies has opened exciting new perspectives in the field of healthcare [1]. The ability to collect, monitor, and analyze a wide range of health data in real-time through IoT devices has revolutionized how we understand, process, and deliver quality healthcare [2]. However, the massive proliferation of these IoT devices has brought forth major challenges in managing, storing, and processing the voluminous data generated at the network's edge [3] . To address these challenges, IoT Edge, Fog, and Cloud architectures have emerged as promising solutions [4]. IoT Edge enables data processing locally, closer to the sensors and medical devices, thereby reducing latency and the required bandwidth for transmitting data to the Cloud [5]. Fog Computing, on the other hand, extends the capabilities of IoT Edge by providing an intermediate layer of computation and storage in more powerful and decentralized devices [6]. Lastly, Cloud Computing offers a scalable infrastructure for storing, managing, and analyzing health data at a large scale, while also enabling access to advanced services and applications [7]. This work aims to provide a comprehensive review of various proposed architectures, spanning from IoT Edge to Fog and Cloud Computing, to address specific needs for health data storage and processing in the medical domain. By gathering research and analyses from diverse scientific papers and articles, this study offers researchers and practitioners an in-depth overview of the latest advancements in this ever-evolving field. This review draws upon a selection of works proposing hybrid architectures ranging from Edge computing to Fog computing and Cloud Computing. In this manuscript, we present a holistic view providing a description of each architecture along with a figure illustrating each one. In summary, this scientific work aims to contribute to the advancement of knowledge in the domain of IoT Edge-Fog-Cloud architecture for health data by offering a comprehensive overview of current approaches. This will enable individuals interested in this research field to quickly dive in and gain a holistic view of these architectures in one place. The structure of this manuscript is as follows: After the introduction, we present the methodology of this work, followed by an examination of the chosen architectures for this study. After discussing the solutions for Edge-Fog-Cloud in the context of IoT, we present a discussion and conclusion of this work. . ...

2 IoMT Edge-Fog-Cloud Architectures: Analysis, Features, and Challenges

Over the past 6 years, and even more, the world of scientific research has shown a keen interest in data processing architectures derived from connected objects in various sectors and domains, with a particular focus on the healthcare domain. This interest has led to the emergence of several proposed architectures, most of which comprise three layers and integrate the computing paradigms of Edge, Fog, and Cloud Computing. In this context, the authors of this work [2] present an architecture that aims to be simple and minimal while providing high data reliability and real-time application support. It consists of two main layers: the Edge Layer and the Cloud Layer, in addition to the IoT devices layer.

The layers of this proposal can be described as follows:
1. Perception Layer: This layer consists of sensors that collect data from patients.
2. Fog Layer: This layer is responsible for real-time data processing and providing immediate feedback to the patient or healthcare provider. It performs data analysis and aggregation.
3. Cloud Layer: This layer is responsible for long-term data storage, analysis, and management. It supports both healthcare applications that require rapid response and non-urgent applications.
The authors have also highlighted several challenges faced in the implementation of IoMT in the healthcare domain, with the most significant being the security of health data due to its critical nature. Additionally, they mention the complexity of IoMT architecture, the need for interoperability among various healthcare systems, managing the massive data generated by IoMT, ensuring patient data confidentiality, and guaranteeing the quality and accuracy of collected data.
In this article [8] , a fog-based architecture is proposed to address the ex-

isting challenges of cloud computing in IoT-based healthcare systems. Additionally, an authentication method for users through identity management is presented to enhance system security and prevent data breaches by unauthorized users. Healthcare systems utilize heterogeneous medical sensors and IoT devices that generate a vast amount of data, which is then transmitted to computing servers for processing. However, this leads to latency and network usage issues during the analysis and processing of medical data on cloud servers.
The proposed fog-based architecture overcomes these cloud computing challenges in healthcare systems and ensures efficient and smooth patient data processing by reducing time and optimizing network bandwidth usage. To achieve this, virtual machine (VM) provisioning is employed in fog nodes for computation and storage, with each VM executing a dedicated function. The data generated by the body sensor network is processed and managed by the Body Sensor Network (BSN) data processing VM. Similarly, clinical and health data are respectively managed by Health Record Management and Clinical Document Management VMs.
Given the sensitivity of healthcare systems to latency, this fog-based architecture is particularly suitable for such systems. Various user roles have been defined, allowing each user to access specific functions. Moreover, to address privacy concerns in healthcare applications, an authentication method based on identity management is introduced. To ensure the security of these identities, SHA-512 hashing and elliptic curve cryptography techniques are used. The User Identity Management VM is responsible for storing and processing data related to user identity management.

In this paper [9], the authors explore the use of Fog Computing for monitoring patients with chronic diseases. The proposed architecture comprises three layers, similar to the majority of architectures studied, including a Sensors layer, a Fog layer, and a Cloud layer. The Fog layer consists of multiple fog nodes and an intelligent gateway, which processes and analyzes data collected from wireless and wearable sensors. Positioned between the cloud and the sensors, the Fog layer is well-suited for time-sensitive applications such as healthcare.
The article concludes that Fog computing is a promising technology that can be effectively utilized to monitor patients and improve health outcomes. the proposed architecture consists of three levels:
Sensor Tier: This is the level where wireless and wearable sensors are located. They collect data from patients with chronic diseases.

Fog Computing Tier: This level includes the fog layer, which consists of multiple fog nodes and an intelligent gateway. At this tier, the data collected by the sensors is processed and analyzed locally, enabling quick decision-making and supporting time-sensitive applications.
Cloud Computing Tier: This is the level where the data processed and analyzed by the fog layer is sent to the cloud. Powerful computing and storage resources are used at the cloud level for further processing, advanced analysis, and long-term data retention.
Finally, the authors do not overlook the many privacy and security challenges that must be addressed to effectively manage the flow of information between the different levels of the healthcare delivery system.
Another architecture is proposed here [10] for the monitoring of patients and elderly individuals using Fog IoT technology. This architecture enables non-intrusive monitoring of patients and elderly individuals by employing sensors and connected devices to gather data about their health status and environment. The data is then processed locally, close to the sensors, to reduce latency and enhance data security and privacy.
This Fog IoT architecture for health monitoring consists of three main layers which are:
1. Sensor Layer: This layer comprises sensors and connected devices that collect data about the health status and environment of patients and elderly individuals.
2. Local Gateway Layer: This layer is responsible for local storage and processing of data collected by the sensors. It also helps in reducing latency and improving data security and privacy.
3. Cloud Lambda Layer: This layer is responsible for processing and storing the data collected by the sensors.
It also allows healthcare professionals to remotely monitor the health status of patients and elderly individuals by accessing the data stored in the cloud. As for the challenges and limitations related to the implementation of this type of architecture, this work sheds light on concerns regarding the security and privacy of health data during its collection. It also mentions other challenges, including the significant costs and investments in terms of resources and time, which require close collaboration between healthcare professionals, engineers, and researchers to ensure that the system meets the needs of patients and elderly individuals.
In the context of home patient monitoring, [11] proposes a Fog Computing-assisted system, which is a layered architecture consisting of three main layers: the Sensor Layer, the Fog Layer, and the Cloud Layer.

The Sensor Layer is the lowest layer and includes IoT sensors that collect patients' health data.
The Fog Layer is the middle layer, comprising Fog servers that perform real-time analysis of the data collected by the sensors and trigger events based on predefined thresholds.
The Cloud Layer is the upper layer responsible for storing the collected data and the results of the analysis performed by the Fog Layer.
The challenges and issues related to the implementation of a Fog-assisted home patient monitoring system are numerous. These include concerns about data security and privacy, energy management, quality of service management, mobility and connectivity management, as well as the complexity management of the system.
We continue our exploration in connected health with [12] which proposes a Mobile Edge Computing (MEC)-based architecture for connected health applications (s-health). This architecture consists of four layers as follows
Sensor Layer: This layer includes sensors that collect data on or around patients, such as vital signs, movements, etc.
Local Processing Layer: This layer performs local processing of the collected data using multimodal compression techniques and edge-based feature extraction for event detection.
Communication Layer: This layer ensures communication between various components of the architecture, including sensors, local processing devices, and service providers.

The main challenges of implementing this architecture include managing data security and privacy, handling device and network heterogeneity, ensuring quality of service, and addressing interoperability issues between different systems. Additionally, managing the complexity of the implementation, latency, and energy consumption are also significant challenges.
The authors of this research [13] proposed a Cloud-Fog architecture for IoT applications dedicated to healthcare, which supports patient mobility and the diversity of medical cases. This architecture consists of four layers:
1. IoT Devices Layer: This layer contains environmental and wearable sensors required for the healthcare system.
2. Data Collection (Sink) Layer: This layer collects and aggregates data from the sensors.
3. Fog Layer: This layer handles healthcare tasks that require a quick response and collects and aggregates data from the sensors.
4. Cloud Layer: This layer manages healthcare tasks that do not require

an immediate response and stores the data collected and aggregated by the Fog layer.
The authors did not discuss the challenges related to the use or implementation of this architecture
[14] In this work, the proposed system is a fog-assisted personalized healthcare support system for remote diabetes patients. It utilizes the Internet of Things (IoT) and Cloud computing to maintain blood glucose levels and predict the risk of diabetes. The architecture of this system consists of three main components: IoT devices, the fog layer, and the cloud server.
IoT devices are used to collect physiological signals and contextual information from remote diabetes patients.
The fog layer acts as an intermediary between IoT devices and the cloud server, providing local data storage, mobility, scalability, and interoperability.
The cloud server is responsible for storing and processing data collected from IoT devices, as well as generating personalized recommendations for registered users.
This proposal, like many others, follows a three-layered architecture and is limited to a specific use case, which is diabetes prediction and monitoring the blood glucose levels of the relevant patients.
As for the challenges related to the implementation of this architecture, the authors mentioned a few, such as data security, energy management, quality of service, and mobility management.
[15] The authors of this work propose an innovative approach for detecting Covid-19 using IoMT (Internet of Medical Things), cloud computing, fog computing, deep learning, and Quality of Service (QoS). The system aims for early detection to limit the spread of the virus. It involves the following steps: image acquisition, preprocessing, feature extraction, classification, and visualization.
This architecture consists of three levels: the user level, the fog level, and the cloud level. At the **user level**, mobile or portable radiography devices capture chest radiographic images of the patient. **The fog level** serves as an intermediary layer between the user and the cloud, performing certain preprocessing steps to facilitate the analysis and classification process at the cloud level. It also ensures the confidentiality and security of patient data.
The cloud level is the main layer of the system, providing several services with extensive computing capacity used in the analysis process. It also offers ample data storage space known as the data center.
In terms of challenges and issues raised in this work, the most significant one

is the necessity to ensure the security and confidentiality of patients' medical data.

The main idea of this work [16] is to propose a lightweight and cost-effective data processing architecture for human activity recognition using Docker containerization technology to manage virtualization processes and distribute cloud and edge applications.

The proposed architecture is based on 3 layers, namely:

1. Data Acquisition Layer: This layer is responsible for collecting raw data from sensors and edge devices. The data is then preprocessed to make it usable by the upper layers.

2. Data Processing Layer: This layer is responsible for processing the preprocessed data to extract relevant features. The authors used Regularized Extreme Learning Machine (RELM) for data processing on edge devices rather than on a centralized server.

3. Application Layer: This layer is responsible for applying the results of data processing for specific applications, such as human activity recognition. The authors used Raspberry Pi devices to represent this technology, as they are inexpensive, robust, and lightweight.

The challenges related to this system can be categorized into three main areas. First, the detection of heart problems is difficult, and the symptoms are often challenging to identify. Additionally, many countries still do not fully trust computer systems to detect heart problems with the required precision and explainability. Finally, there are technical challenges, such as the need to manage large amounts of patient data and ensure optimal performance in terms of accuracy, response time, network bandwidth, and energy consumption.

The architecture presented in the article [17] is a three-level architecture for IoMT (Internet of Medical Things) systems. The first level consists of wearable sensors that collect data. The second level consists of fog nodes, which act as local servers. The third level consists of cloud servers that store the collected data and make it available for healthcare applications. This architecture enables the collection and processing of health data in a distributed manner, which can improve the reliability and security of healthcare systems. Once again, we encounter a three-level architecture, with the term "Fog" being used to refer to Edge computing, indicating that these two terms are used interchangeably.

The authors emphasize that the implementation of IoMT systems raises challenges such as data security and privacy, energy management, system reli-

ability and availability, as well as the complexity of analyzing massive data produced by these systems.
On the other hand, in [18] , we have a real-time Medical Internet of Things (IoMT) architecture for monitoring elderly patients, which consists of two processing levels: the "fog" level and the "cloud" level. The "fog" level represents the processing layer closest to the sensors and medical devices. It is responsible for collecting patients' health data, preprocessing it, and transmitting it to the higher level. This layer is also in charge of real-time anomaly detection and alerts for healthcare providers.
The "cloud" level is the upper processing layer that stores the collected data and processes it to provide valuable insights to healthcare professionals. This layer is responsible for data analysis, report generation, and real-time decision-making for patient care. With two processing levels, we again have a 3-layer architecture: Sensor - Fog - Cloud, specifically designed for the monitoring of elderly individuals.
Implementing this architecture requires integration with existing healthcare systems, which can be challenging in terms of compatibility and regulatory compliance, as well as ensuring the security of patient data.
Here, [19] , we have an intelligent health monitoring platform called Edge-IoMT, consisting of three main layers: the Edge layer, the Network layer, and the Application layer. The Edge layer is designed to collect necessary patient data using IoMT wearable devices. The Network layer is responsible for communication between different layers of the architecture, while the Application layer processes the collected data and provides intelligent healthcare services. The Edge layer itself is composed of three sub-layers: the User Interaction layer, the Edge Computing layer, and the Cloud layer. In terms of layers, we have a total of 5 layers.
However, for data processing and computation, we essentially have two layers, namely Edge Computing and Cloud Computing.
This architecture shares commonalities with many other architectures in terms of layers. Notably, it employs the term "edge" to encompass both edge and fog computing, treating them almost interchangeably. The main focus of this architecture is video processing for remote health monitoring.
Ensuring data security, authentication, minimizing latency, and facilitating data sharing are critical considerations for the development of the smart healthcare monitoring platform. These parameters play a pivotal role in crafting a robust and effective system.

3 Conclusion and discussion

This non-exhaustive review of IoT Edge-Fog-Cloud architectures for IoMT highlights the emergence of innovative solutions for storing and processing health data from connected medical devices. Through the analysis of various studied architectures, we have identified the main features, benefits, and challenges of each approach.

The IoT Edge, Fog, and Cloud architectures have proven to be complementary in the context of IoMT. IoT Edge enables local data processing, enhancing responsiveness and reducing network load, which is crucial for medical applications where latency can be critical. Fog Computing adds an intermediate layer of computation and storage for more powerful and decentralized devices, providing greater flexibility in processing and analyzing health data near IoT devices. Cloud Computing, on the other hand, offers scalable infrastructure and massive storage capacity to manage health data on a large scale and enable access to advanced services.

Comparing these architectures, we have observed that each presents specific advantages and limitations. IoT Edge is ideal for applications requiring low latency and high energy efficiency. Fog Computing offers better resource management and increased resilience in case of connectivity loss. Cloud Computing excels in large-scale storage and the provision of centralized services.

The relevance of these architectures for IoMT is evident, as they enable real-time processing of health data generated by connected medical devices, providing more personalized and efficient healthcare services. However, practical implementation poses significant challenges, especially in terms of data security, privacy, and costs. Appropriate measures must be taken to ensure the protection of sensitive health data and to guarantee ethical and secure use of these technologies.

This study also highlights future research opportunities in the field of IoT Edge-Fog-Cloud architectures for IoMT. Innovative approaches to integration and optimization of these architectures, as well as effective resource management and performance control methods, could further enhance connected healthcare systems.

It also emphasizes the general challenges associated with these architectures and particularly during the implementation and realization of the proposed solutions.

In conclusion, this review has provided a deeper understanding of IoT Edge-Fog-Cloud architectures for IoMT and their crucial role in health data management. By offering a comprehensive overview of advantages, limitations, and research opportunities, this work lays a solid foundation for the future development of connected healthcare systems, contributing to the improvement of healthcare in the era of IoMT.

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