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A COMPREHENSIVE STUDY OF CLOUD, FOG, AND EDGE COMPUTING TECHNOLOGIES FOR HEALTHCARE IoT SYSTEMS

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Abstract

Cloud computing technology significantly emerged in various systems to enhance the platform and infrastructure of services. Fog and Edge computing technologies transform computing power and processing close to the end-user and resolve many data processing challenges. Healthcare IoT systems refer to using medical sensors and mobile computing to manage patients' conditions and use cloud-based technologies to transfer collected patients' data to the cloud computing storage. Many previous research efforts focused on the use of edge, fog, and cloud computing technologies in the field of healthcare IoT systems. However, no previous research study summarized the main research topics and trends in these research efforts. To that end, we conducted a systematic and comprehensive empirical research study to understand the main research topics and the employed computing technologies and trends in these research topics. This study investigated 100 research studies focusing on cloud-based technologies in the filed of healthcare IoT systems published in highly reputable venues over the past decade. We created a taxonomy of the main research topics of the investigated research manuscripts and reported the main focus of these research efforts and the trends in this field. Our investigation concluded that the researchers mainly focused on the following five research topics: big data, security, network latency, energy efficiency, and QoS. However, some research topics are well studied while others are poorly investigated and need more attention. We found that the highest number of research papers focused on big data, i.e., 63% of the studied papers, while the energy efficiency topic had the lowest number of papers, i.e., 17% of the papers. Researchers and practitioners interested in the cloud-based healthcare IoT systems can use our findings to gear their work on the areas that are poorly investigated to find better solutions.

KEYWORDS:
Healthcare system; Internet of Things (IoT); Cloud computing; Fog computing; Edge computing.

1 INTRODUCTION

Internet of Things (IoT) is growing in many daily life sectors. According to newly published research by Statista[1], the number of IoT devices will grow up to 25.44 billion devices in 2030 compared to 2019. The number of currently active IoT devices is 7.74 billion devices. IoT is essentially defined as a network of connected smart devices everywhere that are expanded to apply a large number of tasks such as healthcare monitoring, environmental sensing, industrial task processing, and various smart city applications[2]. The most important core technology in IoT is Wireless Sensor Networks (WSNs) and the major technology used in the healthcare IoT system is the Body Sensor Networks (BSNs). BSN is defined as a collection of sensors that are deployed around and inside the patient body[3].

Cloud computing aims to provide flexible resources and deployment facilities at a lower cost compared to on premises applications. In addition, cloud-based computing provides high availability features which means that the data can be accessed anywhere, anytime by providing both applications and data storage services over the Internet[4]. Due to the ubiquitous of Information and Communication Technology (ICT) in the healthcare field, healthcare resources are enhanced and utilized widely by enhancing the quality of healthcare through instructing healthcare professionals and improving the safety of the patients by monitoring the online treatment[5]. Healthcare IoT services are equally provided for all patients with a minimal cost compared with traditional healthcare services[6]. Many available wearable IoT sensors can measure a particular patient's physiological signs like respiration rate (RR), heart rate (HR), and blood pressure (BP) with a single touch. In this sense, IoT facilitates mobile health, and Ambient Assisted Living (AAL), which allows remote patient monitoring and follow-up the elderly people living alone at home or in the hospital to take special treatment. Wearable IoT sensors and communication technologies are trying to improve traditional interaction between healthcare providers and many patients in more effective healthcare services. Typical healthcare IoT systems include data collection sensors, communication technologies, computing technologies, and advanced algorithms to process and analyze data. Sensors are used to collect data from various patient devices. Advanced algorithms are applied to filter and process data and then analyze all filtered data through different application programs. Data is pre-processed partially at Edge computing or Fog computing and then loaded to the center Cloud remote processing unit. After that, healthcare providers retrieve collected data to diagnose, observe and treat patients efficiently, which allows patients to have access to many services at the same time as depicted in Figure 1 .

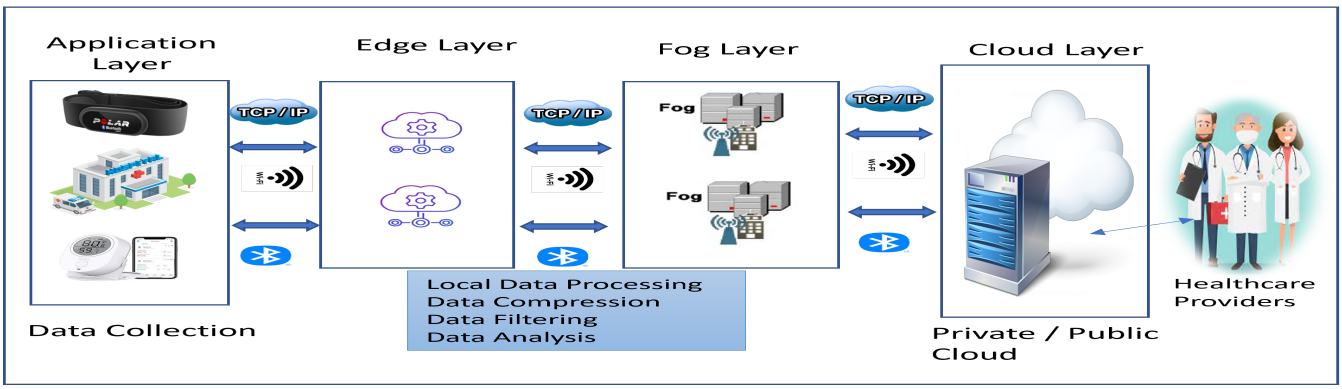

FIGURE 1 Healthcare IoT System Architecture

IoT applications have been integrated with healthcare fields to supply more efficient medical treatment to patients. Cloud computing technology in the healthcare IoT system brings many opportunities to healthcare providers and significantly enhances healthcare services. Edge computing provides interoperability between various sensors by separating the edge devices from the center of the network[7]. The sensors used in the healthcare IoT system produce a huge amount of data every second. Processing of these data is practically impossible using traditional processing data techniques. Therefore, big data is a critical concept in the healthcare IoT system which needs specific techniques for analyzing and processing.

[0]**Abbreviations:** A COMPREHENSIVE STUDY OF CLOUD, FOG, AND EDGE COMPUTING TECHNOLOGIES FOR HEALTHCARE IoT SYSTEMS

In this study, we investigated large number of healthcare IoT system researches that are utilizing various computing technologies: Cloud, Fog, and Edge. To that end, we conducted a large-scale comprehensive study by analyzing the related research papers based on exclusion and inclusion criteria. We present a detailed taxonomy of the main research topics of the healthcare IoT systems. Moreover, we discuss the related concepts, services, and the main used applications.

The main contributions of this study are provided as follows:

- A comprehensive study of healthcare IoT systems with different computing technologies.
- A taxonomy of the main research topics that are addressed in healthcare IoT systems when the cloud, fog, and edge computing technologies are employed with these systems.
- Providing statistical results of the collected data for each addressed research topic.

The rest of the paper is organized as follows: Section 2 presents a background of the related technologies. Section 3 presents the related work. Section 4 demonstrates the methodology we followed in this research. Section 5 provides the main results and findings. Sections 6, 7, 8, 9, and 10 present each research topic in more details. Section **??** discusses the results. Finally, the paper concluded in Section 11.

2 | BACKGROUND

This section presents a concise background of healthcare IoT systems, Cloud computing, Edge computing, and Fog computing technologies.

2.1 | IoT

Internet of Things (IoT) is considered a new technology that intends to combine various embedded technologies with physical objects that communicate with each other and interact with the external environment. IoT is incorporated with additional technologies such as Cloud computing, Edge computing, Fog computing, communication technologies, Internet protocols, smart sensors, RFID, and various big data analytics technologies [8].

IoT uses many features of these technologies, and as a consequence, IoT inherited open issues and challenges from all these technologies [9]. Actually there are a lot of challenges in the promising technologies (e.g., big data, wearable devices, Fog, Edge, and cloud computing) that are used in healthcare IoT systems. Many of the appeared challenges are related to security, data management, and data exchange between devices. Therefore, new concepts and solutions have emerged in the cloud computing, Edge computing, and Fog computing technologies to solve such challenges, and to facilitate the integration of these technologies with the different IoT systems.

2.2 | Healthcare IoT

In recent years, the propagation of IoT smart devices lead to a rise in demand for the remote healthcare system. The successive demand to deliver high quality healthcare services and to enhance the management of health information opened a lot of research fields in the domain of Healthcare IoT [10].

In the healthcare industry, ICT (Information and Communication Technology) enhanced the equal provision of healthcare services for elderly people and patients on a large scale. Sensors and various communication technologies, combined with IoT, are used to enhance healthcare services by improving the communication between patients and healthcare providers [11]. On the other hand, many research studies focused on the combination of wearable IoT sensors and smart mobile devices in different routine activities, healthcare monitoring, healthcare diagnosing, tracking, and locating healthcare-associated things [12]. IoT technology moves the healthcare system from a centralized manner to a decentralized one to improve patient treatment. Today, home becomes the main healthcare services center for most elderly people and patients, which reduces medical costs and healthcare response time [13].

Healthcare IoT system indicates the use of medical sensors, mobile computing, and cloud computing technologies to really manage patients' conditions and use communication technologies to transfer collected patient data to the cloud computing storage [14]. Therefore, healthcare providers retrieved collected data to diagnose, observe, and treat patients efficiently on the time.

The cloud received structured and filtered data and makes important operations on it. It performs various data analytics methods, ontology, semantics, and machine learning to improve data handling and convert it into useful knowledge [15]. Different services provided by the cloud can be reached by different stakeholders like physicians, patients, blood banks, hospitals, insurers, IoT service providers, cloud service providers, healthcare providers, etc.

2.3 | Cloud Computing

Cloud computing, defined in [16] is an evolving model that provides required computing resources including services such as networks, data storage, and elastic applications to consumers with minimal management effort. In general, cloud computing aims to provide flexible resources and deployment facilities with a low cost compared with real building computing infrastructure on the companies. Also, cloud computing supports the high availability feature by providing both applications and data storage services over the Internet, which means that users can access data from anywhere at anytime. [17]. In addition, main cloud computing providers help IoT companies pay for the only specific resources used with no additional cost for a software license, maintenance contract, installing upgrades, and control of resources [18].
Cloud computing has a lot of resources in terms of extensive processing as those needed in deep learning and big data storage. The main disadvantages of cloud computing are the high distance between healthcare IoT nodes and cloud computing storage. This leads to more latency of highly sensitive services and makes personal patients' data vulnerable to many attacks by unauthorized entities [19]. Also, all the collected data from the wearable IoT sensors may not necessarily be transferred to cloud storage across the Internet.

2.4 | Fog Computing

The concept of fog computing refers to expanding the cloud computing model to the edge of the network. Recently, fog computing has been introduced to allow new types of services in Information technology as local storage, local computation, and control for IoT devices in minimal time when compared to cloud computing [20]. The healthcare system is one of the most domains that realize this concept by developing a middle layer of smart gateways in the network between IoT sensors and the cloud. Fog computing provides many advantages for healthcare IoT applications which include improving privacy, reducing latency , enhancing reliability, and supporting geographic diversity [11].
In Fog architectures, gateway nodes make data processing locally along with a transmission of data to the cloud servers. Various analytical processes like data processing methods, data cleaning, feature extraction, and real-time analysis are transferred to the fog computing layer [21]. Furthermore, fog computing allows management of the resources at the local layer, but most of the management techniques are limited to low computation costs methods as rule-based algorithms [22]. Although Fog computing-based systems provide a lot of advantages for healthcare IoT systems as shown in Table 1 , Fog computing nodes have bounded functionality due to the restricted computational capacity in the edge devices.

2.5 | Edge Computing

Edge computing technologies have been applied since 2002 [23]. Healthcare IoT devices collect data and act as an edge node to provide an entry point to the active network. The edge computing module moves the control of the services in the network from central nodes or cloud computing nodes to the sensors themselves which are defined as edge nodes. Edge computing differs from fog computing through the location of where the extra computing power is found [24].
In edge computing, the processing control and communication abilities are in the IoT devices themselves directly. The edge node can be a detector, an embedded system, a sensor, or a smart object [23]. But the processing control in fog computing is applied in the local area network, where collected data are analyzed and processed in the node, router, hub, or gateway and sent to the suitable devices.
The edge computing devices and fog computing nodes can perform many defined processes, including sending data during milliseconds and reducing the amount of data for permanent cloud storage or temporary storage in the edge device or fog hub as shown in Table 1 . Many healthcare actuators must respond quickly to IoT sensor data in seconds and cannot be late for minutes to send data to the cloud to be analyzed and then transfer the results back to the patient sensors.

TABLE 1 Summary of advantages and disadvantages of computing technologies with healthcare IoT system

	Edge Computing	Fog Computing	Cloud Computing
Advantages	Making critical decisions in-situ, reducing network traffic, minimizing operating cost, and improving system performance	More storage space and computational power compared to edge computing	Unlimited computing power and huge storage space
Disadvantages	Limited storage and limited computing power compared to Fog computing	Limited storage and limited computing power compared to Cloud Computing	Slow response time and require high bandwidth

3 | RELATED WORK

In this section, we provide some of the previous surveys that have focused on studying healthcare IoT systems. Previous studies have concentrated on specific aspects of healthcare IoT systems. But most of these studies have not discussed the healthcare IoT systems from the computing technologies prescriptive (Cloud, Fog, and Edge), and to find the gaps and main challenges in those systems with a comprehensive study of different aspects.

In[25] to guarantee the high level of healthcare IoT system performance, they analyzed the main challenges that need to provide an efficient and secure healthcare monitoring system. In[26,27], different IoT security and privacy features from the healthcare aspects were surveyed that include threat types, attack classifications, and security requirements, and reviewed the last technical trends in IoT healthcare solutions. Further, to minimize security risks, they proposed a smart, collaborative security model and presented IoT policies and controls for healthcare services that benefit various stakeholders' technologies in different countries. Farahani et al.[6] provided a thorough study of several case examples of applications and services that are used with fog computing. Also, they discussed the applicability of IoT in medicine and healthcare by displaying a comprehensive architecture of the eHealth IoT system.
Ida et al.[28], provided an overview of the IoT security vulnerabilities and the main security and privacy challenges in the cloud for the eHealth context from the network and the hardware prescriptive. Also, they presented various solutions for the IoT and Cloud security, especially to preserve the health information, while Ghosal et al.[29], studied various machine learning approaches that are used to solved various security attacks. Scarpato et al.[30] and Darwish et al.[31], presented different solutions used to improve the role of the healthcare system from a security and communication prescriptive.
Qi et al.[32], presented a set of problems related to IoT healthcare systems that include high dimensionality of produced data, heterogeneity of connected IoT wearable devices that produced a huge amount of data, and how to make processing of these data. AbdElnapi et al.[33], focused on the latest IoT technologies for healthcare as important medical sensors, cloud computing, and various communication technologies when dealing with the big data generated from different medical IoT sensors.
Aazam et al.[34], reviewed the main elements and architecture of fog in the healthcare cloud-IoT environment also provided how fog can be used to solve latency problems, especially in an emergency. Mahmoud et al.[35], they talked about efficient solutions for obtaining energy efficiency in data transmission and processing required in the healthcare solution. Dhanvijay et al.[36],

reviewed the most recent network architecture topology and applications in the healthcare IoT-based solutions also focused on the Wireless Body Area Network (WBN) technology, especially for elderly people.
Most previous studies have not discussed the effect of cloud, fog, and edge computing in healthcare IoT systems with a comprehensive review of aspects related to each type of computing technology. Therefore, this study addresses detailed taxonomy and insights for many challenges and issues facing healthcare IoT systems for the realization of an efficient healthcare IoT system.

4 | METHODOLOGY

This section shows the methodology applied in this study. We choose the most relevant research that covered topics related to the Internet of Things (IoT), healthcare, and computing technologies that include Cloud, Fog, and Edge computing. Many studies regarding IoT technologies and architectures have been carried out in various subject areas such as medicine, computer science, and healthcare. In our study, published research papers have been studied using the Scopus database, to create a complete list of research papers on IoT in the healthcare field with the Cloud, Fog, and Edge computing technologies.

The selected papers were searched using the online database service Scopus[1]. The main benefits of using Scopus as opposed to other similar resources are ease of use. Scopus is used as a high-quality bibliometric and a curated data source for academic research in quantitative science study[37]. Also, Scopus database gives access to STM journal articles, and the references involved in those articles. It brings together better quality, advanced analytics, and superior technology in one solution. Make the research workflow more effective and efficient by providing the save list techniques to save the search result after each search query[38].
We extracted research from the Scopus database using the following search keywords in different query structures: Healthcare, e-Health, Smart Health, IoT, Cloud, Fog, and Edge. In our study, we found the related research papers by analyzing each paper's abstract, introduction, and conclusion. Then, we selected the papers that would be more relevant to our study. More specifically, we searched for papers and selected the relevant ones according to the three main phases, i.e., Exploration phase, Investigation phase, and Analysis phase, which are described in Figure 2 .

4.1 | Exploration phase:

In the exploration phase, data are collected using the Scopus database, this phase contains a set of steps to find the necessary research articles as follows:

1. Using the Scopus site to find out research about smart healthcare IoT systems and cloud computing technologies using the article title, abstract, and keywords in the search field.
2. Searching using 3 specified query structures as follow:
    - IoT and Cloud and (Healthcare OR smart Health OR e-Health), with the result of 968 papers.
    - IoT and Edge and (Healthcare OR smart Health OR e-Health), with the result of 620 papers.
    - IoT and Fog and (Healthcare OR smart Health OR e-Health), with the result of 516 papers.

    We found that the number of extracted papers was relatively large, with 2104. Manually, we removed duplicate papers on the title of each paper. After identifying and removing duplicate papers, 850 papers remained among which the inclusion/exclusion criteria were applied.
3. Include papers based on specific criteria as follows:
    (a) Publication year of research between 2011 and 2019 as shown in the Figure 3 .
    (b) Papers that have Q1 or Q2 Journal rank or conference papers with a high citation number.
    (c) Papers that have an experimental or case study in the healthcare IoT system field.

[1] https://www.scopus.com

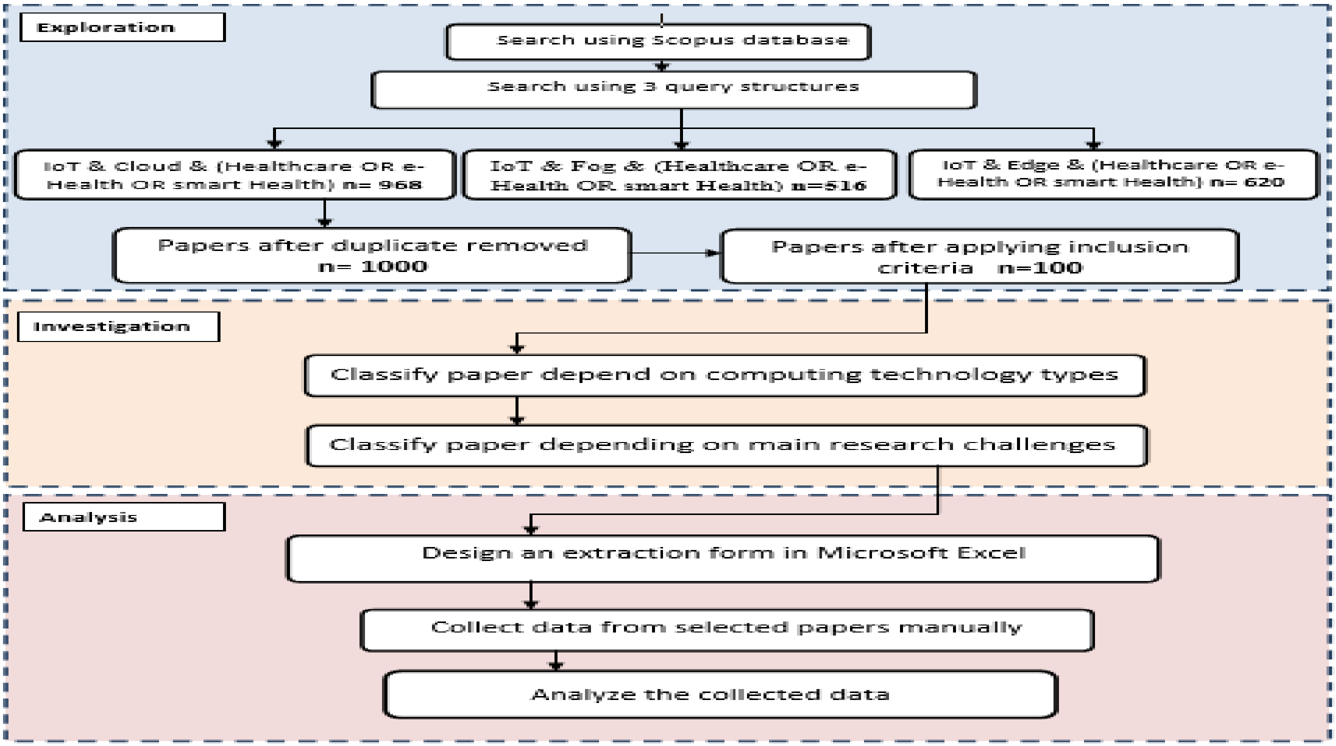

FIGURE 2 Flowchart diagram of the systematic research steps

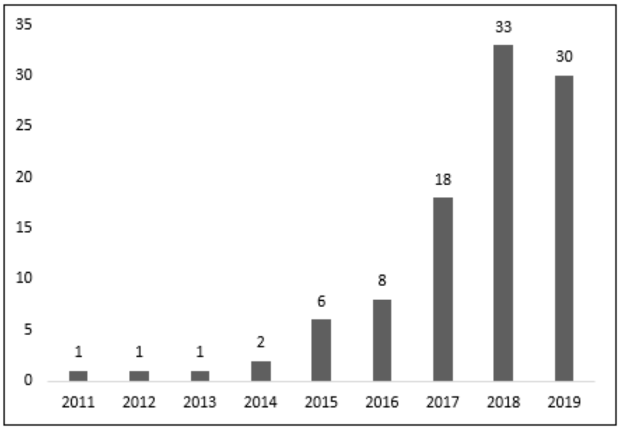

FIGURE 3 Number of annual publications on healthcare IoT systems

From ScimagoJR site[39] we got rank for all paper then sort them descending and take the highest Q1, Q2 and conference paper. At the same time, we check each paper if have experimental or case study in the healthcare IoT systems, by reading abstract, introduction and conclusion of each paper.

After applying these steps and inclusion criteria, we ended up with 100 papers used in our research. We found that the highest number of research has Q1 rate with 51 paper out of 100, Q2 with 31 paper, and conference paper with 18 paper, as shown in the Figure 4 .

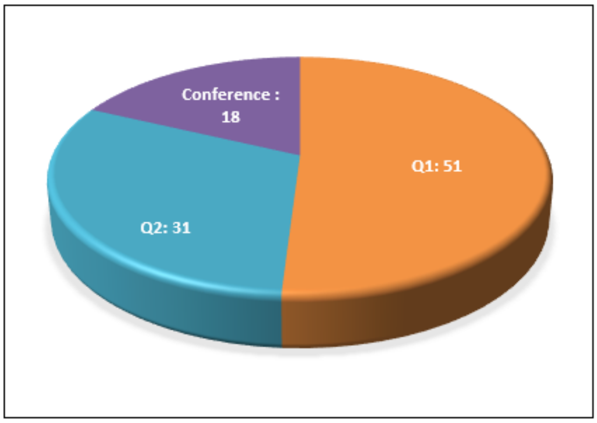

FIGURE 4 Number of paper classifications (Q1, Q2, Conference)

4.2 | Investigation Phase:

In this phase, we classify articles using two criteria, type of solved issues and type of computing technology in the healthcare IoT system.

4.2.1 | Main Research Topics Classification

This study considers different healthcare IoT research areas with the different computing technologies Cloud, Fog, and Edge. First, we define the main research topics that are considered in each paper. Then, we discuss how to solve each topic that affects healthcare IoT systems when combined with Cloud, Fog, or Edge computing technologies. Finally, we discuss the related concepts, services, and applications.

4.2.2 | Computing Technologies Classifications

There are different technologies in the computing environment for healthcare IoT system, including Cloud computing, Fog computing, and Edge computing [11]. In Cloud computing, patients and doctors can connect directly to the cloud using the Internet. Transmission of a huge amount of data in a short time is not efficient in a typical cloud computing architecture. To overcome these problems new computing paradigms such as Fog computing, and Edge computing have been applied which process the data in the local gateways or connected devices [4].
Fog computing nodes process the request from IoT devices using local resources or transmit it to the cloud server's resources. Therefore, fog computing can manage delay-sensitive computation, and decrease power consumption while reducing traffic congestion [40]. Generally, the main characteristics of fog computing with healthcare IoT systems are low latency, location awareness, real-time processing, wireless and mobile access, scalability, and geographical distribution support [41]. To improve the accuracy of diagnosis and analysis of diseases in healthcare IoT systems, many researchers applied Fog computing architecture.
Also, Edge computing provides storage, computation, and networking services to IoT users. Healthcare IoT devices collect data and act as an edge node to provide an entry point to the active network [38]. In healthcare IoT systems, edge computing guarantees the efficiency of provided services. The data processing of the patient needs an efficient platform that ensures less delay in response time.

4.3 | Analysis Phase:

In this phase, we read the full text of the selected papers to extract the critical data. To gather the data, we designed an extraction form in Microsoft Excel. Then, we collected the data from 100 selected papers manually.
For each paper, the following data were collected: type of computing technology (Cloud, Fog, Edge), main issues that considered in each article, how to solve these issues, type of network protocols, type of communication technologies, type of disease, system place, data collected technologies, data storage techniques, authors country, funding country/university agency, publication year, citation number, cloud provider type, and the main participated stakeholders in the system.

In this phase, we try to interpret the collected data, including the type of computing technologies and the main issues in healthcare IoT systems. In each studied issue, we used different graphs and views to present the number of studies that were solved by different types of computing technologies (Cloud, Fog, and Edge). The findings can show differences in the data which should be considered. Also, the following section shows the main findings and results.

5 | RESULTS AND FINDINGS

This section describes the results and findings of our comprehensive study of cloud, fog, and edge computing technologies within the domain of healthcare IoT systems.

5.1 | Computing Technology

Among the selected papers, we found that 60% of them used cloud computing technology to address healthcare IoT systems' challenges, 24% used Fog computing, and 16% used Edge computing. Also, we found an increasing number of studies for healthcare IoT systems using Fog computing technology from 2017 to 2019 compared to previous years. Figure 5 shows the number of healthcare IoT system trend studies between 2011 and 2019. From 2011 to 2014, there were stability and weaknesses in healthcare IoT research that depend on cloud computing technology. But we observed a significant increase in the number of studies from 2016 to 2019.

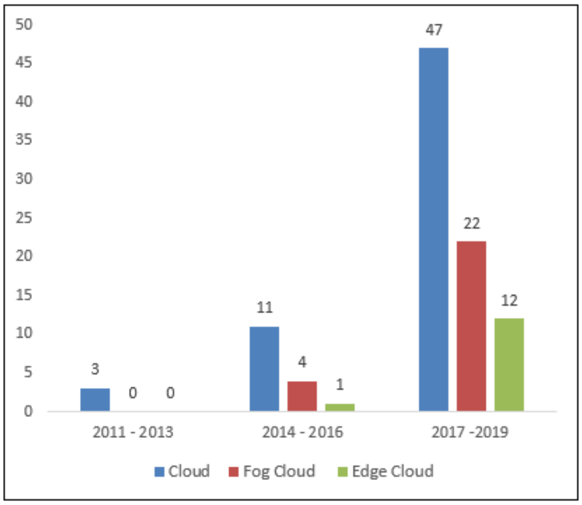

FIGURE 5 Number of annual publication trends of healthcare IoT systems using different computing technologies

5.2 | Main Research Topics

We found that the most investigated and studies research topics in the cloud computing-based healthcare IoT systems are big data, security, energy efficiency, latency, and other QoS aspects. Depending on our study, Figure 6 shows these main research topics.

Also, Figure 7 shows for each research topic the number of papers that address it. For example, We found that the highest number of research papers focused on big data, i.e., 63 out of 100 research papers, while the energy efficiency topic had the lowest number of papers, i.e., 17 papers.

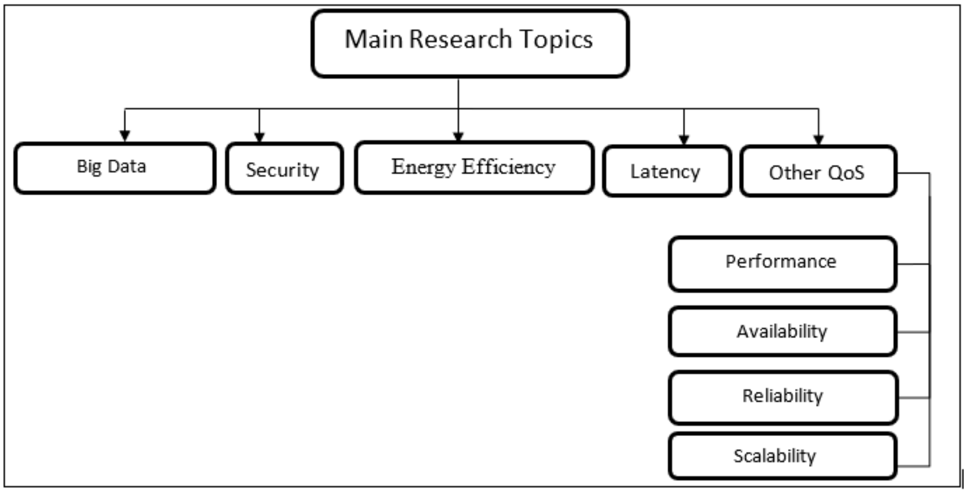

FIGURE 6 Main research topics in healthcare IoT system

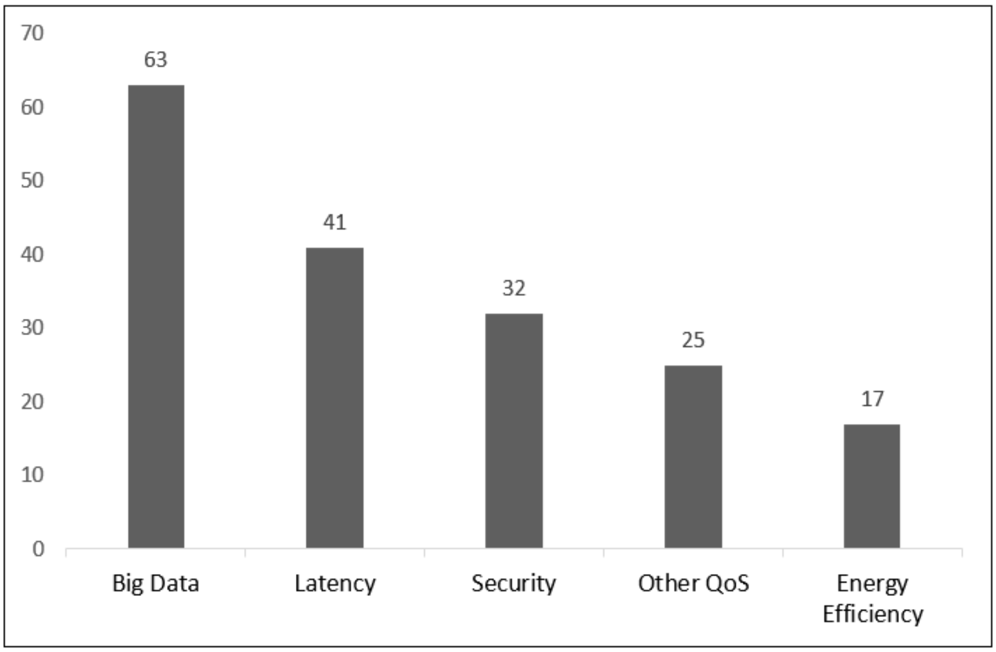

FIGURE 7 Number of papers that address each research topic

6 | BIG DATA RESEARCH AREA

Recently, huge data was collected from sensors and wearable IoT devices in the healthcare IoT systems. This data is varied and often unstructured, and requires huge resources for processing, which raised a concern in the computing resources and time needed to analyze the collected data[42]. Therefore, healthcare providers had to employ new technologies like cloud computing and fog computing to deal with such varied and big data streams. A set of choices are used to overcome some of the big data issues by reducing the processing cost and supporting early diagnosis of illnesses[12,43]. In order to get helpful information from big data streams, an essential step is required to reduce data complexity, and this step includes data cleaning such discarding unnecessary and redundant parts of the data.

In the following subsections, we present how cloud computing, edge computing, and fog computing technologies addressed the ability to process huge and complex healthcare data flows. Figure 8 shows the number of papers that addressed the big data aspect using cloud, fog, and edge computing technologies. For example, 55.56% of studied papers used the cloud computing technology to solve big data issues, 28.57% used Fog computing, and 15.78% used Edge computing.

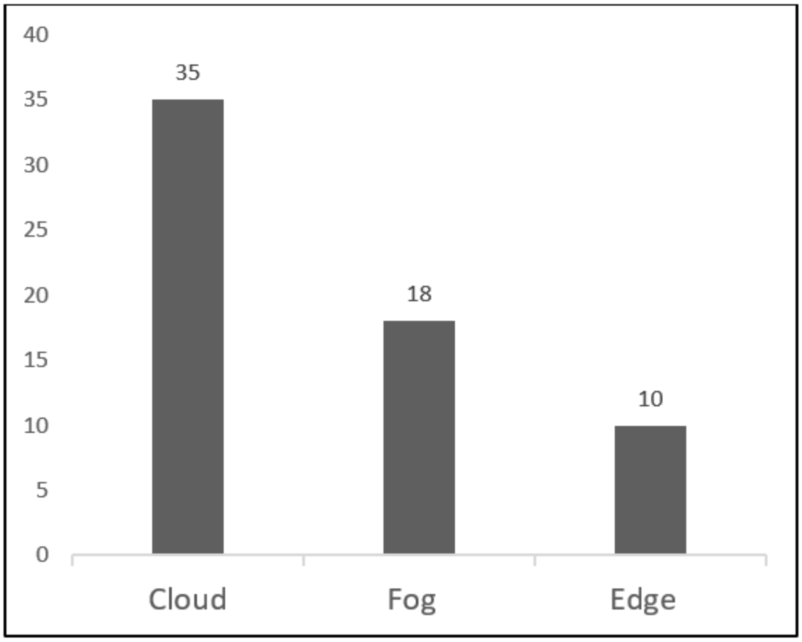

FIGURE 8 Number of papers that addressed the big data topic using cloud, fog, and edge computing technologies

6.1 | Big data processing in Cloud computing

One of the main advantages of cloud computing is saving a huge amount of data and various resources in a huge data center on the Internet. Moreover, current cloud computing architectures provide effective execution enhancement by combining different environments to execute the applications at different levels. Also, cloud computing offers pay-as-you-go to services that include virtualization, networking, big data analytics, and data-parallel processing on customized servers[44,45].

Moreover, advanced healthcare providers are improving their infrastructure to deal with a huge amount of data produced by WBAN IoT sensors by using multi-cloud data computing to ensure the highest level of cost-efficiency, data availability, and reliability[46]. The multi-cloud computing architecture enables the deployment of the tasks to the proper environment (public, private or hybrid cloud), which speeds up the processing steps. The authors of[47,48] used Microsoft Azure and Google as multi-cloud computing with OpenIoT structure. Furthermore, the survey conducted in[49] found that 86% of respondents are dealing with current cloud computing as multi-cloud.

6.2 | Big data processing in Fog computing

Cloud computing sources were extended to the edge network, known as the Fog computing layer. Both Cloud and Fog layers provide data processing, storage, and application features to the users.Data processing on the fog computing layer performs an essential role in healthcare monitoring systems. This layer is necessary especially for medical scenarios that involve emergency cases, which require taking critical decisions and sending notifications to the specialists with the least possible time. In[21,4,50],

they used fog computing, which is placed in the patient's home, to decrease the processing time, increase efficiency, reduce the amount of data required to send to the cloud, and avoid more latency.
In[51,52], they used fog computing to improve the healthcare system and enhanced the fog computing layer with distributed data storage and data mining techniques.

6.3 | Big data processing in Edge computing

Big data processing using edge computing power and storage near the healthcare IoT devices allows data cleaning and analysis in low response time before sending data to the centralized cloud system, which improves data transmission efficiency. In[52], they deployed edge servers at the already known places of a city to collect the Chikungunya virus data from users and make the processing of the data, then transmitting it to the Cloud. In[53,54], they found that the use of edge computing to process data has a better effect on disease detection when compared to cloud computing, and found that edge computing helped in sending earlier notification announcements to the medical service provider compared to cloud computing.

7 | SECURITY RESEARCH AREA

Combining IoT devices in the healthcare field with Cloud, Fog, and/or Edge computing technologies led to a lot of security issues that need to be resolved[55,56]. These issues can happen at different phases, such as the security of the collected data from healthcare IoT devices, either during sending data to (cloud, Fog, and Edge) to make processing, or while saving data in computing storage[57,58]. This section concentrates on the security issue related to the data flow of healthcare IoT systems with the different computing technologies (Cloud, Fog, and Edge).

7.1 | Security in Healthcare IoT Systems Using Different Computing Technologies

Collecting patient-sensitive data is the main subject of evaluating security protocols and algorithms. There are different paradigms about the computing environment for healthcare, including Cloud computing, Fog computing, and Edge computing. Many solutions include secure algorithms, computing technologies, and Internet protocols to protect collected patients' sensitive and health information. Figure 9 provides the number of studies that consider security issues by computing technologies. According to Figure 9 , the most percentage including 59.4% of studies used cloud computing technology architecture to solve security issues, 31.3% used Fog computing architecture, and 9.3 % used Edge computing architecture.

Depending on Figure 9 , cloud computing is the most used layer to solve security issues in healthcare IoT systems. However, as will be described in the following sub-sections, the fog computing layer plays an essential role in the confidentiality and the security of healthcare IoT systems.

7.1.1 | Security issue for healthcare IoT system in Cloud computing

In healthcare IoT systems, the cloud architecture can enhance healthcare services and improve the frequent updating of the healthcare system[3,59,60]. However, security is one of the main issues when integrating cloud computing with the healthcare IoT system because of the high level of data interoperability, integration, and sharing of these data between healthcare providers and organizations[61]. Distinguishing between the actual user and the attacker at the cloud level is a complex process. There are many security threats in the cloud as Denial of Services attack (DOS/DDoS), Man-in-the-Middle attack, and Sleep Deprivation attack[6,8,4]. To mitigate these threats, cloud computing technologies process and save collected data in distributed cloud servers privately[58,19], and only allows authorized users to securely use patient data by authenticating themselves using robust authentication algorithms. However, most commonly used security techniques in practice are overlooked at the cloud level because of the trade-off between the efficiency, speed up of the system, and security problems in healthcare IoT systems[62].

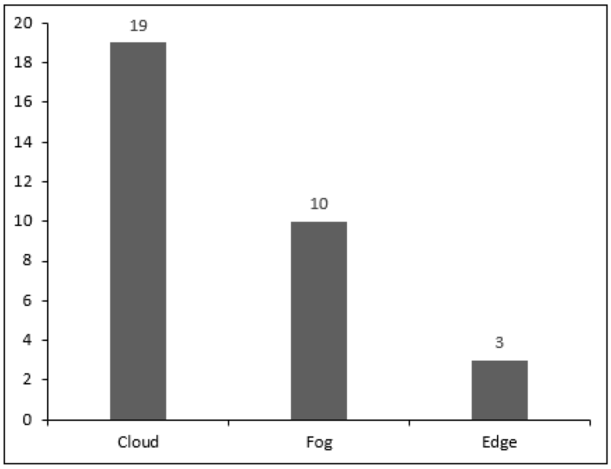

FIGURE 9 Number of studies consider security issues by computing technologies

7.1.2 | Security issue for healthcare IoT system in Fog computing

Compared to the cloud layer, fog nodes use more powerful encryption schemes, access control policies, isolation measures, and integrity checks to preserve the security of patient-sensitive data[8]. The fog computing paradigm is qualified to overcome the security issues that typical cloud computing architecture is exposed to[50]. Providing fog computing as a middle layer and acting on the edge-side improves data security, consistency, accuracy, minimizes the latency rate, and improves service quality. Because fog nodes spread near the end-users and some places with relatively weak monitoring, it is more vulnerable to malicious attacks. Furthermore, Man-in-the-middle attacks can stop sending patient data from the healthcare IoT devices to the healthcare provider, which leads to life loss in some cases[7,63,64]. As a solution to these issues, the multi-layer communication approach was used, which helped in solving many security and privacy issues, including authentication and authorization, identity management, data sharing policy, quality of services, etc.

7.1.3 | Security issue for healthcare IoT system in Edge computing

The edge computing layer is very close to the end-users, and therefore, it introduces a platform at the application layer for protecting the data collected by various IoT sensors[65]. For example, in[7,66], they proposed techniques for encrypting the patients' data at the application layer before sending the data to the cloud servers. Furthermore, To ensure availability while receiving denial of services (DoS) attacks, the edge architecture uses backup systems and redundancy techniques.

8 | LATENCY RESEARCH AREA

The latency issues vary depending on the nature of healthcare IoT applications. It differs with the type of application and the healthcare IoT systems field. Some applications have more constraints than others. Some healthcare IoT applications are authorized to have some delays while others are not. For instance, sending blood pressure can allow delays up to 2 to 4 seconds[67]. While ICU applications, ambulance applications, and emergency applications allow less delay. Surgery applications need to send multimedia data as interactive video and audio to remotely and the allowed latency for these applications must not beat more than 300ms[68].

If cloud computing is used, normally raw data is sent from IoT nodes to the cloud to be processed and stored. While transferring the data, unpredictable network circumstances may cause delayed responses. The case is even more dangerous when in the case of transferring streaming-based data as EEG or ECG signals. To overcome this possible delay for critical data, the analysis of such data is done in the distributed edge gateway and (i.e., the local network level) using time-sensitive procedures[69]. Then, the analyzed data is transferred to the cloud server for further processing and permanent storage.

8.1 | Latency Issue in Healthcare IoT Systems Using Different Computing Technologies

Healthcare IoT sensors produce a huge amount of data. Processing and analyzing these data need more time, leading to delays in the provided services to the patient, especially in the cloud environment. Recently, traditional services of cloud environments have been unable to obtain the latency requirements of healthcare IoT systems. To solve this problem, in[9], they used near edge devices to process and store data locally, to overcome latency problems and provide better QoS. In[70], to execute healthcare monitoring applications using BAN, they used cloudlet computing as a solution to solve high latency problems, especially in critical tasks. They used WiFi direct communication between concentrator and cloudlet to reduce data transmission latency, or LTE to transfer data from the concentrator to the cloud without using cloudlet technology. In[43,71], to minimize the time of data processing and the number of communications, they used a local cloud or cloudlet with the MapReduce technique which leads to reduce the overall processing delay.
In[6,21,50,72,73,74,75], wearable IoT sensors can produce a huge amount of raw data within a short time. But it is not necessary and not feasible to transfer these data from many patients to the cloud. Therefore, fog computing is reasonable to filter, process, and compress the data before moving it to the cloud, which is crucial for better visualization, low latency, and context awareness in emergency and ICU rooms. Consequently, the latency can be reduced because of the shorter physical distance. In[76], when applied fog computing concept, they decreased 90% of exchange data from patients to the cloud and reduced up to 20% of the processing time. As provided in Figure 10 , we found that most researchers used the Fog computing paradigm to solve latency issues.

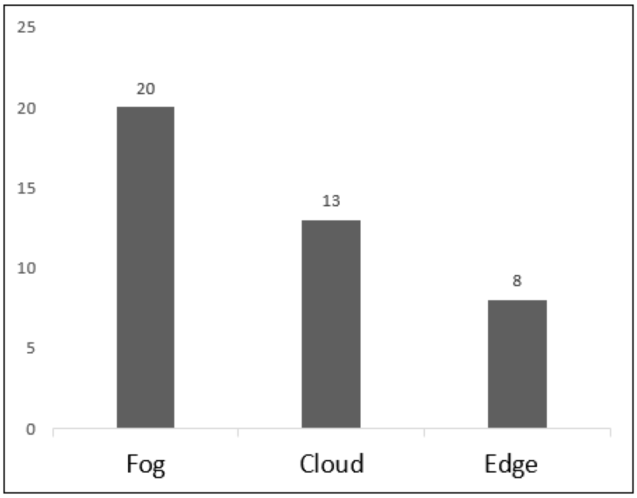

FIGURE 10 Number of studies that consider High Latency issues using different computing technologies

In conclusion, based on our findings, to reduce the latency in the cloud environment between healthcare IoT sensors and patients, the fog computing techniques are integrated with the cloud environment. Fog computing is designed to be close to IoT sensors, which provide quicker responses to patients in emergency cases compared to cloud computing.

9 | ENERGY EFFICIENCY RESEARCH AREA

Energy efficiency is one of the most important aspects in the field of healthcare IoT systems due to its impacts on the environment, operating expenses, and service quality. Healthcare wearable sensors generate a high amount of data that needs high energy and lead to a short lifetime of the battery. In terms of resource consumption due to data processing, the most resource consumption techniques are the speech and image processing techniques[67]. Depending on our study, to obtain energy efficiency in healthcare IoT systems, researchers used different optimization algorithms, different computing techniques as Edge or Fog computing, different types of communication technologies, and appropriate hardware according to the type of system. To decrease the usage of energy, optimization algorithms were also applied. An efficient energy architecture for healthcare IoT systems is proposed in[77]. This approach uses sleep mode method to reduce the energy consumption depending on turning IoT sensors to sleep mode in three cases: the battery level is low when the area size covering override the rank of battery level, the situation of battery level, and the demand of collecting data from patients in a specific interval of time. Therefore, Cloud resources allocated to the system are saved when IoT sensors changed to sleep mode. In[48,78], they used Raspberry Pi because it has features of having less power consumption of nearly one-tenth when compare with other hardware.

9.1 | Energy Efficiency in Healthcare IoT Systems Using Different Computing Technologies

Data transmission and computational tasks are the most energy consuming processes in healthcare IoT system. According to Figure 11 , the most significant percentage comprising 47.1% of the reviewed studies used cloud computing technology architecture to address the energy efficiency field, 35.3% used Fog computing architecture, and 17.6% used Edge computing architecture. In general, the work to reduce energy consumption in IoT healthcare systems focused on eliminating unnecessary communications. For example, using fog computing in the intelligent gateway with efficient scheduling tasks can reduce energy consumption in healthcare IoT sensors. Also, in the data centers, determining the appropriate place to process collected data in the Cloud or Fog depends on the type and amount of collected data. Also, most healthcare IoT systems focus on privacy and security protocols that consume less energy in the IoT devices, and therefore, lightweight protocols are used.

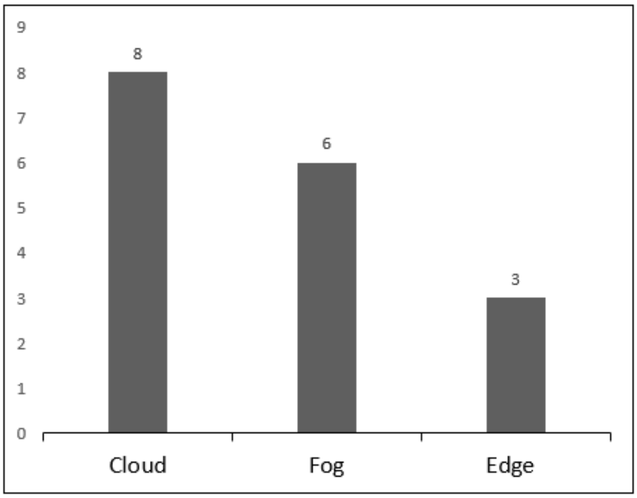

FIGURE 11 Number of studies that address the high energy efficiency topic

10 | QUALITY OF SERVICES RESEARCH AREA

In IoT healthcare systems, providing quality of Service (QoS) requirements is one of the critical aspects. Quality of Service (QoS) controls the network's capabilities and resources to afford a reliable backbone to healthcare IoT services. For example, QoS controls latency, delay variations, packet loss, and bandwidth and communication protocols. IoT healthcare systems that are based on cloud, edge, and fog computing technologies have multiple QoS aspects to be controlled, such as performance, reliability, scalability, and availability. The following subsections discuss those aspects.

10.1 | Performance

Performance is a very important aspect to be addressed in healthcare IoT systems because they include a wide variety of heterogeneous tools that collect huge amount of medical and health data for acute and chronic cases, and such data need to be processed quickly using high performance computing technologies. Therefore, healthcare IoT systems must contain improved methods to ensure high-performance results. Scalability and interoperability perform the main role in the performance of IoT healthcare systems. Furthermore, IoT big data should be processed in a distributed and parallel way to enhance the performance of data analysis.

Many techniques were introduced in different domains to obtain high-performance healthcare IoT systems[4,7,10,19,79]. For example, correct interaction and connection between different IoT healthcare devices guarantee that both the tools and patient personal information are under suitable care. Furthermore, a low-power WBAN device gives reliable and efficient infrastructure to all embedded, non-embedded, and wearable sensor devices for the patient body. In[7,80,23,73,81], the tasks between fog computing nodes and cloud computing system must be coordinated, so high computational tasks are performed permanently in the cloud computing resources, but other analytical tasks are performed in the fog nodes to reduce the load and enhance the performance of different healthcare activities.

10.2 | Availability

IoT availability is defined as the reachability of IoT services when the network link or device failures occur. A minor interruption of critical healthcare services, especially for older people or in an emergency, may disrupt that service's provisioning and lead to patient death. The availability of IoT healthcare services in a cloud-based computing network is the first major demand. Cloud computing platforms include data storage and computing resources that are distributed on large networks. These networks must be consistent in healthcare IoT performance and availability services.

Healthcare IoT systems require interoperability, and therefore, these systems must use protocols, as 6LoWPAN, and IPv6 which are significant for healthcare systems where availability always must be provided. In[66], they proposed a service placement algorithm to increase the service availability and the quality of service (QoS) satisfaction rate by mapping applications to the nearest fog devices and then pass the services of the applications to other fog devices depend on the available fog nodes.

10.3 | Scalability

Healthcare IoT systems must be developed to help a large number of patients. Also, doctors and other healthcare specialists must use the devices and troubleshoot any problem remotely. This requires transacting with a huge amount of connections from the wearable IoT sensors and devices to the healthcare servers. Scalability is defined as the ability of the healthcare IoT system to keep meeting system requirements in case of an increase in demand for its services. In[6], they used a clustering approach to improve scalability with more efficient communication among sensors, and to increase the duration of the network connections by decreasing the number of directors between the IoT nodes and their corresponding coordinators.

In[82], they used a load balancing algorithm with cloud computing to improve the scalability of the IoT network. This algorithm enhances energy consumption and processing abilities and reduces the time consumption of the data processing.

10.4 | Reliability

Reliability of healthcare IoT systems has absolute importance. Any problem in such a system availability often has direct consequences on patients and end users, so the system must operate without any failure. The unpredictable reliability could drive many problems in obtaining reliable health monitoring and transferring important signals from patients to healthcare services. Recently, many researchers addresses the reliability aspect using fog computing techniques. This gateway can offer a lot of features such as local data processing, local storage, secure data mining, etc.[50,83,84,64]. The reasons for using fog computing and local data processing are: (1) for long-range remote monitoring of patients suffering from chronic diseases, Internet disconnection may happen frequently. Therefore, local data processing and local data storage improve system consistency and reliability[8], and (2) fog computing allows preserving the system's operation locally in the local storage of the fog layer.

11 | CONCLUSION AND FUTURE WORK

Healthcare IoT systems use medical sensors, mobile computing, and cloud computing technologies to manage patients' conditions and use communication technologies to transfer collected patient data to cloud computing storage. With the rapid increase of using IoT devices in the healthcare field, combining IoT with different Cloud, Fog, and Edge computing technologies improved healthcare IoT systems. Cloud computing technology significantly emerged in various healthcare IoT systems to enhance the platform and infrastructure of services. However, healthcare IoT sensors produce a huge amount of data, so processing and analyzing this data need more time, especially in the cloud computing environment. Fog and Edge computing technologies transform computing power and processing to the end-user and resolve many data processing challenges including latency and performance.

In this study, we conducted a survey to identify the main research topics that have been addressed in the domain of healthcare IoT systems when used with cloud, fog, and edge computing technologies. We applied a large-scale comprehensive study by analyzing the related research papers based on the exclusion and inclusion criteria that are described previously in the paper. Our investigation found that healthcare IoT systems address mainly five research topics, namely: big data, security, latency, energy efficiency, and QoS. We found that the highest number of research papers focused on big data, i.e., 63% of the studied research papers, while the energy efficiency topic had the lowest number of papers, i.e., 17% of the papers. Most of the papers that focused on the big data topic used the cloud computing technology to solve big data processing issues, i.e., 55.5% of the research papers that address big data used cloud computing. Likewise, 59.4% of the security-related papers addressed the security aspect in the cloud layer. Most of the papers that address the latency topic used the edge and fog layers, i.e., 68% of the latency-related papers, to reduce latency in healthcare IoT systems. Most of the papers that address energy efficiency used cloud computing, i.e., 47% of the papers, and fog computing, i.e., 35% of the papers, to improve energy efficiency. Overall, we found that the Fog computing layer has a better performance, less latency, and better security protocols compared to the cloud layer. The edge and fog layers also enhance the cloud layer by applying early data cleaning and processing tasks to the received raw data before the data is finally transmitted to the cloud layer for further processing and storage.

Finally, considering future research, we plan to investigate, deeply and in details, the state-of-the-art technologies that are applied in the identified five reserach topics, which are: big data, security, latency, energy efficiency, and QoS. Furthermore, we will investigate the gaps and open research problems in these topics. As an another future work direction, we plan to how healthcare IoT systems emerged and changed before and after the Covid-19 pandemic period and study the pandemic impact on the different computing technologies, i.e., cloud, fog, and edge computing, that are employed with these healthcare IoT systems.

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An Acknowledgements section is started with `\ack` or `\acks` for *Acknowledgement* or *Acknowledgements*, respectively. It must be placed just before the References.

11.2 | Bibliography

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