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Enabling technologies for fog computing in healthcare IoT systems

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HIGHLIGHTS

- The study explored the highlight problems, issues, and challenges of Fog computing in healthcare applications.
- Performance evaluation of fog computing implementation in healthcare applications.
- Numerous lessons related to fog computing. Fog computing without a doubt decreased latency in contrast to cloud computing. Researcher show that simulation and experimental proportions ensure substantial reductions of latency is provided. Which it is very important for healthcare IoT systems due to real-time requirements.

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ABSTRACT

Context: A fog computing architecture that is geographically distributed and to which a variety of heterogeneous devices are ubiquitously connected at the end of a network in order to provide collaboratively variable and flexible communication, computation, and storage services. Fog computing has many advantages and it is suited for the applications whereby real-time, high response time, and low latency are of the utmost importance, especially healthcare applications. **Objectives:** The aim of this study was to present a systematic literature review of the technologies for fog computing in the healthcare IoT systems field and analyze the previous. Providing motivation, limitations faced by researchers, and suggestions proposed to analysts for improving this essential research field**.** Methods: The investigations were systematically performed on fog computing in the healthcare field by all studies; furthermore, the four databases Web of Science (WoS), ScienceDirect, IEEE Xplore Digital Library, and Scopus from 2007 to 2017 were used to analyze their architecture, applications, and performance evaluation. **Results**: A total of 99 articles were selected on fog computing in healthcare applications with deferent methods and techniques depending on our inclusion and exclusion criteria. The taxonomy results were divided into three major classes; frameworks and models, systems (implemented or architecture), review and survey. **Discussion:** Fog computing is considered suitable for the applications that require real-time, low latency, and high response time, especially in healthcare applications. All these studies demonstrate that resource sharing provides low latency, better scalability, distributed processing, better security, fault tolerance, and privacy in order to present better fog infrastructure. **Learned lessons:** numerous lessons related to fog computing. Fog computing without a doubt decreased latency in contrast to cloud computing. Researchers show that simulation and experimental proportions ensure substantial reductions of latency is provided. Which it is very important for healthcare IoT systems due to real-time requirements. **Conclusion**: Research domains on fog computing in healthcare applications differ, yet they are equally important for the most parts. We conclude that this review will help accentuating research capabilities and consequently expanding and making extra research domains.

1. Introduction

A number of IoT services, such as computation resources, storage capabilities, heterogeneity, high processing, and others that

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brought a technological revolution, are provided by cloud computing. The cloud provides the virtualization of computing resources at various levels [1]. Almost all the human life domains have adopted cloud computing [2]. However, cloud computing has drawbacks in terms of high delays which have an adverse effect on the IoT tasks that require a real-time response. Furthermore, it does not match industrial control systems which require a low-delay response time [1]. In 2012, Cisco announced an infrastructure paradigm called fog computing, which is a new computing concept, so as to tackle the limitations of cloud computing [3]. They asserted that fog computing is applicable at three networking levels: (1) the collection of data from the devices in the edge (sensors, vehicles, roadways, and ships); (2) multiple devices connecting to a network and sending all the data; (3) the collected data from the devices should be processed in less than a second along with decision making [4]. The term fog computing shifts capabilities of the cloud near to the end user, and provides storage, computation, and communication to edge devices, which facilitate and enhance mobility, privacy, security, low latency, and network bandwidth so that fog computing can perfectly match latency-sensitive or real-time applications [5]. On the one hand, fog computing infrastructure consists of plenty of fog nodes, edge device networks, and even virtualized data centers or IoT devices that are connected to these nodes [6]. These are connected to the cloud for the purpose of implementing large storage and rich computing [7]. The distribution of functions between the cloud and the fog nodes is considered a crucial factor [8]. Millisecond to sub-second latency offered by fog, even faster than real-time interaction, supports multitenancy and performs better in low-latency applications [9]. The concept of fog computing has been designed to satisfy the applications that require low latency with a real-time response such as healthcare IoT systems [10].

Similarly, the performance of emergency and health monitoring services can be affected in terms of low latency, and also the delay that may be experienced while transferring data to the cloud f receiving the instructions back to the application [11]. Healthcare applications provide large volumes of data which require storage in the cloud rather than depending on the limited computing resource and storage devices. The outcome data of healthcare applications is fairly large [12]. In healthcare diagnosis, a large amount of data is generated, which should be stored and retrieved in a perfect manner [13]. Streaming-based transmissions in E-Health applications should be managed considering the real-time requirements [14]. For designing healthcare applications, fog computing is considered the best method to rely on because these applications are latency sensitive, show low response time, and produce a large amount of data. Fog computing significantly contributes to healthcare applications by serving elderly people through home nursing [15]. Real-time monitoring (e.g., neurological diseases) is one of the important features in healthcare applications that require a low latency and high response time, therefore fog computing can be the best solution for such applications [13].

One fog node or many computation nodes that are connected jointly can be used to build fog computing infrastructure. The connected fog computing nodes can significantly improve scalability, redundancy, and elasticity, and when more computing is required, it is possible to add more fog nodes. The above-mentioned characteristics conform to the requirement of healthcare applications [16]. It is clear that one can rely on fog computing as it properly supports many healthcare applications because of its enhanced service quality, minimum response time, low latency, location awareness, high mobility, etc. However, fog nodes (e.g., smart routers, gateways, servers, base stations, etc.) cannot meet these requirements unless the architecture of fog nodes is redesigned to be compatible with healthcare applications [17].

This study presents a systematic literature review of fog computing in the healthcare field and analyzes the previous studies that focused on fog computing architecture with shared resources. The criteria and attributes that were considered for enhancing understanding on different relevant aspects of this field in literature were motivation, limitations faced by researchers, and suggestions proposed to analysts for improving this essential research field. The main contributions of this research are; first, problems, issues, and challenges in healthcare IoT systems are highlighted. Secondly, performance evaluation of fog computing implementation in healthcare IoT system. Lastly, in order to provide or enhance the current knowledge of resource management in healthcare IoT systems by adopting the main three factors Computation offloading, Load balancing and Interoperability, research studies motivate to propose (or develop) and use fog computing framework in Healthcare IoT systems. The organization of this paper is as follow: Section 2 describes the methodology of the research; related works are presented in detail in Section 3. Section 4 discusses the role of fog computing in healthcare applications. Section 5 presents the limitations of the research. Performance evaluation, motivation, challenges and recommendations are discussed in Section 6. Learned lessons viewed in Section 7. Lastly a conclusion is presented in Section 8.

2. Research methodology

The performance of the fog computing in healthcare applications is reviewed considering the guideline [18–21]. In brief, this guideline implements three phases: planning review, conducting review, and documenting review (see Fig. 1).

In the planning review process of fog computing in healthcare applications, the following steps are followed: (1) identify the need and requirement for a systematic literature review of fog computing in the healthcare applications, (2) define and investigate the research gap, questions, and highlight the problems encountered in the previous studies, and (3) improve/assess the procedure to perform systematic literature review on the subject of fog computing in healthcare applications. The actions related to directing the systematic literature review of fog computing in the healthcare applications involve the following steps: (1) identify the fog computing in the healthcare applications research, (2) literature selection procedure, and (3) information extraction for fog computing in the healthcare applications. The documenting review phase implements the outcomes of the systematic literature review of fog computing in the healthcare applications and examines how to select the studies.

The objective of identifying the research questions and research motivations is to provide a better understanding of fog computing in the healthcare applications. In addition, it involves the identification of the scope and objectives of our study through architecture, motivation, applications, performance evaluation, motivation, open challenges and issue, and recommendation criteria as shown in Table 1.

2.1. Sources of information

The investigations were systematically performed by applying the following four databases: Web of Science (WoS), ScienceDirect, Scopus, and IEEE Xplore Digital Library. The selection of research was index based that demonstrates a simple and complex query in many journals and conference research papers in computer science and medical science. As a result, both technical and healthcare studies were considered in this selection process, providing a more extensive perspective on research studies considering different scientific fields (see Table 2).

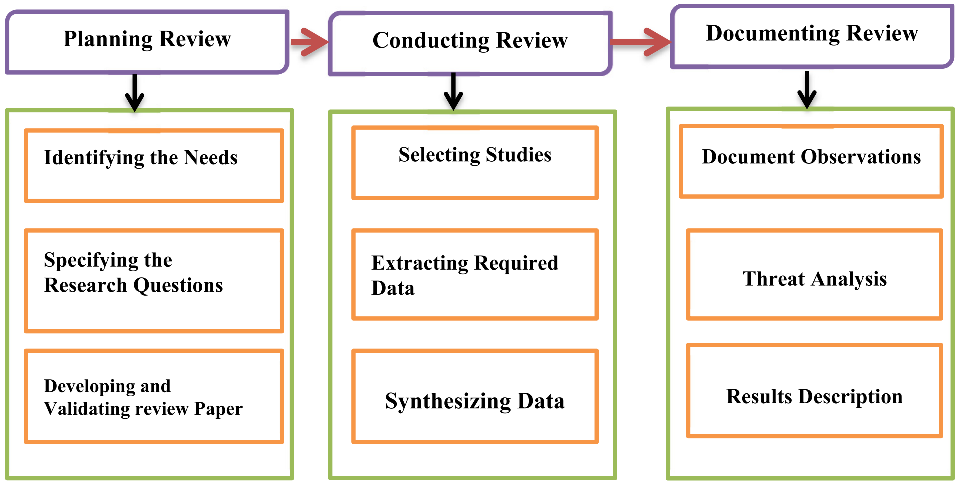

Fig. 1. Research methodology guideline.

Table 1
Research questions and motivations.

Research questions	Motivations
RQ1: What is the present state of a systematic literature review on fog computing in healthcare applications?	Following the successful realization of fog computing applications, it is imperative to obtain clear insight of its architecture and fundamental aspects to be utilized in healthcare applications.
RQ2: Which performance evaluation objectives are achieved by fog computing in healthcare applications?	Computing tasks in healthcare are important and may be improved by fog computing, due to the need to aggregate data and wireless device constraints, processing on higher network tiers is essential.
RQ3: Which popular methods are used to achieve such performance evaluation objectives in fog computing in healthcare applications?	The state of the art in best employment determination of fog computing in healthcare applications.
RQ4: Which are the current studies on fog computing in healthcare applications and what are the future directions in Fog computing architecture, motivation, applications, performance evaluation, motivation, open challenges and issues and recommendations?	Collecting information on fog computing technologies that are successfully implemented in healthcare applications.

Table 2
The inclusion and exclusion criteria for articles.

Criteria		Prenominal
Inclusion	Research articles (Framework, Model, Architecture, Implemented system, Review, and Survey) that are related to cloud, edge, fog computing in healthcare applications.	Scientific reports that present fog/edge computing as a pre-processing layer between end devices and cloud computing.
Exclusion	• Books, Book Chapters, and Thesis. • Non-English articles. • Un-related articles.	Books and Book Chapters were excluded from the search results as well as all the non-English articles and unrelated articles.

2.2. Study selection

The method of selection of studies for efficient review is difficult, considering various research areas. It seems to be the most essential and maybe the most ignored perspective while exploring a particular point. Considering the titles and abstracts of the research studies, the first step was to exclude the duplicated and unrelated articles. The second step was to read the full text of the remaining papers.

2.3. The SLR search

We created the query using specific keywords and operated it in IEEE, ScienceDirect, Scopus, and WOS databases on 14 December 2017. The search queries were divided into three parts. The first part was about the cloud computing string ("cloud" OR "cloud computing"), whereas the second part consisted of the following keywords ("fog computing" OR "fog networking" OR "fogging" OR "edge computing" OR "edge networking" OR "edge technologies"). The third part (health) limited the search to all the research that was related to cloud and fog in health applications. All the query parts were combined by "AND". In each database, we selected journals and conferences as an advanced search, without selecting other options such as chapters or books or any other types of documents. The search query, study selection, and exclusion and inclusion of papers are shown in Fig. 1. The settings that are used when we operated search query is presented in Table 3.

2.4. Eligibility criteria

This paper focuses on fog computing in Healthcare, and the taxonomy was initially divided into three main categories. These categories were derived from the previous surveys and literature reviews. The exclusion was carried out in three levels. In the first level, the duplicate papers were removed. In the second level, after reading the title and abstract of each paper the unrelated papers were excluded. In the third level, after reading the papers completely the papers were excluded.

2.5. Article search results

In a span of ten years, from 2007 until 2017, the results of an initial query resulted in 1029 articles: 751 from IEEE Xplore, 185 from Science-Direct, 80 articles from Scopus, and 13 articles from WOS. In all databases, 134 duplicate articles were found. After reading the title and abstract of each paper, 771 articles were excluded as unrelated papers. By using different methods and techniques, 99 articles were found on the main topic of the search "Fog Computing in Healthcare". The research taxonomy that presents the articles focusing on fog computing in healthcare is presented in Fig. 2. The taxonomy was split into three major categories. The first category targets the methods that consist of frameworks and models that were proposed (16 articles). The second category includes the systems that either proposed infrastructure or implemented the system (49 articles). The third category covers the review and survey articles about fog computing in healthcare applications (34 articles).

3. Fog computing in healthcare IoT systems

In this section, articles that use fog computing are presented and discussed in order to demonstrate the importance of employing fog computing in healthcare IoT Systems.

Monitoring is considered as one of the important methods in IoT healthcare Systems. A fog-based monitoring system was presented [20], which provides remote monitoring with low cost. Moreover, in this case, the system is comprised of smart gateways and efficient IoT sensors. Furthermore, ECG signals, body temperature, and respiration rate are collected by sensors and sent wirelessly to gateways in order to produce notifications following an automatic analysis. Considering privacy and security as important aspects of healthcare applications, a fog-based healthcare framework was proposed [21], which implemented fog between the cloud and end devices as an intermediate layer. Privacy and security were enhanced at the edge of the network by using a cloud access security broker (CASB). The framework was applied by applying a modular approach. Data aggregating from multiple sources could be supported by the framework and adequate cryptographic assessment. Latency-sensitive healthcare data could affect the performance of healthcare applications. A fog-based computation platform was discussed in order to deal with latency-sensitive healthcare data [22]. The large-scale geographically distributed healthcare application was managed by using a programming model. In this application, data consistency and data accuracy can be retained and service delivery time can be improved. A fog computing system architecture was proposed in order to validate and evaluate sensed raw health data. In this process, embedded computing instances were constrained by resources [23]. The identification of the important patterns was performed through instances and then these were forwarded to the cloud. The primary objective of this system is to process huge data using reduced power fog resources. A smart e-health gateway was implemented [14,24] in fog computing as a means to support healthcare services in IoT and to offer data processing, data analysis, and real-time local storage. The smart e-health gateways were distributed and positioned geographically. The responsibility of each gateway is to carry out the task of managing a set of IoT devices that are directly connected to the patient. The system has the ability to monitor patients independently irrespective of their movement. In the fog-based system, energy-, mobility-, and reliability-related issues can be resolved effectively. The diagnosis of the patients who were infected with Chikungunya virus (CHV) was proposed in the fog-based healthcare system [25]. The system constitutes of three main layers: wearable IoT sensors, fog, and cloud layer. The system is used for identifying and controlling CHV virus. The diagnosis of the infected patients was carried out using Fuzzy-C means (FCM) and emerging alerts. Time-sensitive healthcare application data was proposed [26] for brain strokes and heart attacks, wherein fog computing was used to notify the users as early as possible. In these applications, fog computing enhances the execution time, network usage, and energy consumption cost. A fog computing distributed computational approach was proposed [27] for chronic obstructive pulmonary disease (COPD) and people suffering from mild dementia for Romanian healthcare regulations. eWall as a monitoring system is used to meet the requirements of the procedure. Fog computing reduces the communication overload and maintains patient privacy.

Fog computing is implemented in the proximity of end-user devices/users as well as for large scale geographically distributed devices, communication in real time, mobility support, interoperability, heterogeneity and preprocessing with respected interplay connection with cloud. Fog computing has the ability to handle a variety of devices and sensors in addition to providing local processing and storage [28]. All the mentioned features of fog computing ensure that fog computing is the most suitable technique for Healthcare IoT systems which require the specified features. Fog computing differs from the traditional solutions to Healthcare IoT systems; fog-assisted system architecture has the ability to withstand the issues in numerous healthcare systems like scalability, energy awareness, mobility, and reliability, as shown in the architecture layer of fog computing in Fig. 2. [5,29,30].

4. Related works

This section shows the related articles that use fog computing in healthcare applications. According to the taxonomy, the research is categorized into three main parts; Methods, which covers all the articles that proposed frameworks or models, System development, which covers all research that implemented fog computing in a system or proposed fog computing architecture. The third and last part targeted reviews and surveys about fog computing in healthcare applications.

4.1. Methods

This section provides a description of the methods which comprise of the frameworks and models that are used for fog computing in healthcare applications. The frameworks were considered to be the main parameters which were the target of searches that use shared fog nodes, smart gateways as fog nodes (shared or individual), foglet/cloudlet if considered in the proposed frameworks and models, enhanced response time as a result of the frameworks and models, and offloading that was included as a parameter which shows the articles that improve this mechanism. It is important to note that security concern is out of the scope of this paper as some articles tackle the security in cloud and fog computing.

Firstly, the shared nodes in fog computing were proposed in some articles. As reported earlier [31], a new computing paradigm (software framework) named Edge Mesh was used to distribute the decision-making tasks by shared fog nodes as well as smart gateways. As reported earlier [3], personal gateways situated at the patient's side serve as an intermediate node, referred to as a fog node, which was applied to process the patients' health data. An algorithm that is used to facilitate resource sharing among fog nodes was proposed [23]. Secondly, other papers used smart gateways and implemented them in fog computing as a fog node or to connect some fog nodes in healthcare applications. As reported earlier [26], a model was proposed which developed two algorithms: the first one picks a fog when the user is at the overlapping part of fogs, while the second algorithm solves the situation when the user changes his location; the shortest path among fogs can be

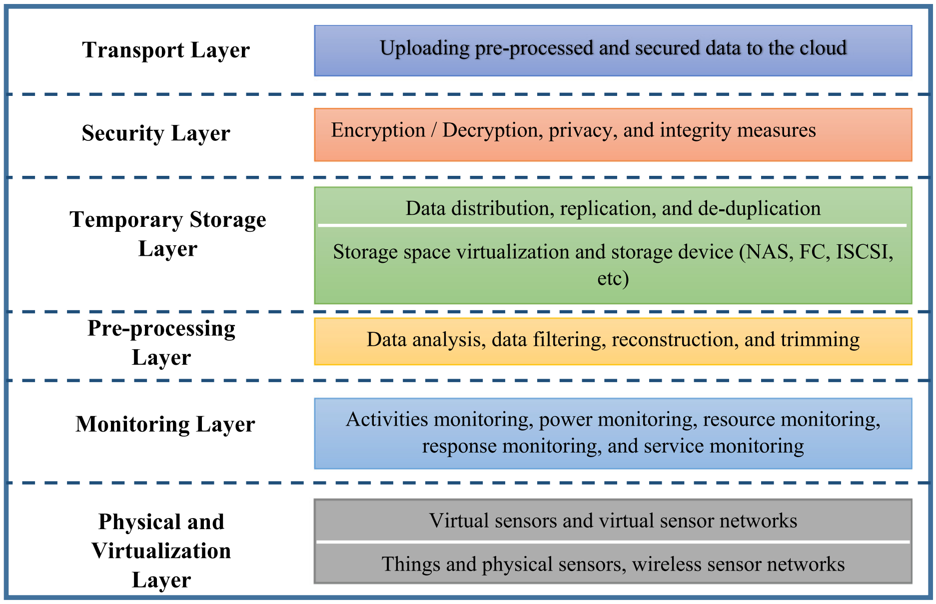

Fig. 2. Fog computing architecture.

found by an integrated gateway connected to every device. A network of Smart e-Health Gateways was suggested, which helps in preprocessing the data and alleviates further processing by weighing down from cloud and sensors [32]. In order to dynamically allocate resources, fog computing with the smart gateway (Micro Datacenter) was proposed earlier [33]. As reported in an earlier study [34], personal gateways act as intermediate fog nodes that geographically deployed between the IoHT devices and healthcare cloud. In order to cluster small cells so as to facilitate resource sharing among them, an algorithm was proposed [35]. A method was presented [36] to optimize the sharing of resources in order to maximize the corresponding utility.

A framework that combine Software-Defined Systems (SDSys) and Mobile Edge Computing (MEC) system abilities to construct a ubiquitous MEC in that a global controller connect many local controllers was proposed earlier [37]. By sharing device resources of users, the mitigation of the IoT resource management by applying Cloud Computing was suggested earlier [38]. A mobile edge computing framework was proposed [39], which shows that real-time and personalized services for people in diverse locations can support large multitudes of people, i.e., a hybrid cloud at the end of the server along with a terminal fog computing (FCTs) on the edge. According to an earlier report [40], edge nodes can be perfectly managed by IoT-Cloud framework named Stack4Things, and computing resources can be located closer to offload processing by reducing the latency. Medical devices that apply the security provisioning model (AZSPM) in fog environments were proposed earlier [41]. According to an earlier work [42], cloud at the edge or fog is considered a virtual platform that serves as an on-request execution environment of micro-services near the data source or devices, which differs from execution of micro-services in the device itself. During this process, the API gateway is placed among micro-services so that the interconnectivity between the aggregation and gateway distribution function can be effected. By using fog computing facilities, a protocol of triparty, one-round key authenticated agreement was proposed earlier [43] considering the bilinear pairing cryptography to produce a session key between the individuals to ensure secure communication among them. Taxonomy of research literature on Fog Computing in Healthcare provided in Fig. 3. A new computational framework was proposed earlier [44], which facilitates remote real-time monitoring, sensing, and scalable high-performance computing for making prognosis and diagnosis.

The table below shows the frameworks and models that implement fog computing in healthcare applications

Healthcare applications still have challenges especially in resource management that need to be solved. A new challenges results in smart universal healthcare systems in attaining the various requirements of the system including low-latency response, energy-efficiency, interoperability, mobility, reliability, security, etc. The architecture of Fog-assisted system is able to cope the issues in ubiquitous healthcare systems such as scalability, energy efficiency, reliability, and mobility issues. Heterogeneous healthcare environments earnestly need complex management tasks to avoid continuous revision of resource allocation in alignment with uneven and uncertain data loads arising from implemented Healthcare solutions [8,14,48,49].

Table 4 shows the critical studies and main factors about resource management in healthcare services. Computation offloading, load balancing/distribution and interoperability are the main factors in resource management of healthcare IoT systems. Table 4 shows the papers that address these factors:

By comparing the recent frameworks mentioned in the previous table, we can clearly observe that none of the frameworks and models are concerned about computation offloading. Furthermore, none of the frameworks seek to address the constraints imposed on all resource management factors. A framework that copes with the main factors of resource management enabling technologies in Healthcare IoT systems is needed.

4.2. System development

This section expounds on research studies which propose or/and implement a system or architecture for fog computing in healthcare applications. The taxonomy was divided into two parts. The first part describes the studies that propose a fog computing architecture while the second part targets the research studies that propose or/and implement fog computing systems.

In the second part, shared fog nodes and smart gateways were also targeted. A data-centered fog platform was developed earlier [9] in order to support smart living together as well as carry

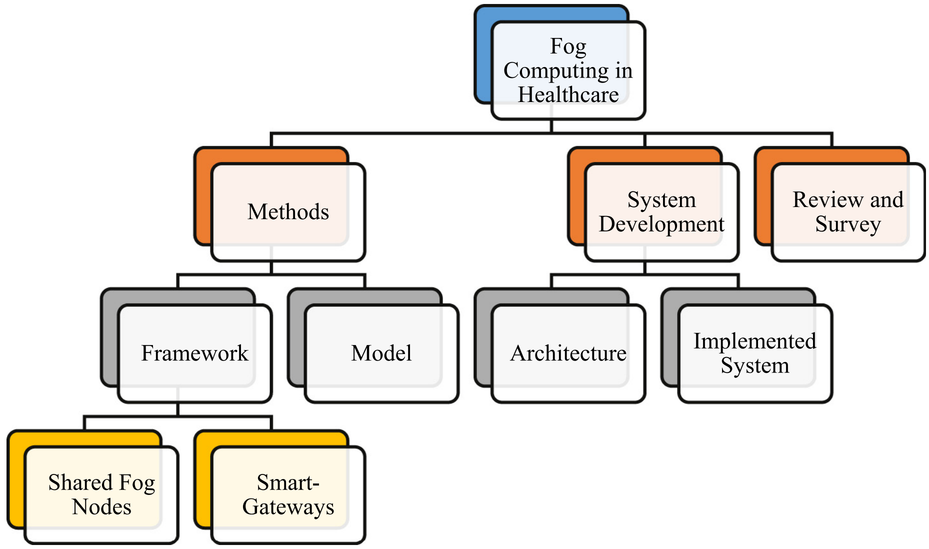

Fig. 3. Taxonomy of research literature on Fog Computing in Healthcare.

out dataflow analysis with the use of Foglet. In this platform, smart objects are linked to a Fog Edge Node (FEN) to build a subnetwork; a FEN runs Foglet which join forces with another FEN and Fog Server (FS), and a few FENs may require to communicate with the Cloud from time to time whereas the others may not need to. A fog-computing for patient health monitoring of an ambient-assisted living (FAAL) was proposed earlier [13] in order to lessen the load imposed on the communication infrastructure in which a group of nodes is connected by a cloudlet. As reported earlier [50], a simulation process was performed through discrete event system specification (DEVS) which connects fogs to a broker to provide lower waiting times and increased data rates. A new computing model called Firework was devised for the role of processing huge data in cooperative edge environment (CEE) [51]. Sharing the data is the main target of Firework, whereas guaranteeing data integrity and privacy of stakeholders in which firework nodes are connected by a firework manager. A platform called Cloud4IoT performs migration of the vertical (offloading) and horizontal (roaming) of IoT functions using a Kubernetes cluster that is organized in three layers: Edge, IoT gateways and Cloud, [52]. An end-to-end security scheme was proposed [28]. Implementing a network of interconnected smart gateways, this security scheme scales down the traffic of communication to 26%, the latency communication between smart gateways and end users to 16%. A dispersed cloud infrastructure called Nebula was presented [53], which uses an edge with voluntary resources for both data storage and computation consisting of a number of nodes which they are voluntary that offer storage, and computation resources, in conjunction with a group of application-specific and global services that are located on stable, dedicated nodes. A semantic edge-based network model was proposed [54], which is beneficial in transmitting tactical as well as non-tactical information across the network by interacting with edge nodes in order to ensure very low latency. As reported in an earlier study [55], a healthcare monitoring system is enhanced by capitalizing on the role of fog computing at smart gateways rendering sophisticated services and techniques such as notification service, distributed storage, and embedded data mining at the end of the network. For sensor data computing, the concept of "distributed intelligence" was demonstrated [56], which distributes intelligent computation to the very smaller but autonomous units, for instance, smartphones, or edge clouds, sensor network gateways, so as to effectively decrease data sizes and render high-quality data to data centers. By using fog computing and gateway, a medical warning system was proposed earlier [57]. For decision making, the hypothesis function described in the component of Analyze is passed on to the component of Plan in the gateway. The system is then reinforced so as to facilitate appropriate decision making on the local network and that data is collected wirelessly with the aid of heterogeneous devices on the sensor network and thereafter forwarded through the gateway to the cloud server. A fog computing interface (FIT), a low-power embedded system, was presented [58], which is a smart gateway used for processing the data of clinical speech. Prior to transmitting speech features onto a secure cloud storage, the FIT gather, stores, and processes the speech data. A low-cost healthcare system for monitoring was proposed [20], which provides for the remote monitoring, analysis and notification of ECG. This health monitoring system was made up of sensor nodes that are energy-efficient along with a fog layer which makes use of IoT. The sensor nodes were capable of recording and transmitting wirelessly respiration rate, ECG, and body temperature, over a smart gateway, in a form that can be evaluated by the respective caregivers.

Other research studies also present the fog computing system in healthcare applications, which does not use the shared nodes or smart gateway techniques. As reported earlier [59], a smartphone-based service, referred to as Emergency Help Alert Mobile Cloud (E-HAMC), provided a means of contacting the respective division in the event of an emergency with the help of fog services for offloading and preprocessing tasks. The benefits that F2C could potentially provide to a particular health area, COPD, were emphasized [49]. In this case, the patients' quality of life hinges upon the patient's mobility, thus leading to the proposal of an embedded F2C box which enriches the POC with F2C capacities. To address the challenges pertaining to interoperability between cloud computing and fog platforms, a framework was proposed, designed and implemented on a software system [60]. The monitoring system (eWALL) is takes on a computational-distributed approach (similar to that of fog computing), that begins processing the information collected using the sensors in the patient's home so as to minimize the communication overload as well as maintain privacy of patient data [27]. The components of the proposed infrastructure [61] include leveraging crowd sensing, heterogeneous data analysis and decision making, along with alternative suggestions and generation. A WIoT architecture was proposed [62] for keeping track of activities in the household. This system was made up of N monitoring devices and edges with storage and computation cloud sharing whereby

Table 3
Frameworks and Models of fog computing in healthcare applications.

Author	Problem	Technique
[31]	1. Existing paradigms do not make use of edge devices in decision-making. 2. Gateway devices are applied in interoperability, communication, and low-level processing.	Edge Mesh, a new computing paradigm (software framework) the tasks of decision-making are distributed among smart gateways across the network as opposed to transform the data to a centralized server.
[26]	Slow response time for sensitive data regarding brain stork, heart attack and accidents.	Two algorithms were modeled: one which chooses a fog if the user is in the overlapping portion of fogs, and the second one is for modifying user's location and identifying the shortest path between fogs.
[38]	Expand in the number of heterogeneous sensors and devices, application of a wide variety of data formats, protocols, and physical sensing resources needs which require management so as to obtain benefits from the deployed devices.	Device cloud method, which alleviates the management issues IoT resource through the application of Cloud Computing methods in the IoT domain.
[32]	DDoS Attack prevention	Certificate-based DTLS handshake for client and Smart e-Health Gateway common authentication.
[45]	Cloud of Things (CoT) , a combination of cloud computing and IoT does not solve emergency, healthcare, and time sensitive services in need of urgent real-time responses.	Fog computing with smart gateway (Micro Data center).
[3]	IoHT patients' health data security	Personal gateways situated at the patient's side to serve as intermediate nodes (fog nodes).
[46]	Degree of management complexity for large-scale geographically distribution of ME servers required to host plenty of applications to be available to millions of users.	A software-defined framework that is a blend between Software-Defined Systems (SDSys) and Mobile Edge Computing (MEC) system capabilities for the development of ubiquitous MEC.
[34]	Challenges in privacy preservation of patient information while applying the IoHT model thus building their level of satisfaction and trust in the administered services.	Personal gateways that deployed at the end-users' side which serve as intermediate fog nodes between the cloud-based healthcare services and the IoHT devices.
[39]	Framework constituting a hybrid of fog computing terminals (FCTs) at the edge and cloud.	MEC framework capable of delivering real time, location-aware personalized services to multitudes of individuals. The framework is a hybrid of fog computing terminals (FCTs) at the edge and cloud.
[47]	Stack4Things/Edge computing a scenario of health monitoring with the help of edge nodes	Stack4Things, an IoT-Cloud framework for controlling edge nodes such as smart objects, work-stations mobiles, and network devices.
[41]	Significant gaps in noted techniques for fog security management of healthcare data i.e. absence of a universal certification authority (CA).	Security provisioning model (AZSPM) for healthcare devices implemented in fog environments.
[42]	Challenges posed by IoT systems to developers.	Micro services connected by API gateway
[43]	Healthcare cloud enface various security concerns for data stored on the healthcare cloud; data theft attacks being of the gravest security breach.	A tri-party one-round authenticated key agreement protocol based on bilinear pairing cryptography that generate a session key between the participants to ensure secure communication among them.
[36]	Shared resources among central data centers, and mobile devices in mobile cloud computing.	Heterogeneous resource sharing architecture and framework for service-oriented utility functions. The framework is unified mapping disparate units such as power, latency and bandwidth are mapped to time. The paper formulates optimization issues for increasing (i) the total of the utility functions, and (ii) the produce of the utility functions, thereafter solving all of them using convex optimization methods.
[35]	Clustering difficulty in radio access points for the applications of fog computing particularly when there are multiple user requests for fog computing services.	Multi-user small cell clustering optimization policy especially designed for fog computing that geographically distributed.
[44]	Inability of current monitoring systems and prognostics approaches to collect huge amounts of real-time data or develop predictive models in large-scale which are instrumental in making advances in cyber-manufacturing.	New computational framework for remote real-time monitoring, sensing, and scalable high performance computing useful for making prognosis and diagnosis.

Table 4
Critical papers.

Study	Computation offloading	Load distribution	Interoperability
[31,32,45]		✓	
[26]			✓

robust data security blend clouds with edges for efficient clinical services. Edge clouds with containers instead of virtual machines (VM) were proposed [63]. In this system, edge cloud architecture PaaS, service orchestration, and application facilitate the management and coordination of applications using the containers. A three-layer architecture consisting of edge, fog, and cloud was proposed [64], which enables the acquisition, processing, storage of healthcare data and real-time decision making. The prototypes of the fog computing platform were implemented [65] along with a discussion of design goals and challenges. Other aspects investigated are the consumption of energy for sensor nodes [66] fall detection system built on an IoT-based patient monitoring system for fall detection as well as the model of a specialized sensor node. The leverage fog computing approach in healthcare applications was proposed [67] by implementing the fog layer as an middle layer between remote cloud data center and the end-user devices in order to reinforce security, scalability, bandwidth, seamless operation and reduce latency. Edge data analytic platform and a unified cloud was proposed [68], which builds on the concept of serverless computing, joint programming activities and analytic management. A serverless stream application model, is defines as a transformation function which is crucial for purposes of encapsulating user-defined data and applying logic in the processing of stream data. A cloud-based solution was proposed, which is made up of wearable healthcare sensors, personalized healthcare devices used to transmit data from the sensor, and the cloud that transfer services of healthcare across the internet assisted by cloudlet servers which process and transmit information onto the medical cloud [69]. A virtualized, decentralized approach was proposed in an earlier work [70]. This approach utilizes a virtual fog layer with the help of a cloud which orchestrates the resources and services of the virtual fog layer so as to ensure resilient and robust operability. An architectural approach was proposed [71] for autonomic healthcare management system. This approach focuses on how to use the autonomic healthcare management architecture system (AHMS) which is built on the concept of fog computing, and has the task of detecting fall over, reporting and taking emergency action to preserve human life, when the situation calls for it. New architecture was proposed, which is able to support IoT implementation, storing and processing of extensible sensor data on healthcare applications [72]. This proposed architecture is categorized into two subarchitectures: Meta Fog-Redirection (MF-R) and Grouping and Choosing (GC) architecture. Afterwards, HPCS framework was proposed to be used in fog–cloud computing() [73]. The system works by data mining using a lightweight method which facilitates real time monitoring of patients' health. Furthermore, a privacy-preserving protocol for approximation the fraction was created to solve the computation overflow problem. An anonymous and secure aggregation scheme (ASAS) was proposed for application in fog-based cloud computing whereby terminal nodes data gathered by the fog node and thereafter sends the gathered data onto the server hosted on the public cloud. A Mobile-IoT-Federation-as-a-Service (MIFaaS) model was designed with the intention of supporting time-critical applications run on high-end IoT devices which are expected to be introduced in the future fifth generation (5G) environments [74]. A dynamic fog model was proposed, which is considered as a high-level programming model particularly designed for time-sensitive large-scale applications distributed over a broad geographical area [22]. As reported earlier [75], a real-time patient monitoring system for fall detection applying the fog-computing model, referred to as U-Fall, was designed and employed. U-Fall splits the task of detection among the disparate edge devices (such as smartphones connected to the end user at the edge of the network) and the cloud server. An architecture of IoT for implementation in healthcare system that based on the implementation of Fog to Cloud and Data in Motion (F2CDM) was proposed [76]. This is a three-site architecture consisting of the embedded device layer, fog network layer, and cloud network. The features of the hybrid PaaS were designed [77] for IoT applications with fog and cloud computing environments in mind. An implementation of hybrid PaaS makes application components available over the cloud and at fog nodes. An architecture for IoT-based u-healthcare monitoring was proposed [78] motivated by the benefits provided by Cloud to Fog (C2F) computing, which notably serves closer to the edge (endpoints) of implementations in smart homes and hospitals. A set of new fall detection algorithms was proposed [79] with new filtering techniques for application in the fall detection process. During the outbreak of the Chikungunya virus, its diagnosis and spread prevention was expedited through the application of the designed fog-assisted cloud-based healthcare system [80]. The system was designed in such a way that alerts are sent to the users' mobile phones from the fog layer. A large-scale e-healthcare monitoring system designed for multitudes spread over broad geographical regions was proposed [81], by integrating many emerging technologies and offering remote monitoring of patients by using the mobile edge computing approach. A hierarchical computing architecture (HiCH) was proposed [82] for IoT-based system for patients healthcare monitoring, which is a novel computing architecture with appropriate machine learning execution and a technique of closed-loop managing. The proposed system takes advantages of the beneficial attributes of cloud computing and fog computing. A Health Fog framework was proposed [21], whereby fog computing was designed as an intermediate layer between end users and the cloud. Moreover, in this framework the cloud access security broker (CASB) was highlighted as Health Fog integrated component. IoT and a fog-based healthcare system was designed [25] in order to detect and contain the prevalence of Chikungunya virus (CHV). Moreover, in this system, the Fuzzy-C means (FCM) was applied on the cloud server, followed by a social network analysis (SNA) being carried out to give a clear picture of the extent of the CHV outbreak. A health prescription assistant (HPA) IoT-based model was also designed [83], which presents a security system with user authentication and controlled access features to safeguard the services and resources. Three major techniques were proposed in an earlier study [84]: data-coloring-based watermarking, fog computing, and user behavior profiling all of which work to resolve the issues highlighted above.

Some other specialized architectures have also been proposed. Real-time Heart Attack Mobile Detection Service (RHAMDS) was proposed [85] so as to minimize the response time in the event of a request for emergency aid by patients suffering from a heart attack. RHAMDS is designed for implementation in which fogs which are connected by an SDN controller. The research paper presents network architecture, workflow, and model variations. More personalized service was provided using a hierarchical fog–cloud computing complex event processing (CEP) architecture proposed [86] in order to minimize response time while at the same time reduce resource waste. A prototype of the system FogCEPCare was also implemented. A flexible multilevel architecture using the fog approach with an edge node was constructed by Field-Programmable Gate Array (FPGA) technology, where mesh nodes were used [8]. Fog-assisted system architecture was proposed [14] with a smart e-healthcare gateway. Fog computing was used as a geographically-deployed intermediary intelligence layer set up between the cloud and sensor nodes. The smart gateway architecture with fog computing was presented [87] in order to ensure that it is possible for data to be pre-processed and reduced prior to sending it across the cloud over a smart gateway, aggregated by fog computing or smart network. The table below shows the implemented systems and architectures that implement fog computing in healthcare applications (see Table 5).

4.3. Review and survey

The review and survey articles were included in this category in order to describe fog computing in healthcare applications. A collaborative edge was proposed, whereby the edges of multiple stakeholders over disparate geographical locations were connected irrespective of their physical location and network infrastructure [102]. Similarly, a fog node that connects various fog nodes was proposed [103] to encrypt data obtained from the patients' health profiles through the application of a global concealment process so as to facilitate manipulation of the encrypted data without the need for decryption beforehand. A fog orchestrator was presented [104] for providing the unified management of the resource pool, mapping applications based on particular requests, providing a digitized workflow of physical resources (in terms of scheduling and deployment), management of workload execution with control of runtime quality of service (QoS), and timely issue of instructions for object manipulation/control. Software-Defined Networking (SDN) and Service Orchestration through SDN with

Table 5
Architecture and Implemented systems of fog computing in healthcare applications.

Author	Problem	Technique
[52]	Increase in the number of connected objects creates a challenge in maintaining confidentiality of the data produced and negatively affects the performances of the supporting networks	Cloud4IoT: a platform that carries out horizontal (roaming) and vertical (offloading) migration of various IoT functions.
[9]	Cloud is usually centralized whereas smart devices are distributed, therefor, data transformation time(i.e., end-to-end response time or latency) between smart devices and Cloud is a critical challenge	Fog scheme is constructed to improve living smartly along with analysis of dataflow with the employment of Foglet
[13]	Data processing time consuming that effects the performance of monitoring systems such as neurological monitoring which is require a real time processing.	Patient health monitoring system with the Fog computing to support AAL. The system will contribute in reducing communication load by using efficient algorithm for clustering.
[88]	soldiers health monitoring and conditions of their weapons	Edge network which interconnecting between tactical and non-tactical information through network
[89]	Limitation of cloud for latency sensitive and other time-sensitive services	simulation done through discrete event system specification (DEVS)
[53]	extensive computing of data may not support mobility of data because of cloud resources centralization problem of , therefor, are highly unappropriated for deployment of applications that are data-intensive	Nebula: an infrastructure of varied cloud that employ a voluntary nodes at the edge to share resources such as storage and computation.
[51]	Edge computing and cloud computing data are under stakeholder control, in which they will not share their data because of privacy as well as the cost of transportation the data.	new computing paradigm, Firework
[28]	security for mobility enabled healthcare Internet of Things	end-to-end security scheme
[90]	Critical cases alarm mechanism should be able to notify in quick and free way to ensure efficient response.	Fog computing for emergency alert service architecture.
[91]	Problems of healthcare monitoring system in IoT	Fog computing and smart gateways are used to exploit patient monitoring healthcare system in order to offer an urban and developed techniques.
[56]	The problem of transmission the huge amount of data that produced by IoT devices to the cloud and perform analytics and processing operations.	Designing techniques and tools to distribute data sensor computing.
[57]	The challenges of IoT systems to provide real time and continuous monitoring of patient health.	IoT monitoring system that offering a smart patient medical alarm. Algorithm of machine learning has been implemented along with computation locally.
[58]	The problems of healthcare for processing clinical speech data.	An interface of fog computing, FIT, facilitate interconnection between the cloud and a smartwatch for the disorder speech of the patients.
[92]	ECG monitoring devices are money consuming, low energy, limited resources and many other challenges.	A low-cost monitoring system for continuous observing of patient ECG signals and analysis automatically.
[93]	Interoperability challenge between cloud fog and fog computing platforms	i) A framework that facilitate exchanging the data among healthcare devices ii) developing a software to be cooperated with health data to provide interoperability
[27]	Communications overload and the privacy on the patient life problems.	eWALL monitoring system
[61]	The challenges of data management to specify the emergency situation through analysis huge amount of data that conducted from various devices.	An enhanced infrastructure of information to support emergency responding in effective way to cope with critical situation.
[62]	Patient's activity monitoring through wearable sensors provide individual processing of data and the information is not incorporated into medical practice.	Clinical cloud computing architecture that use patient activity data and share the computation and storing.
[63]	The problem of lightweight visualization in edge cloud and fog computing, which is unable to implement platform and application technologies as a services.	PaaS edge cloud architecture that use containers to orchestrate service and application.
[64]	Challenges arising from the adoption of IoT: the architectures design has the ability to satisfy the needs of the applications.	Architecture consists of three layers, has the ability to produce a decision in real time after conducting and processing the data.
[65]	Cloud computing limitations such as location-awareness, insufficiency of mobility assist and inappropriate latency.	Implemented and evaluated a prototype fog computing platform.
[66]	Timely medical attention of fall detection problem.	An IoT-based system which takes benefits of WSN's, Cloud and Fog computing, and wearable devices.
[67]	IoT nodes large number of deployment, heterogeneity, and massive distribution, disrupt existing functional models, and creating confusion.	IoT support new applications rising, with automated healthcare monitoring platforms being amongst them.
[68]	High response time and latency in cloud computing for variety and volume of data that received from edge devices and sensors.	A platform that analysis the data at cloud and edge, which extends the notion of server less computing to the edge and facilitates joint programmatic resource and analytics management.
[70]	Challenges of collecting the information of AAL emergency system into a centralized and remote cloud such as ethical, social, security, user experience, and cost issues.	A decentralized and virtualized method that implemented within a virtual fog layer and make use of the cloud in an assistive manner to ensure flexible and strong operability.

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Table 5 (*continued*)

Author	Problem	Technique
[94]	The challenges of getting knowledge from big data analysis to acquire a valuable decision and healthcare big data security issues.	IoT architecture to process and store the big data that has been acquired from healthcare sensors. The architecture is made up from two parts; namely, Meta Fog-Redirection (MF-R) and Grouping and Choosing (GC) architecture
[73]	Privacy leakage to unauthorized parties	(HPCS) Hybrid privacy-preserving clinical decision support system in fog–cloud computing.
[95]	Security and High bandwidth problems between cloud server and fog.	A fog node conduct the data from edge nodes and transform the data to the cloud server using Anonymous and secure aggregation scheme (ASAS).
[74]	Delay sensitive in IoT devices problem	A paradigm called MIFaaS (Mobile- IoT-Federation-as-a-Service) that support applications with delay-sensitive for IoT devices to support fifth generation (5G) environments.
[91]	The challenged of patient healthcare monitoring system.	The employment of smart gateways in fog computing layer at the edge of network produce various benefits such as distributed storage, notification service and embedded data mining.
[22]	Problems of developing a fog computing in real-world based the data of monitoring system.	A high level programming, dynamic Fog model that match the requirements of time-sensitive applications that are large-scale, latency-sensitive and geospatially distributed.
[75]	Patient healthcare monitoring system problems such as network latency and high response time.	Designing Fall detection system by employing the paradigm of fog computing to ensure analysis and edge intelligence distribution and a real-time detection.
[76]	Providing low delay and high capacity of storage.	An architecture for network of IoT healthcare based on Fog to Cloud and Data in Motion (F2CDM).
[96]	PaaS unable to support communication with fog nodes, located at the edge of the network, for applications' components provisioning.	Implementing an IoT healthcare application provisioning prototype in hybrid cloud/fog environment.
[78]	Healthcare decision making problem	Architecture for IoT based u-healthcare monitoring with the advantages and inspiration of Cloud to Fog (C2F) computing which interacts more by serving at the edge of the network.
[97]	Problems of developing a fog computing in real-world based the data of monitoring system.	Fog computing employment to detect patient fall based on pervasive data.
[98]	The current healthcare applications do not provide a sufficient diagnosing and preventing the outbreak of Chikungunya virus.	Design a system to diagnose and prevent the outbreak of this virus using fog assisted cloud based healthcare.
[99]	Remote monitoring for crowd patients	An e-healthcare system that support large scale patients monitoring, whereas the patients are geographically distributed in wide area. The system has the ability to integrate several emerging technologies such as edge computing, big data, cloud computing, mobile computing, and supporting decision making system.
[82]	Accuracy, reliability, and availability problems of centralized cloud-based IoT systems and fully data analytics outsourcing to the edge of the network due to the limited computational capacity in edge nodes.	Develop a HiCH architecture that use fog and cloud features to provide an efficient methodology for healthcare IoT management monitoring system.
[12]	Certain challenges in cloud like data privacy and communication cost need serious attention.	Health Fog framework that employ Fog computing in intermediate layer between end users and the cloud. Cloud access security broker (CASB) has been introduced as an integral component.
[25]	Identify and control the outbreak of Chikungunya virus (CHV).	IoT Healthcare system that based fog computing.
[83]	Telemedicine requirements and security problems	Health prescription assistant (HPA) IoT-based model, which supports patients to follow the recommendations of the doctors properly. A security system has been designed to ensure authenticated and protected resources access, and authentication.
[100]	The problem of providing a high level of healthcare security in cloud computing.	Three major techniques: Data coloring based watermarking, fog computing and User behavior profiling.
[87]	The difficulties of integration IoT with Cloud computing has many challenges such as data trimming.	Fog computing or smart network associated with a Smart Gateway.
[85]	Heart attack emergency for the patients in vehicular networks in particular, and the possible resulting vehicle collisions.	Real-time Heart Attack Mobile Detection Service (RHAMDS), a novel service in healthcare based IoT.
[8]	Cloud computing challenges such as: unpredictable delays, security and safety concerns and high bandwidth requirements.	A multi-level architecture that employ a fog computing approach with Field-Programmable Gate Array (FPGA) technology that built the edge node.
[86]	Increasing of complexity and the scale of personalized because the deployment of various types of biomedical sensors, which cause a rising in response time and wasting the resources.	A hierarchical fog–cloud computing CEP architecture for personalized service to minimize resource waste and speed up response time.
[14]	Challenges in IoT-based health systems: reliability, interoperability, scalability, energy efficiency, and mobility issues.	Smart e-Health Gateway and make use of Fog Computing in Healthcare IoT systems. Smart e-Health Gateway called UT-GATE IoT-based Early Warning Score (EWS)
[101]	Service oriented architecture challenges and processing context-aware data.	A Collaborative ConText Aware Service Oriented Architecture (COLLECT)

Cloudlets were connected via OpenFlow-enabled switches at different physical locations [105]. An overview of cloud, fog, and edge was presented [11] in order to solve latency in managing and processing the data by allowing data processing in the end-user's proximity by edge computing (fog computing). A survey of the IoT technologies, protocols and applications, and the connection between IoT and other emerging technologies comprising big data analytics, cloud, and fog computing was presented [106]. The factors, such as the level of the network that these fog computing tasks can execute, tradeoffs in terms of healthcare computation tasks that can benefit from fog computing, and the need to amass the data obtained from healthcare devices and the privacy issue, were discussed in an earlier study [16]. The most important technology concepts that were presented [107], which are based on the convergence of the larger tactile internet and budding 5G systems, outline the essential technical and architectural necessities, edge-AI and edge cloud capabilities, and highlight the economic impact of the tactile internet. A comprehensive survey of related works along with the technological advancements pertaining to MEC was presented [108], which laid out the definition, advantages, architectures, application areas, security and privacy issues, along with the existing solutions pertaining to MEC. Questions such as the definition of edge computing, its implementation using fog computing, the application of fog for IoTs and its utility on an edge were raised and addressed [109]. The disruptive technologies that embody the hyper connectivity value chain (i.e., security, energy harvesting, computing and storage, communication, sensing, and services) were presented [110], and the hyper connected society presented challenges emanating from the main actors as well as the users. The techniques that were employed for data privacy and security were identified [111], and a data-centric perspective that illustrates the primary data management techniques for reusability, granularity, interoperability, and consistency of data that generated by the IoT for smart cities was provided. The validation of the efficiency and utility of EC, the scrutiny of edge systems, and a proportionate evaluation of cloud computing systems were presented [92]. The mobility support in a fog environment and the main challenges arising in this process were discussed [112] considering a fusion between IoT and fog computing. The properties of fog computing and the services it is capable of rendering in the healthcare system were discussed [94]. Management and signal communication methods of sensitive heart conditions with the input from wearable ECG sensors were analyzed [113] in order to apply them as part of a cloud-based patient heart monitoring system. Fog computing architecture was described [114], and its rendered services, industrial applications, security and privacy challenges in fog computing were also reviewed. Fog computing characteristics, components, software systems, applications, modeling and simulation, and challenges were discussed [115]. A description on how the fog works and how it helps in the efficient, effective, and equitable management of IoT resources along with the underlying devices was presented [7]. An survey of the Industrial Internet with a focus on the architecture, enabling applications, technologies, and existing challenges with the use of edge computing was presented [116]. A summary of cutting edge integrating, and automating systems across the domains of healthcare, smart manufacturing in Industry 4.0, energy efficiency, autonomous vehicles, and smart cities was presented [117]. The integration of Cloud and IoT was discussed [118], which is called the CloudIoT paradigm. "Small Data" manipulated on the fog, which is considered to be an extension of the cloud to the edge of the network (near the IoT devices that stream private health-related information) was presented [119]. An synopsis of the essential aspects, that are instrumental in formulating the next-generation healthcare network infrastructures is presented [120]. The architectural aspects pertaining to healthcare IoT systems were also discussed [121]. In these architectures that serve healthcare IoT systems, gateways can be connected in the form of a daisy chain which enhances the fault tolerance. Moreover, a gateway can store the backup copy of the previous gateway positioned immediately ahead of the gateway along the daisy chain. This approach facilitates the recovery of up to two gateway faults that occurred concurrently. A detailed overview of potentials, trends, as well as challenges of edge computing (fog, cloudlet, mobile edge, and microdata centers) was presented in a survey [10]. A survey on the integration of cloud and IoT, which is called the CloudIoT paradigm, was presented [122]. As reported in an earlier study [123], the applicability of IoT in healthcare and medicine presents a holistic architecture of the IoT eHealth ecosystem in which the ecosystem requires a multilayer architecture consisting of (1) device, (2) fog computing, and (3) cloud to handle complex data in matters pertaining to variety, speed, and latency. An overview of fog computing model architecture was presented [124], which includes key technologies, applications, challenges, and open issues. The prevailing technical challenges emanating from a mismatch between the requirements of smart connected object applications in the sensing environment and the properties of the present cloud infrastructure were addressed [125]. The performance evaluation study is presented [126] from migrating Multi eHealth Cloud Service Framework (MeCa) to a fog computing environment so as to gain performance-improved perspectives. The advantages of implementing fog computing in IoT-driven e-health system were analyzed [127]. A review of the architecture and properties of fog computing along with an overview of the vital roles of fog nodes were presented [128], which include real-time services, transient storage, data circulation, decentralized computation along with the security and privacy requirements in fog computing were also discussed. The analysis of the cutting edge cloud-supported IoT was presented [129] in order to clarify the security aspects that have room of improvement in future works. The security and privacy issues of people living within a fog were discussed [130].

5. Limitations

Despite many advantages of shared resource techniques in healthcare applications, they also suffer from several major limitations that should be managed properly. Preprocessing is an exorbitant process in terms of time and money, and is oftentimes characterized by high latency in service provision to consumers [56]. Fully outsourcing data analytics to the edge of the network can consequently give rise to a diminished level of accuracy and adaptability arising from limited computational capacity at the edge nodes. Despite the benefits arising from the use of cloud-based and fog-based architectures, their utility is meager due to architectural limitations [82]. Simple broadcasting of all data leads to network congestion and data redundancy. Features like load distribution and cooperation are not clearly defined in fog computing [31]. Edge devices are not able to handle multiple applications competing for the limited resources, thereby resulting in resource contention and greater processing latency [115]. A fog-based middleware would have many challenges in cloud healthcare recommended services [3]. The fog layer requires the ongoing management of large volumes of sensory data over a short time duration and appropriate response under various conditions. For the fog layer, it is also essential to be reconstruct able and malleable over time, especially in the occurrence of critical events [14]. The fog node is not able to handle a massive number of events per second in the fog nodes since has a specified limited capacity [101]. The provisioning of resources can be delayed for certain tasks, especially for resource-limited fog nodes [65]. The probability of failure is increased by scaling a fog system [104].

6. Discussion and open issues

This paper highlights the research studies that focused on fog computing in healthcare IoT systems. The related articles were arranged and presented in taxonomy. This review specifically focuses on the techniques and methods that target the employment of fog computing in healthcare applications, especially the infrastructure that uses shared resources. The details of fog computing in healthcare applications considering performance evaluation, motivations, challenges and issues, and future directions are presented in the following sections.

6.1. Performance evaluation

In order to perform the evaluation of various resource sharing implementation techniques in fog/edge computing in healthcare IoT systems, the criteria of performance evaluation were the most common methods that were used in the studies involved in this literature review. The performance of resource sharing was evaluated while considering factors such as low latency, real-time processing, response time, a decision taken in less than a second, scalability, mobility, automatic deployment, dynamic configuration, battery life, network traffic, bandwidth, and energy consumption [131–139].

In order to uphold data privacy and cut down on the volumes of data transmitted at a time, a new computing paradigm "Firework" target was proposed [51] so as to facilitate data sharing while maintaining data privacy and integrity of stakeholders using fog computing. Low latency, distributed processing, better scalability, fault tolerance, better security, and privacy are advantages of the Edge Mesh as described in an earlier study [31]. Critical applications such as healthcare applications can benefit from this feature because of their need for higher reliability, real-time processing, mobility support, and context awareness. Fog computing significantly reduces data transmission latency, response time, and end-to-end delay, and also scales down the data volume toward the cloud [9]. According to an earlier report [26], fog computing is considered to be superior to cloud computing in healthcare applications in terms of time-sensitive data, execution time, energy consumption cost, and network usage. A real-time monitoring system was presented [13,140], which reduces the load on the communication infrastructure in data transmission. In the same context, the focus was on monitoring and dealing with processing, and storing and sharing the information in healthcare applications [54]. A high level managing system was proposed in the physical sensing resources so as to make better use of deployed devices [38,141]. In an earlier study [50], the focus was on providing quick response and other time-sensitive data in healthcare services. Enhanced data security and reliability in the healthcare system was presented [104]. Low-cost computational solutions formulated in the proximity of the present-day edge devices were presented [105]. The distributed in situ data-intensive computing including location-aware data and computation placement, replication, and recovery were applied [53,142]. The response time was accelerated [86], which reduces resource waste. An earlier study [85] reported that the response time of emergency aid for heart attack patients in vehicular networks was improved, thereby preventing heart attack induced vehicle collisions. The main aim was to make the communications more secure and to reduce the load on the resource-constrained medical sensors [32]. The objective in an earlier study [32] was to compute heterogeneous devices at the edge in order to collect the data and to provide minimal computing task latency. The roaming of data and offloading migration can be used in healthcare data exploitation and remote diagnostics [52]. The work presented earlier [101] helps in facilitating the amalgamation of IoT heterogeneous domain context data and simplified data delivery among several agents. The work reported previously [28] presents end-user authentication and authorization, secure end-to-end communication, as well as mobility. The advanced services such as real-time local data processing, local storage, and embedded data mining were provided [14,143]. A report presented real-time response, resource management, data filtration, security measures, and preprocessing [33]. The work presented in an earlier study [11] supports decision making, data fusion, and trending of data, which helps in reducing network traffic and bandwidth by reducing data that is sent to the cloud. Efficient aggregation of health data and maintenance of the privacy and the confidentiality of health profiles were presented [3,144]. A study focused on achieving efficient network bandwidth, high-quality service, and the minimum response time in generating real-time notification [25]. The main focus was on reducing the volumes of data transmitted across the network at a time, delay and elevating the service quality [37].

6.2. Motivation

In order to provide or enhance resource management in healthcare IoT systems by adopting the three main factors: Computation offloading, Load balancing and Interoperability, research studies gear toward proposing (or developing) and using fog computing framework in Healthcare IoT systems to overcome the limitations in the traditional approaches.

It was confirmed that shared resources assist in the resource management of a resource pool on demand [38]. An improved user experience was presented by combining fogs with the cloud, which decreases the latency and lessens the number of outdated packets [50]. An automated workflow to physical resources (deployment and scheduling) simplified the maintenance and enhanced data security and system reliability [104]. In the same context, it was proved that the real potential of multi-tier edge computing can be achieved by using shared resources [105]. Furthermore, the distributed data-intensive computing was applied by using a number of optimizations including location-aware data and computation placement, replication, and recovery [53]. As a result, the shared resources hasten the response time and reduce resource waste [86]. Therefore, vital signs such as real-time heart attack mobile detection service is considered one of the important healthcare applications, which can be easily set up by implementing fog computing in healthcare IoT systems due to its low error rate [85]. Another important feature proposed by previous studies for implementation in healthcare is a real-time fall detection system for stroke mitigation with the application of the fog computing paradigm called U-Fall; it has the ability to detect only real falls and has high sensitivity while at the same time portraying high specificity (low false alarm rate) [75,79]. As reported in an earlier study [32], connecting all medical sensors by smart e-health gateways situated at the fog layer ensures a secure and mutual authentication between the smart e-health gateway and the client. Managing heterogeneous devices by applying shared resources at the edge of the network gives rise to data collection, computation of a task with minimal latency, and the display of physical signs that are helpful to the user; this creates awareness about the context and the location [8]. As reported earlier [14], the implementation of the shared resources presents healthcare solutions with both intelligent and predictable capabilities suited for daily life (home/office) and in hospitals. As explained [28], mapping of the resources that are to be shared reduces communication overhead and lowers communication latency between the smart gateway and users, which further lessens the amount of data sent to the cloud, network traffic, agile response, closeness to real-time, bandwidth, and energy consumption [11].

6.3. Challenges and issues

In recent years, the use of fog and edge computing has heightened in healthcare applications so as to overcome the limitations of cloud computing central processing. Although fog computing has many advantages in healthcare IoT systems, it also has some limitations and challenges in resource management. One of the important characteristics is shared resources that affect the performance of fog computing. In order to match the requirements in healthcare IoT systems, the infrastructure of fog computing should be managed properly. The challenges and issues concerning shared resources are discussed in the subsequent part of this section.

The difficulties observed in the management of resources, which were caused by the devices, provisioning, elasticity, or resource pooling and sharing, were described [38]. Similarly, in an earlier study [50], it was demonstrated that processing sensitive data within a local network is a challenging task. The number of sensors, devices, and computing resources should be increased in fog computing infrastructures to process a complex task [104]. On the contrary, some technical challenges arise by upon repositioning computational infrastructure in the proximity of the user [105]. It further creates complexities if not managed properly. Edge computing, on the other hand, needs the resolution of the technical challenges identified by researchers in previous studies, as earlier discussed, so as to become pervasive. A major challenge is inefficient data mobility thus making it unsuitable for dispersed-data-intensive applications which may be applied and situated across multiple geographical locations [53]. The scale and complexity of medical sensor deployment increases the response time and resource waste [86]. Latency, sensitivity and geographical awareness were discussed [85]. DDoS security attacks prevent session resumption based on end-to-end security in healthcare [32]. Limited ROM, RAM, CPU, and energy resources in the medical sensors that are used in healthcare applications achieve global connectivity through the use of devices installed on the current internet infrastructure, which is also an issue [28]. Mobility, energy efficiency, scalability, and reliability issues were explained in an earlier study [14]. Shortcomings in terms of latency, network traffic management, computational processing, and power consumption were described [11].

6.4. Recommendations

This section presents important recommendations from the articles that focused on shared resources. The composition of the aggregation layer, latency, and reliability should be considered a priority [38]. By enhancing load balancing to reduce the processing time of a request, the adoption of parallel processing results in a potentially better user experience [50,145]. The time efficiency can be improved by incremental re-planning of fog computing infrastructure [104]. In addition, it is also imperative that the range of data-intensive applications and frameworks, resource partitioning across frameworks, and applications running across shared resources is expanded [53]. The focus should be on time complexity of the full permutation [86]. It is important to develop automatic detection by using a real-time response system [85]. In order to improve the access time, the mobility factor of the medical sensors between different smart e-health gateways should be considered [32]. Easy interoperability of a variety of nodes applying disparate protocols is also suggested [14,146–151].

7. Learned lessons

Numerous lessons related to fog computing have been learned. Fog computing, without a doubt, decreased latency in contrast to cloud computing in healthcare IoT systems. Researchers show that simulation and experimental proportions provide many advantages such as distributed processing, privacy, security, scalability, fault tolerance, and low latency. These advantages are beneficial for vital signs patient monitoring systems, which demand substantial reliability, mobility, context awareness, and processing in real-time.

8. Conclusion

Fog computing is considered as one of the important research directions for many purposes in healthcare IoT systems. Research endeavors in this direction are still in progress. However, pertinent portrayals and limits continue to be considered ambiguous. In this study, acquiring understanding and insights into this domain is considered to be significant. By reviewing and arranging applicable research exertions, this study intends to add to such understanding and knowledge. Hence, a few specific examples are provided, which were categorized into four classes, namely, methods of fog computing in the healthcare applications, system development in fog computing in the healthcare applications, and review and survey of fog computing in the healthcare applications. By serious perusing and investigation of different review articles, a high-volume of indispensable data was acquired, for example, the issues, difficulties and challenges, motivation, and advantages, and suggestions identified for future work in fog computing in the healthcare applications. In this study, we have identified issues, difficulties, and challenges, and provided different suggestions to determine current and potential difficulties and issues of resource management in healthcare IoT systems that can be overcome by adopting the main three factors Computation offloading, Load balancing and Interoperability. Hence, research studies motivate to propose (or develop) and use fog computing framework in Healthcare IoT systems. Moreover, we have provided a methodical review that depicts methods that apply fog computing in the healthcare IoT systems. Furthermore, we have examined the weaknesses of the current methods, systems, and frameworks and determined the scope of improvements that can be used for future research studies.

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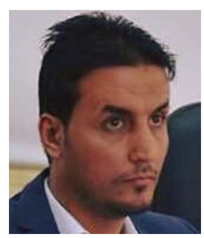

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