Fog Computing in Healthcare: A Review

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***Abstract*—The high cost of patient care has been a concern for the agencies responsible for this area as this situation has been aggravated by the growth of the elderly population and the increase in the number of people with chronic diseases. However, the popularization of the Internet of Things and the Cloud Computing paradigms brings the possibility of creating low-cost solutions to monitor these patients' health, contributing to the improvement of their quality of life. However, Cloud-based solutions cause delays that can lead to the failure of the health systems. Thus, Fog Computing emerges as an alternative to be combined with these solutions, aiming to reduce their latency. This work seeks to explore the state of the art and challenges of Fog Computing applied to the healthcare area. Therefore, this review helps to understand how this paradigm has been used in the health area and shows some points that need to be investigated in order for this use to be improved.**

***Index Terms*—Fog Computing, Healthcare, E-Health, Internet of Things**

I. Introduction

Nowadays, high expenditures on medical care have been a primary concern for health care agencies. This situation has been aggravated by the increase in the percentage of seniors in the world population, which is projected to reach 21.5% by 2050 [1]. Also, the growth in the number of people with chronic diseases has also contributed to making the situation worse [2]–[4].

On the other hand, the use of intelligent devices and sensors connected to the Internet have been widely diffused. Thus, the Internet of Things (IoT) emerges representing a paradigm in which people's everyday objects can communicate with each other and with users [5]. Thus, these devices can be used to create cost-effective solutions for monitoring patients' health [4], helping to prevent the most severe medical conditions and providing a better quality of life for them.

However, these sensors have several restrictions related to storage, processing, and battery capacity. Thus, the opportunity to use Cloud Computing as an infrastructure that can integrate monitoring devices, analysis tools, visualization tools and the availability of the information based on clients that are accessed by users from anywhere and at any time has arisen [2]. However, Cloud-based solutions can cause intolerable delays to health applications, which may result in these systems' failure [6], [7].

In this context, Fog Computing (Fog) has emerged, extending the traditional Cloud Computing paradigm to the edge of the network, bringing computing and storage capabilities closer to end users and/or data sources and thus avoiding delays [8]. Thus, Fog Computing is a layer between devices and the Cloud that takes users' information to the edge of the network [9] and performs processing tasks to reduce the amount of data sent to the cloud [10].

This work shows a review of the state of the art, as well as challenges of applying Fog Computing to the Healthcare area. Therefore, this review helps to understand how this paradigm has been used in the health area, showing the types of applications that have been developed, the groups of diseases addressed, the types of research carried out, the Fog characteristics used in the solutions and the motivations of its use in healthcare. Finally, the paper shows some points that need to be investigated in order for this use of Fog in the health area to be improved.

The remainder of this article is organized as follows: Section II describes the methodology used in this study. Section III shows the results of the review. A discussion on the review is carried out in Section IV. Section V shows a technological vision elaborated in this work. Finally, Section VI discusses this study's conclusions.

II. Method

This state of the art review was based on the method defined by Kitchenham and Charters [11]. In this work, the goal was to evaluate the state of the art and challenges of applying Fog Computing to the Healthcare area.

A. Research Questions

Considering this review's context, the **Research Questions (RQ)** formulated for this work were:

- **RQ1** - For what types of healthcare applications has Fog Computing been used?
- **RQ2** - What groups of diseases have Fog Computing studies addressed?
- **RQ3** - What kinds of research are used in health-related Fog Computing studies?
- **RQ4** - What are the characteristics of Fog Computing health solutions?
- **RQ5** - What are the reasons for using Fog Computing in the health area?
- **RQ6** - What are the health-related challenges of Fog Computing?

B. Selection Process

The process of selecting the studies used in the review was carried out in the Elsevier's electronic database Scopus[1], which was chosen because it indexes the main academic repositories in the area of Computer Science and Engineering. Table I shows examples of some repositories that are indexed by Scopus.

TABLE I
EXAMPLES OF REPOSITORIES INDEXED BY SCOPUS

Repository	Address
ACM Digital Library	https://dl.acm.org/
Elsevier	https://www.elsevier.com/
IEEE Xplore	http://ieeexplore.ieee.org/
Springer Link	https://link.springer.com/
Web of Science	http://webofknowledge.com

To define the Search String, we used terms related to the Internet of Things (IoT), Health and Fog Computing, to obtain the highest number of articles that associated these three areas. Thus, the following search string was defined: *("iot" OR "internet of things") AND ("health") AND ("fog computing" OR "fog networking" OR "fogging" OR "edge computing").*

C. Inclusion and Exclusion Criteria

This review included studies published in any year, since we aimed to find as many works as possible relating to IoT, Health, and Fog. However, we excluded studies that were not written in English; studies that were not fully available; works that focused on the Fog area, but not on Health; and works that focused on the Health area, but not on Fog.

D. Data Collection

The data extracted from the studies were: year of publication, type of document, different Health nomenclatures used, goals, target audience, sensors used, Fog architecture used, characteristics, protocols, motivation, challenges, and opportunities.

E. Process Validity

To guarantee the process validity, the studies were analyzed by two researchers. However, the main bias of this review is that its conclusions may be influenced by the researchers' opinion due to the subjectivity of the tasks in this kind of work's protocol.

III. RESULTS

This section summarizes the results of this state of the art review. First, it presents the execution of the steps of the selection process. Finally, it shows an overview of the works selected in this study.

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

A. Selection Results

The process of selecting the works analyzed in this state of the art review is shown in Fig. 1. First, the Search String was executed in the Scopus database, which returned 42 documents. In phase 2 the titles, abstracts, and keywords of the studies found in phase 1 were read, and 24 of them were selected. In this stage, the exclusion criteria described in Section II-C were considered for the disposal of 18 of the studies found. Finally, in phase 3 all the remaining works were carefully read. For each study, an identifier (ID) was assigned, and the data collection process mentioned in Section II-D was carried out. These works can be viewed at https://goo.gl/4b1gdq.

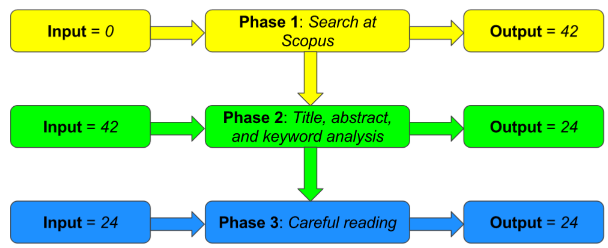

Fig. 1. Stages of the selection process.

B. Studies Overview

In Fig. 2, it is possible to see the distribution of the articles accepted in this review over the years. Through it, it is possible to note that the publication of works relating IoT, Health, and Fog has been increasing in the course of time. It is worth noting that the protocol of this review was executed before the end of 2018, so the number of articles indexed in this year was still low. Also, even without limiting the year when selecting the studies used, the oldest works accepted in this study were from 2015. A possible reason for this is the fact that the term "Fog Computing" was only created in 2012 and it took some years for this paradigm to be used in the healthcare area.

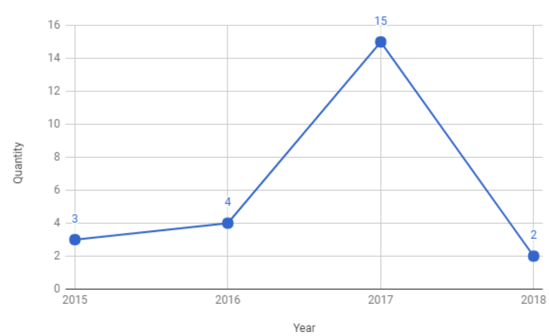

Fig. 2. Distribution of works over the years.

As shown in Fig. 3, more than half of the works were collected from the IEEE[2] repository. The Springer[3] and Elsevier[4]

[2]http://ieeexplore.ieee.org/
[3]http://www.springer.com/
[4]https://www.elsevier.com/

databases were the two most representatives for this review, where each one contributed with 12.5% of the studies analyzed in this work. Moreover, two types of studies were examined: most were conference publications (66.7%), and the others were newspaper articles (33.3%).

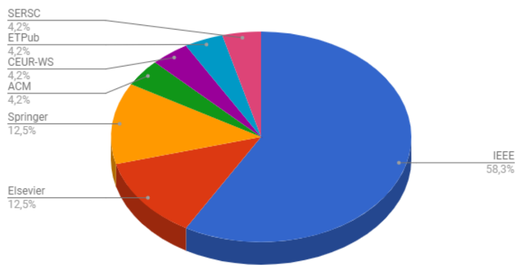

Fig. 3. Distribution of the works in the research repositories.

IV. Discussion

In this section, this state of the art review's research questions are answered, and other findings are shown.

A. For what types of healthcare applications has Fog Computing been used?

To answer this research question, the categorization of applications defined by Olla and Shimskey [12] was used. Their work describes eight categories for health applications. However, only three of these categories were identified in the studies analyzed in this review, as shown in Fig. 4. They were: **Patient Monitoring** - uses a combination of technologies to enable patient monitoring; **Environmental Monitoring** - gathers information on environmental factors that can affect people's health; and **Education and Reference** - applications that educate patients about healthy habits.

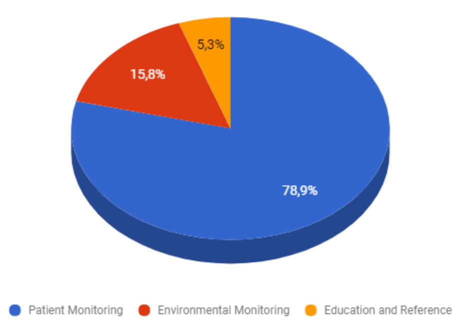

Fig. 4. Percentage of studies per type of application.

Thus, we identified that 15 studies addressed health applications and the majority of them addressed monitoring issues, whether of patients (78.9%) or the environment (15.8%). One reason for this may be the fact that health-related monitoring applications are susceptible to latency, a characteristic that motivates the use of the Fog Computing paradigm. The other five groups of applications may not have appeared because they are not as sensitive to low latency.

B. What groups of diseases have Fog Computing studies addressed?

Ten papers analyzed in the review answered this research question. Thus, they were organized according to the international diseases classification proposed by the OMS [13]. In Fig. 5 it is possible to see that the groups most approached in the studies were circulatory system and respiratory system diseases, which occurs because Fog Computing has the real-time characteristic, which is essential to applications that explore the patients' heart and respiratory rate to identify situations that endanger their health.

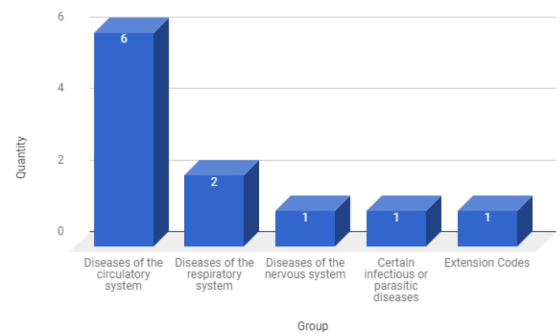

Fig. 5. Number of studies per group of diseases.

C. What kinds of research are used in health-related Fog Computing studies?

All the papers analyzed in this review were classified by type of research according to the categorization proposed by Wieringa et al. [14]. This classification is divided into six groups, but the papers examined in this review fit into only four of them: **Philosophical Paper** - shows the study as a taxonomy or conceptual framework; **Proposal of Solution** - proposes a solution, but does not entirely validate it; **Validation Research** - investigates a solution proposal that has not yet been put into practice; **Evaluation Research** - solutions implemented and thoroughly examined in practice.

Fig. 6 shows that most of the studies fit in the Proposal of Solution and Validation Research categories, thus indicating that most of the works were not tested in real environments or with real patients. This fact shows the need to develop more studies that test their techniques in real situations to identify the benefits of these solutions in patients' lives and the improvement in the quality of life provided by them.

D. What are the characteristics of Fog Computing health solutions?

Table II shows the number of works that use each of the Fog characteristics. As can be seen, *low latency* and a *strong presence of streaming and real-time applications* are among the most frequently addressed characteristics, since health systems need to obtain rapid responses on patients' health status to reduce the risk of severe medical problems. Also, another feature that stands out is the one related to *security and privacy*, since the patients' data is sensitive information and its use is related to several ethical, legal and security issues.

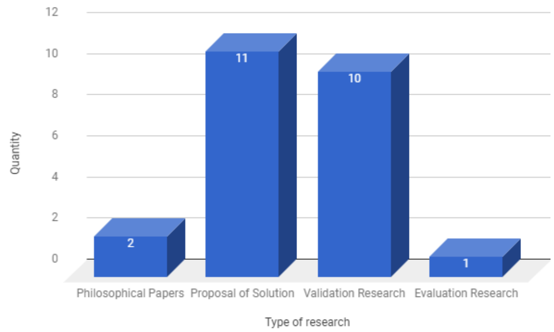

Fig. 6. Number of studies per kind of research.

TABLE II
CHARACTERISTICS ADDRESSED IN THE WORKS

Feature	Quantity
Low latency	16
Security and privacy	13
Streaming and real-time applications	12
Reducing the dispatch of information on the network	7
Location awareness	5
Heterogeneity	5
Interoperability	5
Storage and computing	5
Mobility	4
Geographical distribution	3
Energy efficiency	3
Large number of nodes	2
Wireless access	2

E. What are the reasons for using Fog Computing in the health area?

The motivation that appeared the most in the selected works is that health applications need to work with **low latency**. This motivation is cited in nine of the studies used in this review ([8], [15]–[22]). Next comes the need for **real-time** analysis and decision-making for health applications, which appeared in six studies ([10], [16], [23]–[26]). Soon after this, the need **to reduce data transmission** between users and servers is mentioned in four works ([10], [23], [27], [28]). Vulnerabilities related to the **security and privacy** of patients' data when using Cloud solutions for health applications are addressed in four articles ([7], [26], [27], [29]).

F. What are the health-related challenges of Fog Computing?

The literature analyzed in this review presents several challenges. The most cited are **security**, **privacy** and **reliability** and appear in studies [7], [10], [15], [25], [29]–[31]. The access of patient information by unauthorized users appears in these works as the major concern.

Other challenges that relate to these are addressed in the study [26], which mentions the need **to investigate social, ethical and legal aspects** and in the article [15], which cites the lack of **regulation** as an obstacle for developing technological solutions for the health area.

Due to the wide variety of devices, protocols and data formats used in medical care applications, **interoperability** and **standardization** are also mentioned as challenges in works [7], [15], [30], [31]. Other relevant challenges that appeared in the analyzed works are:

- The absence of a unified strategy or reference architecture for Fog Computing applied to medical care [7];
- Fog's limitation regarding a place for data storage and its processing power compared to Cloud [32];
- Scalability problems [15], [30];
- Managing the data stored in Fog [15] and the automatic management of Fog itself [7];
- Concerns about mobility issues [30];
- The solutions' energy efficiency [30].

G. Other Findings

In step 2 of the selection process shown in Fig. 1, a variety of terms were found to refer to the health area. Thus, we decided to put together the different terminologies used in the works analyzed in this review. Table III shows the variety of terms obtained. By examining it, it is possible to note that there is no standardization to refer to technological solutions for the health area. Besides, we can conclude that the best term to use in Search Strings is "*health*" since all the different nomenclatures include it.

TABLE III
DIFFERENT HEALTH NOMENCLATURES

Nomenclature	Quantity
healthcare	13
health	12
e-health	6
eHealth	3
health care	2
mobile health	2
fog health	1
health-care	1
smart health	1
u-healthcare	1

Regarding the groups of sensors used in the studies analyzed, it can be seen in Fig. 7 that medical devices are the most used for the development of Fog solutions for health.

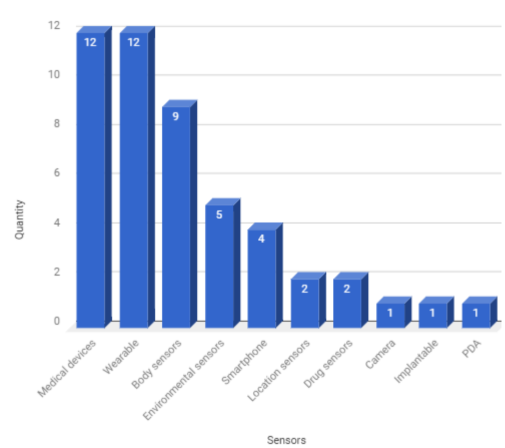

Fig. 7. Types of sensors identified.

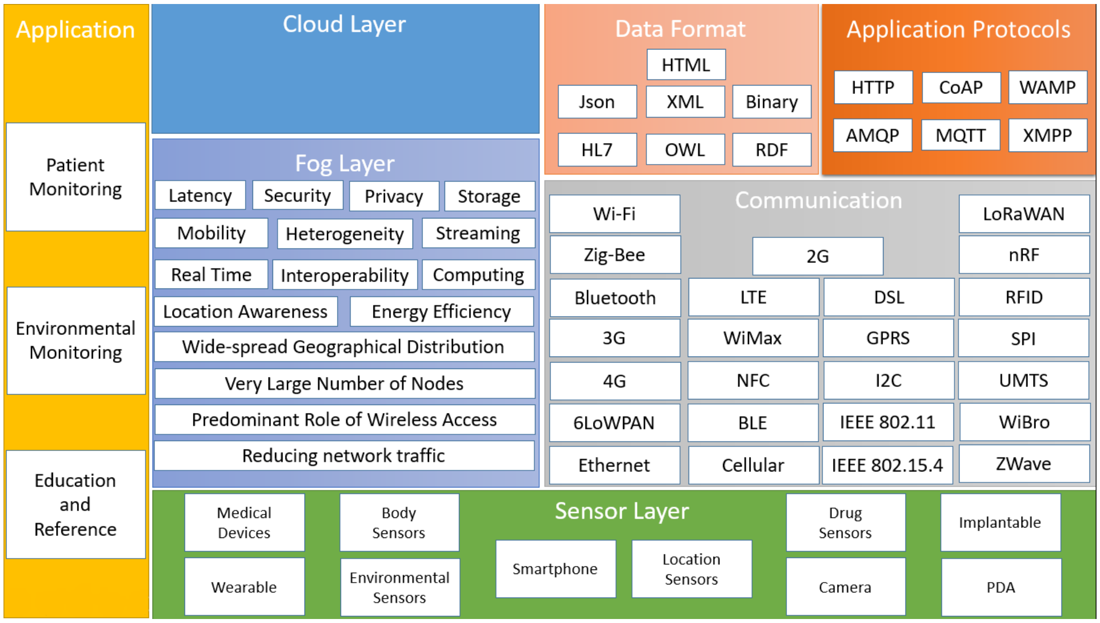

Fig. 8. Technological vision.

Wearable sensors come next and, after them, body sensors. The environmental sensors appear in the fourth position among the most used ones. Thus, these results can be related to those obtained in Section IV-A, in which the applications used for monitoring patients and the environment were highlighted. Therefore, it makes sense that sensors with these characteristics, such as medical devices, wearable sensors, body sensors, and environmental sensors stand out.

During phase 3 of the selection process, we sought to identify the architectural style most commonly used in the works analyzed. We found that the layer-based style is widely adopted [8], [10], [15], [21]–[24], [28], [30]–[33]. Also, despite using nomenclature variations, one can consider the recurrence of the following three layers: 1) **Sensor Layer** - it includes the devices responsible for collecting patient or environment data; 2) **Fog Layer** - intermediate layer that is responsible for bringing the Cloud's tasks closer to the final devices; 3) **Cloud Layer** - responsible for processing and storing information on remote servers.

The different names found for each of the layers were:

- **Sensor Layer** - *IoT eHealth Device Layer* [15], *Smart Devices* [30], *IoT Sensor Layer* [23], *Sensors* [10], [22], [24], [28], [32], *IoT* [31], *IoT domain* [8], *Sensors Nodes* [33] and *End Devices* [21];
- **Fog Layer** - *IoT eHealth Fog Layer* [15], *Edge/Fog Layer* [30], *Fog Layer* [23], [33], *Smart gateways with Fog Layer* [24], *Fog computing* [10], [31], *Gateways* [32], *Fog and Gateways domain* [8] and *Fog* [21], [22], [28];
- **Cloud Layer** - *IoT eHealth Cloud Layer* [15], *Cloud Layer* [23], [30], [33], *Cloud* [10], [21], [22], [24], [28], [31], [32] and *Cloud domain* [8].

In addition, this review sought to identify the protocols and patterns used in the solutions proposed in the analyzed works. The communication protocols cited were: Wi-Fi, Zig-Bee, Bluetooth, 3G, 4G, 6LoWPAN, Ethernet, 2G, LTE, WiMax, NFC, BLE, Cellular, DSL, GPRS, I2C, IEEE 802.11, IEEE 802.15.4, LoRaWAN, nRF, RFID, SPI, UMTS, WiBro, and ZWave. When it comes to application protocols, HTTP, AMQP, CoAP, MQTT, WAMP, and XMPP were mentioned and the data formats used were HTML, JSON, XML, Binary, HL7, OWL, and RDF.

V. Technology View

Fig. 8 presents a view of the technologies identified in the papers analyzed in this review. By looking at it, you can visualize a general layered distribution in which these technologies are separated and how they relate to each other.

The *Sensor Layer* is formed by the types of sensors shown in Fig. 7. Above it, we can find the *Fog Layer*, which includes all of the characteristics described in Section IV-D. Next, the *Cloud Layer* is shown, which is responsible for storing and processing historical health data.

The three previous layers were created based on the architecture layers described in Section IV-G. Also, the *Application Layer* was created to group the types of applications shown in Section IV-A. This layer was placed sideways to the *Sensor Layer*, *Fog Layer*, and *Cloud Layer* because, in an IoT environment with Fog Computing, there may be applications that interact directly with sensors, with the Fog and/or with the Cloud. Finally, the communication and application protocols and the data formats identified in Section IV-G, which are most commonly used in IoT solutions using Fog developed for the health area, were included.

VI. Concluding Remarks

This review was carried out with the purpose of understanding the state of the art and challenges related to Fog in the healthcare area. As shown in Section IV-F, there is still no reference architecture for Fog applied to medical care. However, in this review, it was possible to identify that the layered architectural style is the most widely adopted for Fog-based solutions and despite the different layers denomination, it was possible to find a pattern for the responsibilities of each layer.

Although it is a consensus that Fog paradigm addresses some important requirements needed for healthcare applications, especially those related to patient and environment monitoring, other significant challenges still need to be better explored. Particularly, issues related to security, privacy, reliability, and interoperability must be adequately investigated in this context, offering relevant research directions.

Finally, we believe that the use of Blockchain-based techniques can be an interesting approach to provide the necessary security and privacy to this scenario. In addition, techniques to deal with the nodes fault that form the Fog layer and an approach that ensures the information integrity need to be used to secure reliability.

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