Intelligent Management Model in an IoT Environment Applied for the Healthcare Sector

Jessie Bravo and Roger Alarcón

Abstract This work pretends to solve the inadequate management of devices and their integration in an Internet of Things (IoT) environment which limits the performance of the network in a hospital. The objective of the work is to develop an integration plan, based on an intelligent management model of devices in an IoT environment. The model was validated through the digital transformation maturity model and is applied to the cardiology department at the hospital as a part of the integration plan in the healthcare sector.

Keywords Internet of Things · Digital transformation maturity model · Healthcare sector

1 Introduction

According to the International Telecommunications Union [1], IoT can be defined as a dynamic global infrastructure for the information society with self-configuration capability based on standard communication protocol interconnecting physical and virtual things, which have identities, physical attributes, and virtual personalities; they use smart interfaces and are perfectly integrated inside the information network. It is evident that many problems to overcome exist in the Peruvian Healthcare System. Peruvian Government budget allocates only 2.2% of the Gross Domestic Product (GDP) in healthcare sector; this is much lower only compared to other Latin American countries [2], problems like the scarce infrastructure, which generates a saturation of patients in hospitals and healthcare centers, the poor management of these care centers, which cause an inadequate quality of the service for the patients, the lack

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of medical staff which doesn't allow a timely patient care, the lack of automation of monitoring and patient control, which creates a lack of immediate action in the face of a patient critical situation.

This work pretends to apply computational intelligence to a device management model in an IoT environment, which allows the improvement of the network performance in the healthcare sector in order to overcome the inefficient management of medical devices and processes.

2 State of the Art

Regarding the management of an IoT system, in [3], they clearly indicate that IoT systems and pure network solutions differ one from the other because the latter offer low-level services and support for business administration, and an IoT system is vastly more complex than a communication system.

An IoT proposed architecture model by Kosmatos et al. [4] explains the architecture based on three layers: the RFID's perspective, the smart object's perspective, and the social perspective, but does not consider the response time in real-time and the diversity of technologies of existing connectivity.

In addition, there is a model proposed by the ITU-T [1] consisting of four layers: application, support services, and applications, network, and device with management and security capabilities related to them, approved in 2012. This model does not focus on device management.

The different investigations carried out in this field corroborate these advances. In [5], the IoT benefits the healthcare sector, such as improving availability and accessibility, the ability to personalize content and a cost-effective delivery, being energy consumption one of the critical points, all of this will be achieved through new IoT technologies such as smart portable sensors for health care, body area sensors, advanced generalized health care systems, and big data analysis. In [6] is presented a proposal to improve the Quality of Service (QoS) in terms of throughput of cognitive body area networks by performing a mathematical channel model for off-body communication. In [7], the results of an exhaustive survey of IoT technologies, methods, statistics, and success stories applied to healthcare were presented. Furthermore, [8] carry out an analysis of current solutions in the healthcare sector, proposing a healthcare model where benefits such as a lower labor intensity and a lower operational cost are entailed. In [9] is proposed a generalized monitoring system capable of sending patients' physical signs to remote medical applications in real-time. The system consists of two parts: the data acquisition part and the data transmission part. An IoT implementation in the healthcare sector is proposed by Sokac [10], who designed a Holter monitor that has electrodes and other electronic components integrated into an elastic shirt, and it is able to communicate to a smartphone via Bluetooth, allowing a permanent patient monitoring.

3 Proposal

In this paper, an intelligent device management model was developed in an IoT environment, and it was applied to the healthcare sector specifically, taking into account, mainly, computational intelligence, the ITU-T device management architecture, the IoT environment architecture and having the knowledge that achieving network quality of service implies, at least, complying with the following aspects: reliable and consistent connectivity, a device real-time operation, efficient online monitoring, and error detection. For the proposed model elaboration, five dimensions have been taken into account: the device dimension, the network dimension, the manager dimension, the provider dimension, and the user dimension, as shown in Fig. 1.

Furthermore, the security is presented in a transversal way to the model and all of this, from a holistic standpoint, will allow integration into an IoT environment applied to the healthcare sector.

The supplier dimension will allow managing the real-time data generated from several IoT and non-IoT devices, and it will facilitate its access anywhere, at any time.

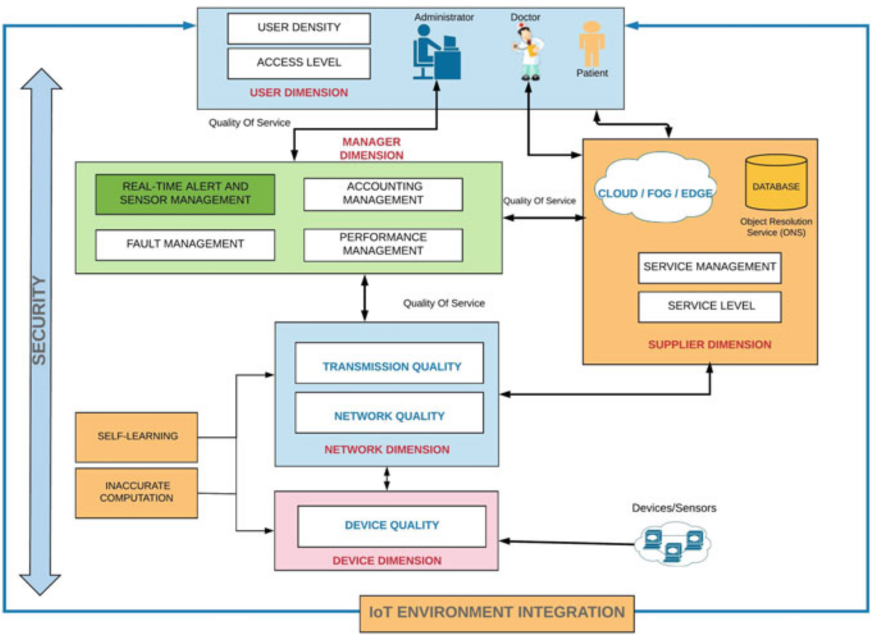

Fig. 1 Smart device management model in the IoT environment

In this dimension, there are three possible ways of storing the information generated by the devices that were considered: Cloud Computing, Fog Computing, and Edge Computing. A Cloud Computing solution is based on data centers with the capacity to process and store large volumes of data, having as a disadvantage that they are generally far away and are slow to respond, and it is also subject to fluctuation that is defined as a variation in the delay of the received packages [11]. Some IoT devices require real-time processing to make decisions and execute immediate actions, also greater mobility and a large number of devices, consequently, in those cases, consider solutions such as Fog Computing and Edge Computing is a necessity [12, 13]. These two architectures can allow the immediate use of the data of the equipment and/or medical sensor, which will deliver better results. For example, glucose values and insulin doses will probably require an immediate response and, therefore, require an automatic analysis and an immediate load in the cloud with Fog Computing or Edge Computing.

As for the device dimension, it is necessary to, first, explain what is understood as a device: physical equipment that can be connected to a network and has some degree of computing and storage capacity. Identification technology will allow the unique identification of the resource.

For this work, a device that interacts directly with users is called a terminal device, such as personal computers, laptops, smartphones, and others. Instead, a device that can help restricted resources to connect to the Internet is called the agent device, such as the wireless sensor networks (WSN) gateway, the RFID reader. The devices that connect directly to the Internet, such as sensors, can also be identified. In this specific case, there are also medical devices, such as tomography, X-ray equipment, ECG, which use the Internet for medical control or self-support. The four types of devices, mainly identified, are:

- Terminal device: a PC, a laptop, a tablet, or a Smartphone.
- Agent device: such as a WSN Gateway, an RFID reader.
- Sensor device: as a temperature, blood pressure, or glucose sensor.
- Medical device: for example, tomography, ECG, X-ray.

The processing capacity is another form of classification, and the devices were classified as basic, regular, high, and the classification is based on their storage memory, the response time, and the energy duration of the device. To achieve the quality of service of the network in this, dimension is necessary to take into account, mainly, the quality of the device: Here, the number of users connected simultaneously to the device must be taken into account, also the device capacity to support a high volume of traffic data and their capacity to work in critical situations.

In the network dimension, the interconnection of the different devices identified in the previous dimension is contemplated, mainly through: Ethernet, WLAN, WSN, RFID, WPAN, WBAN, and WWAN.

In this dimension, in order to achieve an improved quality of service of the network, the following aspects need to be taken into account:

- Quality of the network: If the network is capable of supporting applications in real-time if the traffic is prioritized, and the type of data transmitted over the network.
- Transmission quality: Aspects such as bandwidth, throughput, latency, jitter, and error rate are measured.

Furthermore, in the device and network dimension, computer intelligence is applied, specifically, machine learning and inaccurate computing that allows the device to make a smart decision and selects how to respond to failure and how to access critical information in real-time that allows an immediate response. The devices must be able to learn from the generated data stored on the Internet in such a way that it will allow immediate access from anywhere. And through inaccurate computing, it will allow prioritizing according to three types of levels: critical, acceptable, and normal and have an adequate response.

The decision trees are the machine learning classification technique that was applied, and the following variables are used in the learning:

- Device type (Medical, Sensor, or Terminal)
- Processing Capacity (Basic, Regular, and High)
- Device priority (Critical, Acceptable, Normal)
- Health condition (Type 0, 1, 2, and 3)
- Network Platform (Ethernet, WLAN, WSN, RFID, WPAN, WBAN, WWAN).

Where the objective is to determine the supplier that best suits each need. The supplier can be Cloud Computing, Fog Computing, and Edge Computing.

In the decision tree, a series of observations are mapped based on the variables mentioned above, and it is determined which would be the best provider, for this the algorithm C5.0 has been used.

As for the user dimension, there are three different roles: patient, doctor, and network administrator. According to the severity of the health condition of the patient, it was classified as:

- Type 0: highest priority requires a real-time monitoring.
- Type 1: requires almost real-time monitoring in every few hours.
- Type 2: requires periodic monitoring, twice a day possibly.
- Type 3: requires monitoring from time to time.

This dimension includes two key aspects to achieve an effective quality of service of the network:

- The density of users: The quality of the service will be influenced by the number of users who will use of patient monitoring and follow-up services. The classification is as follows: high-density, medium-density, and low-density.
- Access level: There is a necessity to define what rights and privileges those users will have to safeguard the security and privacy of the stored data. The device is important, but the knowledge of who is accessing it, from where the access is coming from, and the time of the access is equally important. Regarding the level of access, the following have been considered: high, medium, and low.

The management dimension is the graphical interface that will allow controlling and monitoring the resources. First, the security management that has been framed as a transversal task immersed in each dimension of the presented model, and second, the alert and sensor management in real-time since this aspect is critical for the medical devices in the context of the proposed model.

The five dimensions defined in a transversal manner include security management, having the need to safeguard the privacy of stored data. To achieve this, aspects of reliability, availability, and integrity in each of the dimensions must be checked. Finally, another considered aspect is, to achieve the integration of existing IoT devices in the healthcare sector to a data network, which will allow improving the service of the hospital that is being studied, mainly in two aspects: real-time patient monitoring and online access to the patient's clinical information.

4 Validation and Discussion

The project was carried out focusing on one of the most relevant departments of the hospital—case study, the cardiology department. The reason is the increase in cardiovascular diseases in the last years. Figure 2 shows the proposed modeling whose validation is further discussed after.

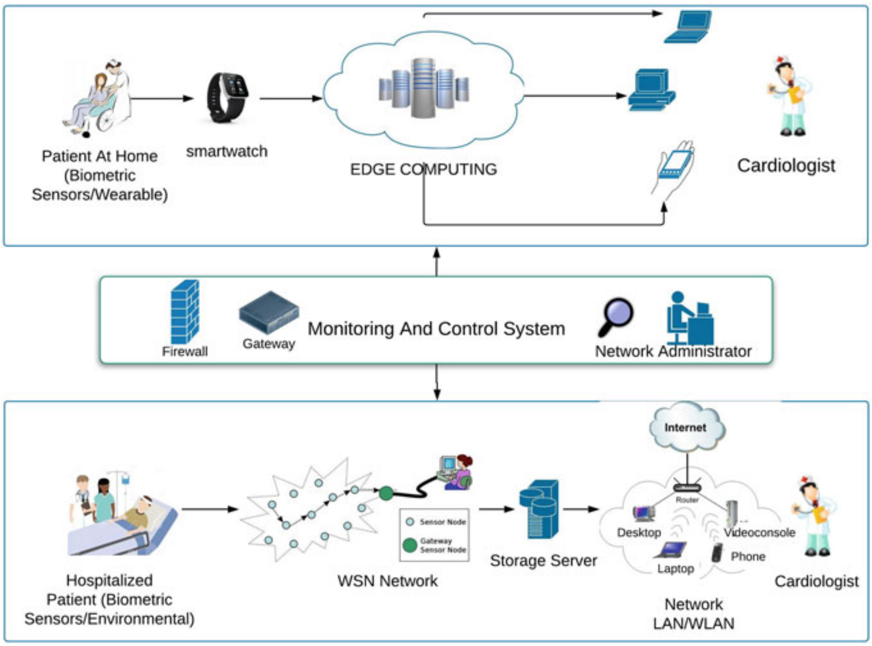

Fig. 2 Model applied to the case study

To corroborate the intelligent management model in an IoT environment in the healthcare sector, to assess whether it is feasible to adopt such a proposal in the organization under study and determine its level of maturity, the application of the maturity model tool was also carried out.

The maturity model suitable for its application is the digital transformation maturity model of an organization and for this purpose [14]. The maturity levels derivate from the model are as follows:

1. **Beginner**: The digital channels are incipient, the web interfaces are not used in an efficient way, and the products or services are not offered through it. Management is still reluctant to change and it is immature in terms of digital culture, and the benefits it generates in the company.
2. **Medium level**: The customer requirements are taken into account but it is still lacking a customer-centric approach, their digital channels are not completely developed, and the mobile channel is inefficient. These companies recognize the necessity of change, and the digital culture is present in some small groups or departments, but it's necessary to be extended to the entire company.
3. **Advanced**: Many innovative initiatives are carried out, which allows the development of digital culture. All channels are fully developed, and the products and services are offered on all channels. The omnichannel experience is complete. The user experience is taking into account, an advanced analysis of the data is applied, and the customer is the priority.
4. **Expert**: The digital transformation is fully applied, and the change is welcome. The customer-centric and omnichannel is approached from the design. Business intelligence is applied at all levels of the company. The digital culture is part of the strategic plan.

The maturity model takes into account three dimensions: The culture and organization, the technology and the business. The following formulas were applied to determine the level of maturity:

For the score calculation in each dimension:

$$\text{Score}_{\text{Dimension}} = \frac{\sum_{i=1}^{n} \text{Score}_{\text{criteria}}}{n} \tag{1}$$

For the score calculation of the model:

$$\text{Score}_{\text{Model}} = \frac{\sum_{j=1}^{nd} \text{Score}_{\text{Dimension}}}{nd} \tag{2}$$

Table 1 Score by dimension

Dimension	Dimension score
Culture and organization	14.67
Technology	7.33
Business	8.67

Table 1 summarizes the scores regards each dimension after applying the validation instrument to the IT staff of our study case.

For the culture and organization level, an *advanced* maturity level is reached, given that the organization has the disposition and the digital culture that is required to adopt the change that is proposed. Regarding the technology dimension, a medium maturity level is reached, since the digital channels are not completely implemented. For the business dimension, the medium maturity level is reached, where employees are involved in the change and the need for the use of analytics for decision making is recognized. The average score of the model is 10.22, this means that the company is in the medium maturity level, so it is concluded that it is feasible to adopt the IoT in our case study.

5 Conclusions

The digital transformation maturity model was applied, obtaining an average level of maturity, so it is concluded that the application of the proposal in the place under study is feasible. It was partially exemplified in a private hospital specifically in the area of cardiology demonstrating its contribution and the achievement of the objectives set.

As future work, it is intended to develop a methodology based on each of the dimensions of the proposed model.

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