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Proposal for an IoT-based e-health model in developing countries: case of Senegal

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***Abstract*—In Senegal, as in most developing countries, access to health care remains a major problem for the population, especially in rural areas. E-health aims to facilitate disease diagnosis and treatment decisions. Thanks to the Internet of Things devices, this field, offers many opportunities and possibilities to relieve the traditional health system in our countries that does not follow the evolving needs of the population in terms of care. These IoT devices can follow patients over a long period of time and transmit data in real time. In this paper we presented the current state of e-health technologies that promise to greatly disrupt healthcare in developing countries. Following this study, we proposed a model that aims to provide intelligent e-healthcare services based on IoT and machine learning for internal or external patient monitoring.**

Keywords— e-health, IoT, machine learning

I. INTRODUCTION

The increasing presence of wireless and mobile technologies in developing countries, the availability of low-cost miniaturised sensors, as well as the services provided by large-scale data centres that take advantage of virtualisation technologies, have enabled new quality and cost-effective health services within existing services.

The rapid processing of the IoT-based healthcare system and the intelligent communication between doctors and patients, have greatly contributed to the development of the medical device market. According to Gartner, some 21 billion various connected objects are currently collecting data and performing all kinds of tasks. Another report from "IoT Health Market for Components, Applications and End Users Global Predictions for 2020", estimates the global IoT health information market at $32.47 billion in 2015 and forecasts an increase in this market value to $163.24 [1].

Patients are increasingly attracted to IoTs in the market, which is primarily driving the surge in medical IoTs and the growth of high-speed connectivity technologies and the focus on patient-centric service delivery.

In both developed and developing countries, particularly those south of the Sahara, the implementation of advanced systems such as Internet of Things technology aims to bring the patient and the health care facilities closer together and to give the patient the opportunity to manage his or her well-being independently. The devices used by patients are multiple, ranging from mobility assistance systems to diagnostic and therapeutic systems under the supervision of a healthcare specialist. These technologies offer several possibilities to patients by facilitating regular monitoring but also provide access to patient data to caregivers [2]. The smartphone is an essential element in this network composed of the patient, the healthcare professional and the connected objects offering the possibility of information exchange through wifi, 4G/5G and Bluetooth networks.

However, the development of these objects can be slowed down if we do not find solutions to these numerous problems, notably the lack of resources necessary to process all the information (data) in real time. This is how some concepts appeared such as fog computing which provides storage and is the link between the objects and the cloud [2].

In this paper, the proposed work is based on the provision of an eHealth platform for low-income countries, whose technological advances are based on the unequal access to opportunities offered by IoT in medicine. Indeed, it must be recognised that connected medicine offers unevenly distributed benefits across the globe [3], particularly in Senegal with the difficulties of medical deserts especially in the eastern regions of the country. This model provides solutions to the many

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difficulties related to the care problems experienced by populations in remote areas, but also by the elderly and the physically disabled. It provides a local decision storage system with learning techniques to act in real time on patients in urban areas (hospital) or in remote areas. The system will allow a synchronization of all data from several health institutions in a data center that will provide universal access to patient data, of course, all in compliance with security standards and protection of patient privacy.

The rest of the paper is structured as follows: in section II, we discuss IoT and e-health, we devote section III to the Senegalese health system, IoT and Senegalese health system are discussed in section IV, in section V we present the system model. Finally, conclusions are drawn in section VI.

II. E-HEALTH AND IOT

A. *Internet of things (IoT)*

The term Internet of Things was used to designate a system where physical objects are connected to the internet [4]. This term is subject to several definitions from researchers, entities associating academics, innovators etc. One of the best definitions of IoT is that it is a dynamic network infrastructure, in which smart objects, physical and virtual entities are identifiable, autonomous and self-configuring [5].

1) *Architecture*

IoT technology uses sensors and actuators to transmit, receive and process data in the different layers of the system: the sensing layer, the network layer and the application layer.

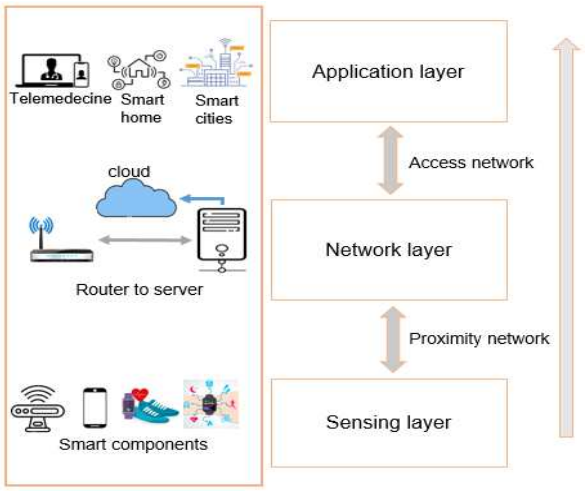

Fig. 1. Basic IoT model architecture

2) *Internet of medical things*

Pulse oximeters, ECG monitors, glucose monitors, blood pressure monitors... are some of the most widely used connected health devices today. With the rapid development of technologies and miniaturization, these sensors may be supplemented by micro and nano chemical sensors that will be able to provide continuous diagnostics and monitoring of diabetic patients and other chronic diseases [6]. IoT technology uses sensors and actuators to transmit, receive and process data in the different layers of the system: the sensing layer, the network layer and the application layer.

The objective of the IoT-based healthcare system is to improve people's well-being and quality of life. This depends on the successful implementation of :

- IoMT efficient in terms of power consumption, reliability, accuracy, robustness and interoperability.
- Integrations of different types of data.
- Connectivity to cloud computing services.
- Efficient algorithms to analyse data.
- Appropriate user interfaces.

3) *IoT and cloud*

The field of eHealth is strongly impacted by the use of cloud computing technology by improving the quality of service through cloud computing features such as cost-effective, scalable, fast, ubiquitous and on-demand access to shared resources [7]. The data center or cloud enables data processing through analytics, gadget frameworks, security controls and device management. The cloud enables the transfer of information to end-user applications, such as in healthcare [8].

B. *E-health*

This area of healthcare involves several players (Fig. 2).

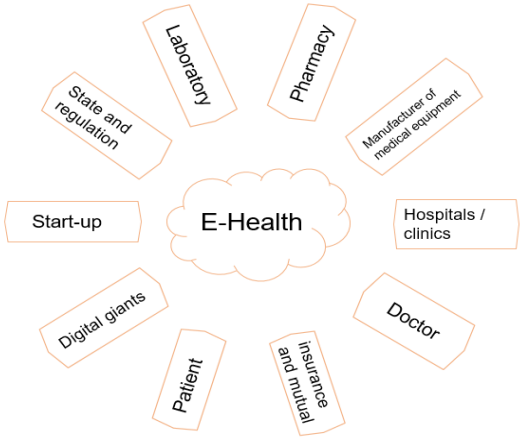

Fig. 2. E-health actors

E-health technologies are oriented towards monitoring patients at a distance and easily provide ambulatory care thanks to the sending and updating of data in real time from connected devices [9].

E-health is a dynamic concept, which has evolved significantly over the last ten years with the evolution of technologies and changing mentalities. Today, several disciplines and concepts claim to be part of it.

The field of e-health corresponds to health or hospital information systems, clinical information systems, computerized medical records, etc. Many measures have already been put in place, aiming at the electronic exchange of medical data between care providers. The objective is to increase the quality of patient care through various levers.

E-health is composed of a set of concepts including telehealth (e-health services, information, training, social networks...) which includes m-health and telemedicine. Telehealth allows the monitoring of a patient's health regardless of location (Fig. 3.). It gives the opportunity to the patient to be more aware of their lifestyle and its effects on their health [10].

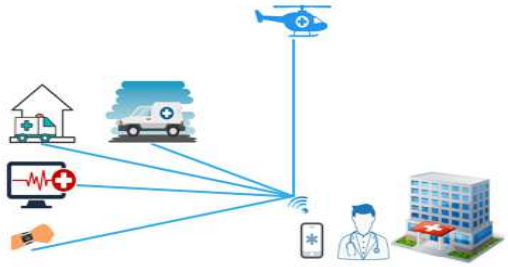

Fig. 3. E-health system

Senegal embarked on telemedicine quite early. The first use dates back to 1997. The country has since launched several telemedicine initiatives, including the satellite interconnection of reference hospitals in Senegal and Africa as part of the Pan-African e-Services Network project, supported by Indian cooperation. The African Telemedicine Centre at the Fann University Hospital is the result of South-South cooperation with some fifty African countries interconnected to Indian university hospital networks. It intervenes in the framework of tele-assistance, tele-expertise and e-learning in Senegal and in the connected states. Other initiatives led by non-governmental organisations and the private sector are being developed in some regions. However, the development of telemedicine is slowed down by "under-utilisation" and the absence of a formal governance framework [11].

The State of Senegal, supported by its partners, developed a digital health strategy between 2015 and 2017. In this perspective, a preliminary assessment of e-health initiatives and projects in Senegal was carried out. The results revealed the existence of around fifty isolated initiatives, a fragmented ecosystem and the need to set up strategic coordination of digital health at national level. In 2016, the ad hoc committee for e-health that had been set up was able to propose a first version of the e-health strategic plan 2016-2020 [11].

1) Telemedicine and connected objects

Telemedicine, electronic health records (EHR) and mobile health technologies aim to improve patient care and safety. E-health and telemedicine are the use of medical data exchanged between two entities via electronic communications. They enable healthcare organisations to share electronic health records, but also reduce the cost of care and increase efficiency by improving chronic disease management, reduced travel times and shorter hospital stays [12].

It uses all the digital telecommunication means allowing a medical act to be performed remotely by a health professional, whether a doctor, a nurse or by prescribing the use of a certified medical device to a patient who will report to his doctor. It takes into account several services: remote monitoring (remote follow-up of a patient), teleconsultation (remote consultation between a patient and a health professional), teleassistance (health professional assists another professional at a distance), tele-training (remote training) [13].

Telemedicine frequently needs connected objects to ensure patient monitoring, but also medical management of "quantified self" data. Indeed, "wellness" data are considered as data that the person wants to know, without it being a medical prescription (for example, the number of steps taken each day, the amount of calories lost or applications advising a balanced diet). They act more as a preventive measure and as excellent health education tools. The doctor can recommend to continue this practice of "quantified self", without the need to include this data in the medical file. It should be noted that digital operators are responsible for collecting them to constitute Big Data, which in the future will reveal the links between behavior and the onset of disease. The ethical debate around the confidentiality of these data collected during the private life of individuals will not fail to appear, as will that of the reliability of the data [13]. Thus, understanding telemedicine facilitates personalized, preventive, predictive and participative medicine via the medical internet of things [14].

In terms of professional telemedicine practice, regional digital health spaces have been set up and are an asset with the provision of common platforms ensuring consistency of use and security for all regional home tele-monitoring applications (such as heart failure, diabetes, complex chronic wounds, respiratory failure, etc.).

Since IoT and telemedicine usually transmit data via the Internet and especially since patient health information and patient identity information are often involved. It is essential to enhance security. This includes both security during transmission and security at rest (in storage).

2) M-health

M-health or mobile health involves connected objects, intelligent textile sensors, etc. Health and well-being services are

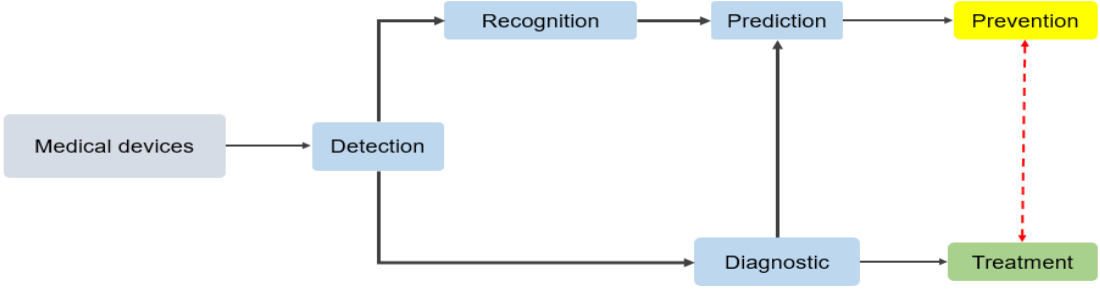

Fig. 4. Patient monitoring system with sensors

provided via a mobile device, such as a smartphone or tablet, connected to a network. M-health is therefore e-health accessible from a mobile device. There is, of course, a significant overlap between telemedicine and m-health applications. Unlike telemedicine, mHealth does not always involve certified devices or a health professional in its use. The main areas of m-health applications currently fall into the following categories: remote monitoring, teleconsultation, etc. (Fig. 4.)

While access to healthcare remains the main concern of people in developing countries, the use of e-health tools is in this context, is a fundamental issue to periodically monitor patients' health information, allowing better diagnoses and timely prescription of appropriate treatments [15].

Several IoT-based monitoring systems have been developed. Raj et al. proposed a remote monitoring system consisting of a wearable sensing unit including medical sensors (ECG, pulse oximeter, EMG, GSR, body temperature and blood pressure). This unit is responsible for acquiring various medical data as well as images of the patient's eye, tongue, and body impact area, following a specified desired sampling rate for the parameters [16]. In [17], Swamy and Murthy proposed an IoT system by implementing an information sharing system between the patient and the doctor through a mobile application. This application allows the doctor to send treatment information and suggestions to the patient through the measurement of oxygen saturation, temperature and blood pressure from the sensors transmitted to the smartphone via Bluetooth. Jabirullah et al. have also developed an IoT-based monitoring system that visualises medical parameters such as temperature, heart rate and blood pressure of the patient [18].
Y Karaca et al. in [19] proposed a novel approach to diagnose stroke by using a mobile phone between the system and the cloud. The MLP (multi-layer perceptron) algorithm is applied to the smartphone for fast execution of the cloud in the diagnostic system. Yeole and Kalbande [20] examined different methods of adopting new technologies to improve health services. They proposed a change management approach that will facilitate the adoption of IoT technology in hospital infrastructures, particularly in India. This proposed model focuses on impact analysis before integrating a new technology into the workflow.

In India the government has set up e-health facilities with the aim of achieving high quality health services for all. Private players are also actively participating in e-health services to improve health. An initiative like Tata Communication has set up a dedicated IoT network using a LoRaWAN. This network is the largest in the world and covers over 400 million people [8].

III. SENEGALESE HEALTH SYSTEM

In terms of structures, the health pyramid translates into the availability of basic health care at the level of health posts, secondary care at the level of health centres and tertiary care at the level of the regional hospital. The rehabilitation, renovation and construction of new infrastructure is a fundamental part of the current programme.

The health district is the operational level where we have a health centre with health posts. The district is located in a department or part of a department where the population is relatively large. The health district is managed by a team that is headed by a chief medical officer. The health posts are located in the communes, the main towns of rural communities or relatively populated villages. In rural areas, they are based on community village infrastructures (health huts and rural maternity wards) created by the local population, who manage them through community health workers or matrons.

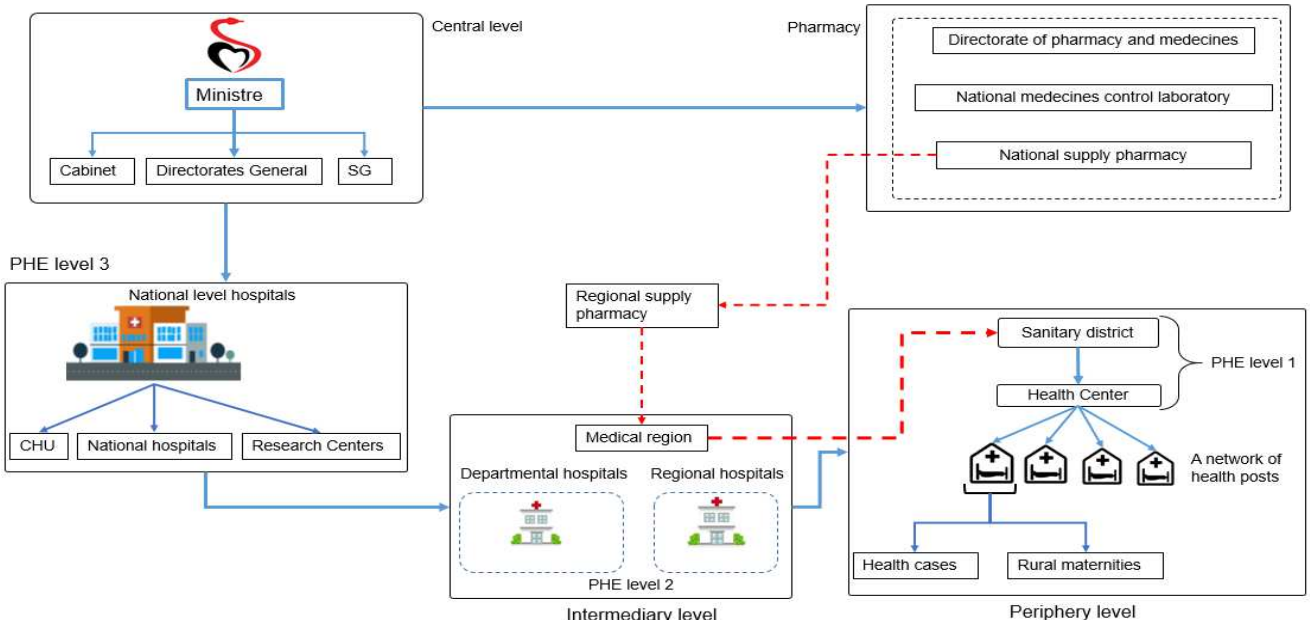

Fig. 5. Organization of the Senegalese health system

The medical region is the coordinating structure at the regional level. Each medical region corresponds to an administrative region. A public health doctor heads the medical region, which is the leader of a team composed of the services attached to the region. Finally, the central level, which includes the minister's office, the directorates and the attached services (Fig. 5.).

A. Health policy

Health policy in Senegal takes into account Senegal's international commitments to regional and global health organizations, including the Millennium Development Goals.

The state and public authorities must ensure the health of their population, particularly the disabled and elderly. But also families in rural areas by providing access to basic health services and ensuring their well-being [21].

The health policy revolves around the following points :

- Promoting health coverage
- Ensuring protection for all vulnerable people
- Strengthening public and private partnership.
- Aligning external aid with national health priorities.

A third national health sector development plan was adopted in 2019, called the National Health and Social Development Plan 2019-2028. This plan is structured around three points [22]: protection, health and social service provision and finally governance and financing of the sector.

B. The health care system

As in most developing countries, the insufficient number of staff admitted to training structures, particularly in universities; the problem linked to the recruitment process in the civil service, which is the responsibility of the ministry in charge of health, which ultimately decides on the timetable and the nature of the staff to be recruited; and the inadequacy of incentives to retain staff and achieve a better geographical distribution.

In remote and especially rural areas there is a shortage of health personnel due to a lack of motivation and an adequate living environment.

C. The information system

Senegal has a management information system (MIS) which has enabled: the standardisation of tools and the harmonisation of data collection procedures at district level, the computerization of the health system, and the creation of the national health information service.

Today, the computerisation of the system must be reviewed and adapted to the current technological environment to better take into account the needs [21] [22].

IV. IOT AND SENEGALESE HEALTH SYSTEM

Even though more and more developing countries have started to integrate connected objects (IoT) for health care as India is an example in this field, there are still many obstacles to overcome especially in Africa.

Kanté and Ndayizigamiye conducted a study to determine whether health policies in developing countries support the IoMT. According to their analysis, which uses the continuum, context and actors defined in these policies, only Senegal has policy on the Internet of Medical Things [23].

Thus, more and more policy makers are implementing policies to provide quality care to their population with the help of technologies that are becoming more and more efficient in terms of precision and miniaturisation. Objects can be of great

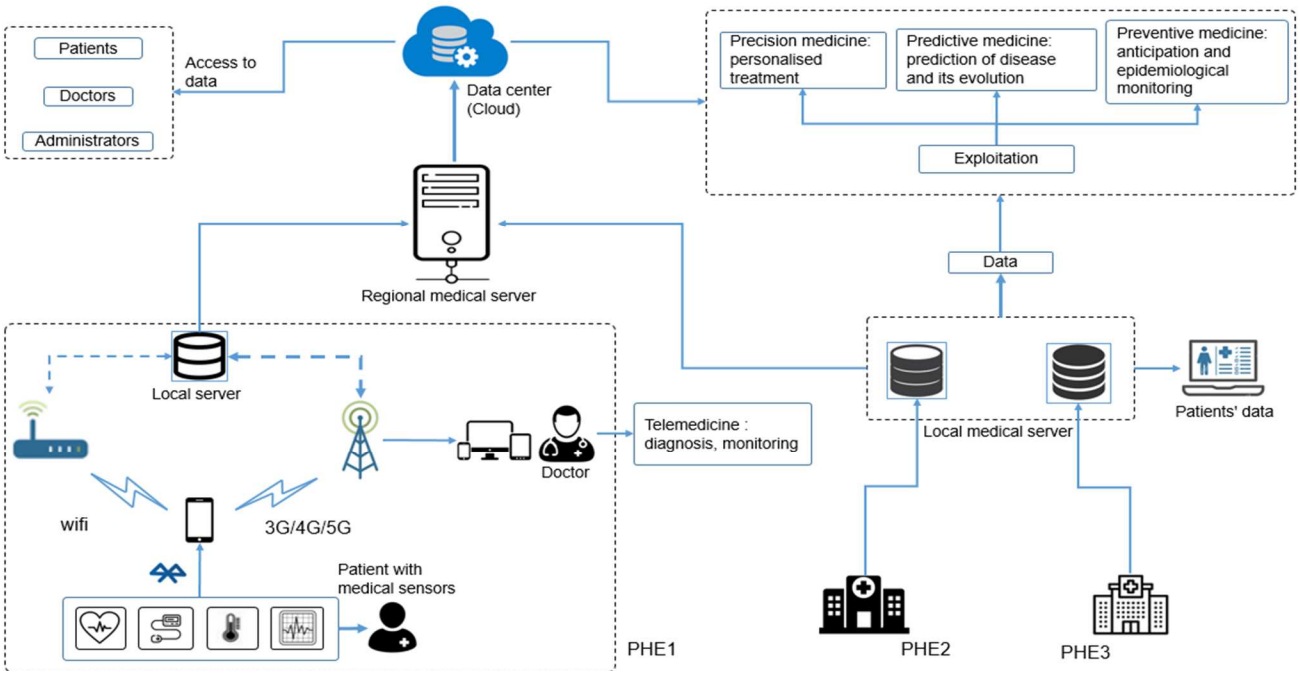

Fig. 6. Model architecture

help in our countries whose medical facilities are still far below average.

V. SYSTEM MODEL

The model presented in this paper is an e-healthcare system (Fig. 6). This work is inspired by several existing models developed across developing countries such as India. It is an Internet of Things (IoT)-based patient monitoring and tracking system that stores patient health data (medical imaging, chronic conditions and other symptoms). For example, the constant is that the number of diagnosed cases of diabetes in the Senegalese population is increasing due to problems of sedentary lifestyle and diet, which is often linked to an excess of starchy foods. This requires preventive measures based on the Internet of Things (IoT). It integrates sensors and medical devices, which transmit information (data) in real time according to an established communication protocol. The system will proactively predict health problems and diagnose, treat and monitor patients inside or even outside the hospital. This care system will be based on data mining and new knowledge to enable targeted and accurate patient management.

The objective is to allow objects to exchange data and interact to perform tasks autonomously. To facilitate interoperability, a platform will be set up to access the data. This raw data collected i.e., blood pressure, body temperature, heart rate, physical and mental state etc. from sensors or detection devices is processed in real time and stored in a local server. Transmission of the information to a doctor's smartphone or computer can be done using network connectivity. The mobile phone (smartphone) in healthcare applications has many advantages such as increasing diagnostic accuracy by enabling continuous monitoring, streaming information, patient record management and especially real-time communication [24].

Each public health establishment (PHE) is connected to a local server. This allows local access to the patient data stored in this server. Here a processing of the data can be done in order to provide personalised and specialised care. This server will be linked to a regional medical server, which will allow follow-up in terms of care and patient records. Patient data is shared at regional level through a server which in turn stores all the data in a data centre (cloud). This cloud of connected servers and warehouses run learning or AI algorithms that examine information from IoT applications to provide valuable data that can be used. To facilitate access, the implementation of an interface for monitoring and analysing patient statistical data is necessary.

Today, in the emerging medical world the processing of large volume and variety of data and storage are essential to extract relevant information. Information systems are involved in many scientific studies with increasingly refined medical sciences and bioinformatics have greatly increased the data in the medical sector. Machine learning algorithms like neural network, decision trees, vector machine... are used [25] to make predictions with these large amounts of data collected from IoT devices.

The exploitation of data allows for decision support, for precision, predictive and preventive medicine using predefined management protocols established from practice guidelines. This structured or unstructured data is essential for assessing the quality of care, in local clinical research, but also for epidemiological studies, anticipating diseases and tracing the patient's journey through the healthcare system.

Smart healthcare has greatly improved income and quality of life through IoT. These devices can help patients improve their own safety and assist medical staff in the hospital environment [26]. But to reap the full benefits of the IoT in the medical field, security must be emphasised. Measures must be considered to protect information but also to manage threats [27]. The management of the eHealth ecosystem, security and privacy of sensitive data [28] are essential to give users confidence.

VI. CONCLUSION

The Internet of Things in e-Health aims to improve healthcare behaviour by continuously monitoring a patient's vital signs in real time. Their use has increased considerably in recent years and many applications have been realised so far. The data provided by these devices is used to detect or predict diseases through learning algorithms. Currently, there are several protocols, making interoperability sometimes difficult due to the many technologies on the market. But in most developing countries, the adoption of these technologies in health care systems remains limited. This proposed model based on the Internet of Things offers many opportunities in healthcare and decentralised storage services. However, unauthorised access must be reduced to provide a trusted IoT system by implementing new lightweight security protocols adapted to the connected object environment.

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