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Fog IoT for Health: A new Architecture for Patients and Elderly Monitoring.

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Abstract

The important increase of the elderly population and their desire to conduct an independent life, even when having medical diseases related to their age, requires the development of new technologies to ensure optimal living comfort for this population. In addition, another category of people, those who are patients with life-threatening problems, may benefit from preventive medical monitoring. In this paper, we present a Fog IoT Cloud-Based Health Monitoring System by using physiological and environmental signals allowing to provide contextual information in terms of Daily Living Activities. Our system enables healthcare providers to follow up health state and behavioral changes of elderly or alone people. Moreover, our system provides a monitoring rehabilitation and recovery processes of patients. Our Fog-IoT architecture consists of a wireless sensor network, a local gateway for data stored locally and quickly, and a Lambda cloud architecture for data processing and storage. The originality of our work resides in the graphical monitoring of new and recent patient data at local smart gateway level. This checkup gives the opportunity to the medical staff quick access to the data, and allows them to validate automatically the observed anomalies. Finally, if a telematic break occurs, the gateway continues to accumulate the data while conducting their analysis. Anonymized data are sent periodically from Smart Gateways to the cloud for archiving and for checkup by medical staff who follow up with patients.

Keywords: Fog IoT; Cloud IoT; Context-Aware; Health at Home; e-Health; Patient Monitoring; Elderly People Monitoring

1. Introduction

According to the United Nations Population Fund (*UNFPA*) Elderly population (aged 60 and more) will increase significantly with a rise to 2 billion by 2050[1]. Doubling the number of people over 60 by 2050 requires major changes in society, in particular, health care and the medical care of the elderly[2]. Moreover, many seniors want to

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continue to live independently despite of the naturally occurring progressive decline in physical and cognitive abilities. Furthermore, an important portion of this aged population suffers from age-related health issues, such as Alzheimer's, dementia, respiratory disorders, diabetes, cardiovascular diseases, osteoarthritis, stroke, chronic diseases, etc.

Health Smart Home (*HSH*) and Health Monitoring Systems (*HMS*) are great solutions that offer a context-aware monitoring to address the needs of healthcare follow-up related to the tremendous increase of senior population and provide e-health services. These systems allow to deliver in-home medical services that were previously available only in hospitals. These services are relied on the collection and processing of patient-related data from wearable sensors. This raw data is not enough to provide e-health services and can lead to misinterpretation by HMS. Understanding the context allows us to enrich our knowledge about the subject and provide a better interpretation of the monitored patient by evaluating their Activities of Daily Living (*ADL*). Context data is obtained by application of raw data consistency validation or metadata enrichment and allows a better understanding of the raw data acquired by sensors through their contextualization with the environment of the subject.

However, the implementation of these devices raises a set of challenges in terms of remote monitoring of the environment, communication technology, existence of intelligent processing systems, provisioning of context-aware services. Currently, in personal sensors network, parameters like the number of sensors, data rate, mobility, latency, communication and transmission are selected based on the application and needs of the subject matter. In addition, energy consumption and battery life still present major challenges for devices in sensor networks. While Multimedia devices is restricted to computational cost and privacy issues[3]. Also, at large scale, real time monitoring is a serious Big Data question.

HSH and HMS uses two types of architectures: centralized or distributed. In centralized architecture, a central processing device is responsible for collecting data from sensor network, providing treatment, and executing various algorithms. Most monitoring systems are based on centralized architectures[3]. The drawback of such architectures is the failure tolerance when the central server crashes, the network is interrupted, or network congestion occurs.

In distributed architecture, each component works independently and communicates with each other over the network. These architectures provide the opportunity to increase the reliability, availability, application performances and the integration of existing system components. However, these systems possess complicated architectural design and components.

In this paper, we propose a new Fog-IoT-Cloud based architecture dedicated to the monitoring of patients returning home after hospitalization and elderly wishing to continue living at home. The rest of this paper is organized as follows: Section 2 proposes a synthesis of the significant contributions related to our work. Section 3 presents our architecture proposal. Section 4 describes performances evaluation using our architecture. Section 5 discuss results obtains, and finally a conclusion and perspectives are given in Section 6.

2. Related works

Health Smart Homes (*HSH*) are based on data processing capabilities located at different levels of architecture. These capabilities are minimal in terms of objects and their proximity; which are maximum at the cloud level. In addition to this, latency evolves inversely. Their capability is directly related to their processing, storage, communication protocol, bandwidth, and energy management strategy of the sensor network. Data produced at lower level (heterogeneous sensors network) is transmitted to a gateway (sink node) or base station which in turn is connected with the gateway and finally reaches the WAN for external exchanges[3]. Due to its limitations, the majority of data processing is done at higher levels. Moreover, at large scale, if data streams increase, receiving a real time alert becomes a Big Data issue[4].

Many projects reduce context to single parameter or objective such as fall detection, location tracking or evaluate a single type of daily activity (e.g. sleeping), a certain cognitive disease (e.g. Alzheimer's), or a certain biological disease (e.g. heart disease)[3]. The distributed architecture model uses Multi-Agent Systems (*MAS*) or service-oriented architecture (*SOA*) paradigms to develop applications. MAS is composed of autonomous agents used for various purposes which collaborate together and share their knowledge[4]. In SOA, software applications and infrastructures are reorganized in set of interoperable, modular and reusable services weakly coupled.

Some recent works have solved issues relating to data rate, means of communication, data accessibility. Among these recent works we will retain the following contributions:

Mshali et al. have proposed a HSH using SMAF[5] evaluation model for human activities to determine the dependency level which in association with historical records allow to personalize the amount of time of each daily life activity. This approach determines an optimal and context-aware sensing, updates dynamically the sensing frequency and use a personalized prediction regarding the subject's behavior[6]. Pham et al. presents CoSHE[7] a cloud-based Smart Home Environment composed of a smart home setup, a wearable unit, a private cloud infrastructure, and a home service robot. Environmental, physiological and activity data are processed in the home gateway. Contextualized raw data are then sent to a private cloud built with Openstack Jena in order to build a Software as a Service model. CoSHE uses also a hybrid data store associating MySQL for structured data and MongoDB to store sensors data in order to provide a rapid access for real-time applications. Narendra et al. developed a real-time health monitoring and alerts system able to use multiple means of communication (BLE, GSM, Wi-Fi) to prevent medical practitioners[8]. This proposition solves the problem of sensitivity of the solutions which only uses a communication mode by multiplexing the information on three channels of communication. In 2018, Verma et al. elaborated a Fog Assisted model composed of three layers where the collect of data is achieved in the bottom layer. The Fog layer processes and validates data coming from the previous layer before classification in normal or abnormal event by means of Bayesian Belief Network (*BBN*). Data retrieved from Fog Layers are analyzed in the Cloud and decision support is provided. Finally, aggregated data from various fog nodes are stored[14]. Energy and network optimization are also challenging for which Mahmoud et al. have proposed an energy-aware application allocation combining an improving round robin (*RR*) and dynamic voltage and frequency scaling (*DVFS*)[11]. Rahmani et al.[12] describe an integrated solution based on a Smart e-Health gateway which target Hospital and Home. In addition to transferring radio frequency protocols to Internet, the gateway also filters, compresses, merges and analyzes data, and ensures data adaptability. Looking at the analyzed data is done at cloud level, but it is possible to visualize ECG and EMG data at fog level in case of emergency.

3. Proposed Architecture

The proposed architecture in this work is a major extension of our previous works on animal's behaviors[15][16], Smart Farming[17], Landslides Monitoring[18], Bee health[19], Pivot Center Irrigation[20] which address similar challenges such as continuously handle a high throughput of data in a short time with the need for a response in quasi real time.

Our distributed architecture is composed of three levels: a sensor network, a local smart gateway (*SG*), a collect, storage and processing cloud architecture. Sensor networks are composed of Environmental sensor: a Bosch Sensortec BME 680 measuring temperature, pressure, humidity and air quality, and also a heart rate sensor (*BPM*) which measures the heart rate in Beats per Minute source and a LED light sensor. The Smart Gateway is built on Cloud Shell 2 of Hardkernel co. equipped of one Odroid XU4Q a Heterogeneous Multi-Processing (*HMP*) solution based on Samsung Exynos5422 Cortex^{TM}-A15 2Ghz and Cortex^{TM}-A7 Octa core CPUs, with 2 Gbyte LPDDR3 RAM and 2 Hard Disks WD Gold of 1 Tbyte mounted in RAID 1. The Odroid device used is a powerful, more energy-efficient hardware, and 7 times faster than the latest Raspberry Pi 3[1]. In terms of connectivity, our Smart Gateway supports Zigbee, Xbee, Wi-Fi, Bluetooth and Ethernet protocols. The power supply of the smart gateway is secured using a UPS.

Atomic elements of our architecture are: one sensors network, one local gateway, collection , storage, and processing cloud architecture (see Fig. 1). The sensors Network comprise of implanted and wearable sensors worn by the patient and environmental sensors whose measurements will enrich the data coming from the Body Sensors Network (*BSN*). Influxdb database stores locally data. Chronograf allows to visualize them while Kapacitor is used to define alerts and sensors thresholds. A web service based on NodeJS process data before sending periodically them to the cloud architecture. All streams of data are stored in Apache Kafka before they are transmitted to Apache Druid and their deep storage on Hadoop File System (*HDFS*). Apache Kylin analyzes data ingested by Apache Druid. Finally, Apache Ambari monitors the performances of the cluster.
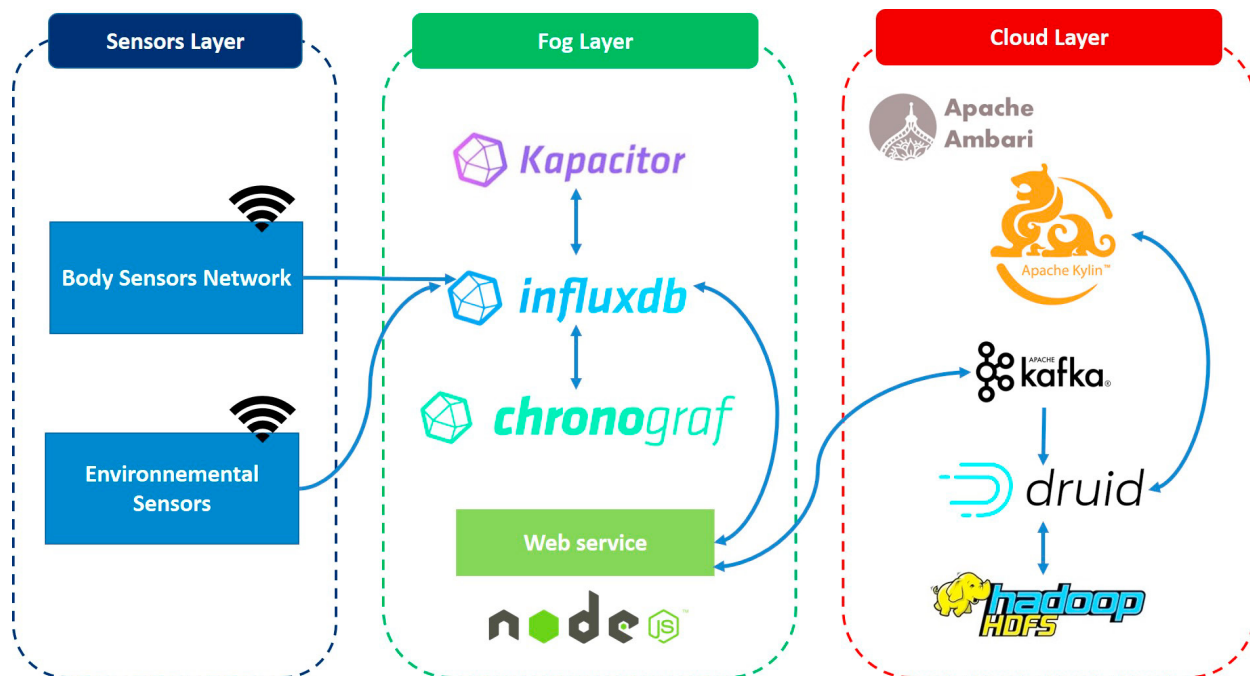
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[1] https://www.hardkernel.com/shop/odroid-xu4q-special-price/

Fig. 1. Global View of our architectural proposal

3.1. Sensors Network

Two categories of data : (1) physiological sensors are implanted on the body or wearable grouped in a Body Sensor Network (BSN) (e.g.: Electrocardiogram - ECG, Electroencephalogram - EEG, Electromyography - EMG, respiration, blood pressure, glucose level, Oxygen Saturation - SpO_2, Passive infrared - PIR, Accelerometer, etc); (2) Environmental sensors enrich and contextualize physiological data (e.g.: temperature, humidity, air quality, noise level, etc). Multimedia sensors are not implemented for of privacy reasons. In our architecture, sensor data are collected and sent wirelessly to a Smart Gateway with TCP/IP protocol. For our application, we used the BME680 Bosh Sensortech to acquire temperature, air humidity, and air quality. The ECG sensor used is an AD8232 Analog Devices, a High-Sensitivity Pulse Oximeter and Heart-Rate sensor MAX30102 Maxim Integrated is also used to acquire Oxygen Saturation and heart-rate, while a MPU-9250 composed of an accelerometer, a gyroscope, a magnetometer allows to evaluate patients movements. Finally, a MLX90614ESF sensor from Melexis Technologies NV measures the body temperature without contact by means of Infrared.

3.2. Smart Gateway

Smart Gateway (*SG*) is placed between IoT sensors Network and the Cloud as an intermediate layer. SG comprises three primary modules: data acquisition, diagnostic, and visualization. Data sent by sensors network by means of different transmission network protocols. The operating system used is Ubuntu 18.04 LTS containing UFW a firewall uses to restrict protocols and ports accessibility.

Data is stored locally on the SG to provide quick access to data for medical staff during interventions. According to GDPR[2], privacy by design principle has been implemented. It allows also patients to view the recent data that is sent to the cloud. Moreover, patient data remains available even if the Internet connection is temporarily interrupted. Processing and validating data at SG level reduce the amount of data transmitted to the cloud and conserving global

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[2] General Data Protection Regulation (*GDPR*)

energy of the architecture and network bandwidth. We use InfluxDB to store data and Chronograf to visualize them. Kapacitor is used to define alerts which verify that the values remain in the patient-specific ranges of acceptable values. For example, we have set an alert in Kapacitor that triggers as soon as the ambient temperature drops below the value of 18°C or exceeds 29°C (Fig. 2).
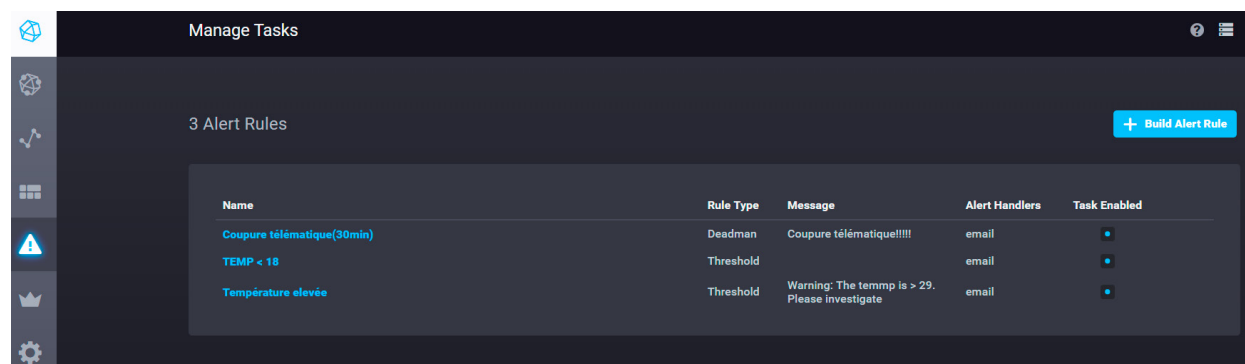

Fig. 2. Kapacitor Alerts Definition

A web service developed in NodeJS with Express Gateway Framework: (1) Anonymizes through the use of Universally Unique IDentifier (*UUID*) which is a system that allows distributed systems to uniquely identify information without strong central coordination and which does not allow the identification of patients in the communication between the SG and the cloud; (2) Enrich raw data with semantic data; (3) Lossless compresses with S-LZW algorithm the data to maintain all features with a precision observable with a tradeoff of 35.2%; (4) Encrypts it before sending it to the cloud via a secure HTTPS connection. It also monitors the battery level and sends an alert when the level is lower than 20%. In case of unavailability of the Internet connection between SG and cloud (Ethernet or Wi-Fi), the Smart Gateway is able to use a backup connection via a 4G modem.

3.3. Cloud & Online analytical processing

Data are regularly transmitted from Smart Gateway and stored temporarily in Apache Kafka 2.2.0, then they are ingested by Apache Druid 0.13-incubating by means of Kafka Indexing Service. Apache Ambari 2.7.3 monitors the health of the cluster. Finally, Apache Kylin 2.6.2 allows to analyze data stored in Druid. Patient data can also be exported on demand to Health Level-7 FHIR[23] (*HL7 FHIR*) format thanks to an application developed in Java using HAPI FHIR[3] library. According to GDPR principle of right to access and data portability is achieved at cloud level. Online Analytical processing allows to detect especially Premature Atrial Contraction (*PAC*), Premature Ventricular Contraction (*PVC*) and Myocardial Infarction (*MI*) by means of Unsupervised learning techniques.

3.4. Abnormal behavior detection

Each patient or elderly people has a personal profile of dependency which must be evaluated to serve as a baseline for the detection of abnormal behavior. On the basis of this profile of the intervals of time to achieve each of the different activities of daily life are estimated. These time intervals must also be corrected according to the pathology suffered by the subject and also take into account historical data to avoid triggering unnecessary alerts and adapt the frequency of collecting sensing data.

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[3] HAPI FHIR - https://hapifhir.io/

4. Experimentation

Experimentation has been achieved for a use case related to bedridden patient at home. In this section, we will present the performance evaluation of our developed platform, mainly on the "Fog" layer; in terms of quality processing and data transmission, as well as the amount of data transmitted.

4.1. Smart Gateway

We have first measured the speed of transmission of the packets between an Arduino Mega using FreeRTOS and our Smart Gateway is 7.5Mbits /s on average. To transmit environmental metrics (temperature, / humidity, pressure, and air quality index) and on the other hand physiological parameter (Heart Rate) from sensors to the Smart Gateway, there is an average delay of 7ms. This value is better than the 21 ms obtained by [12] under similar conditions. This difference could be explained by the LAN environment used. Indeed, several factors could influence this latency, among which: the type of Wi-Fi card at the Arduino level, the network connectivity at the level of the smart Gateway (wired or Wi-Fi), the amount of data (in our case, for each metric record, we have 3 fields: Time, Local Identifier, Measure). To efficiently process data from different sensors, it is important to have a local server that can handle the large amount of data in a continuous manner. To do this, we measured the use of the CPU by our time database "InfluxDB", the use of the disk and the use of RAM. The graph presented in Fig. 3 shows the evolution of CPU use (8 cores at 100%). According to this result, we conclude that the average CPU usage by the time base "influxDB" is 7.86%; Whereas in the article [22] presents the use of a Raspberry less powerful then our smart Gateway at the CPU level.
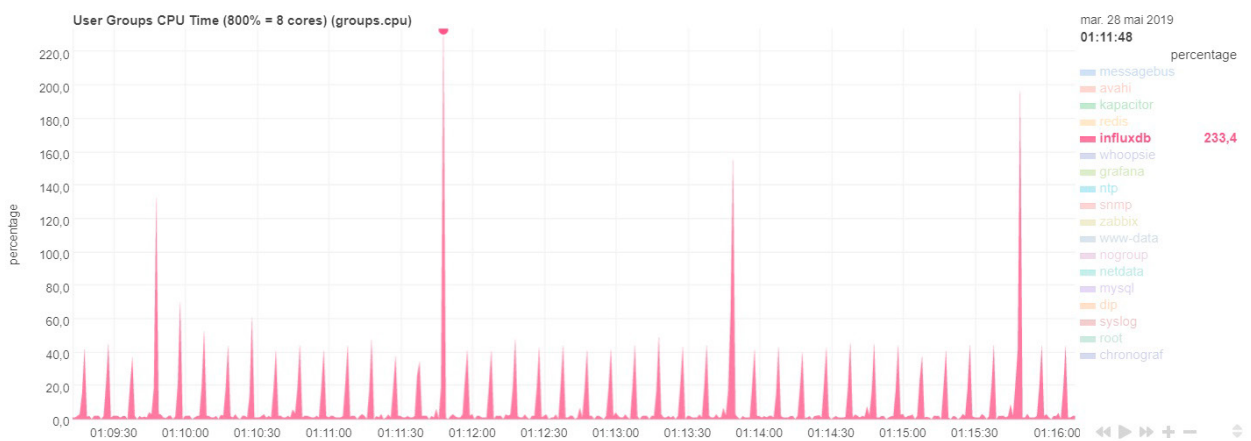

Fig. 3. Smart Gateway RAM and CPU uses

4.2. Cloud architecture

For cloud experiments, we measured hardware performance at the server level when ingesting data. Indeed, the data is pushed to the Druid system in every 20 minutes. The data transfer occurred when the data is coming from Smart Gateway. The consuming of RAM and CPU show an increase of 2 Gb (Fig. 4) and 73% of CPU (Fig. 5) related to Druid ingesting from Apache Kafka.

5. Discussion

Our system was deployed and tested for 24 hours during which environmental data was collected using BME680 sensors and heart rate (Arduino Puls/Heartbeat Rate BPM sensor). These data allow us to calculate the following parameters:
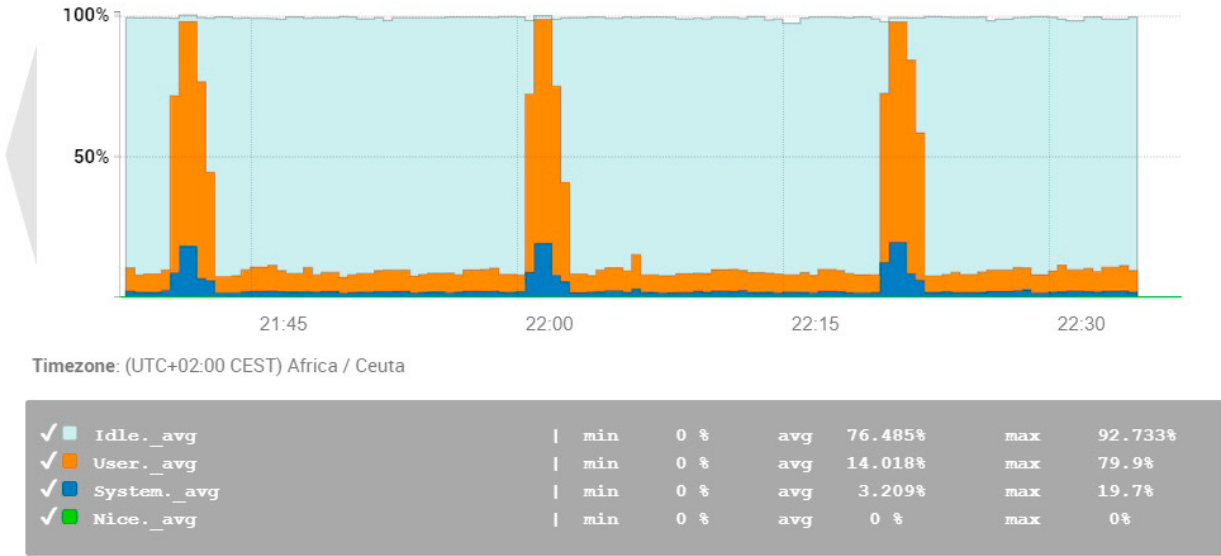
Timezone: (UTC+02:00 CEST) Africa / Ceuta

✓ Idle._avg	|	min	0 %	avg	76.485%	max	92.733%
✓ User._avg	|	min	0 %	avg	14.018%	max	79.9%
✓ System._avg	|	min	0 %	avg	3.209%	max	19.7%
✓ Nice._avg	|	min	0 %	avg	0 %	max	0%

Fig. 4. Memory Usage

Timezone: (UTC+02:00 CEST) Africa / Ceuta

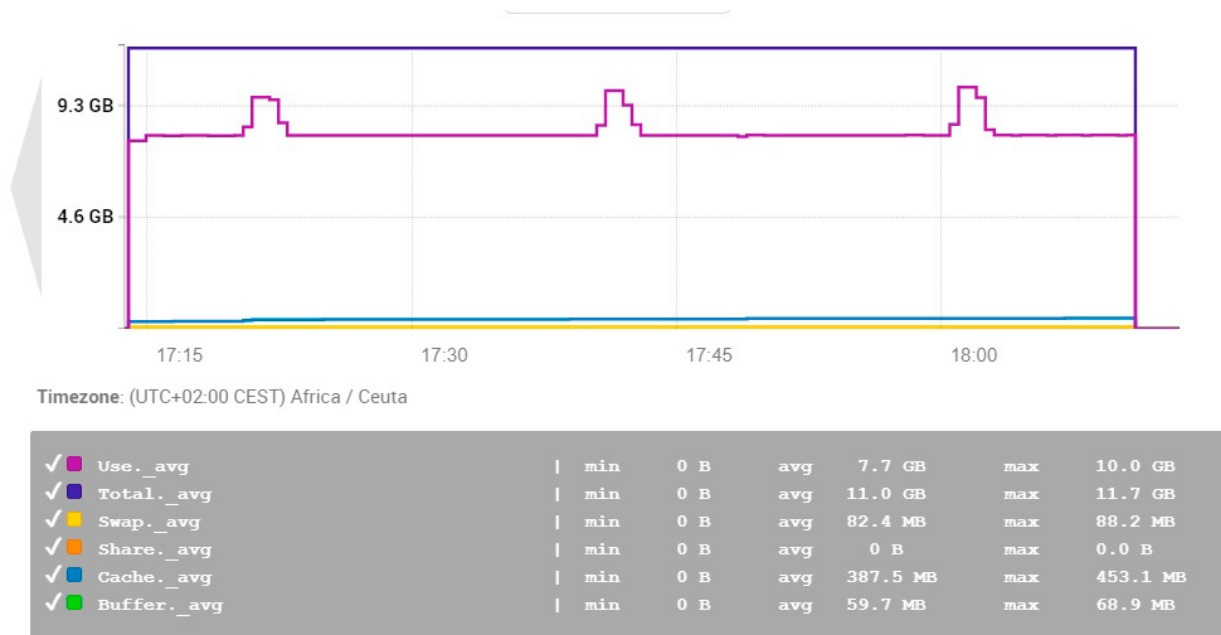|							
✓ Use._avg	|	min	0 B	avg	7.7 GB	max	10.0 GB
✓ Total._avg	|	min	0 B	avg	11.0 GB	max	11.7 GB
✓ Swap._avg	|	min	0 B	avg	82.4 MB	max	88.2 MB
✓ Share._avg	|	min	0 B	avg	0 B	max	0.0 B
✓ Cache._avg	|	min	0 B	avg	387.5 MB	max	453.1 MB
✓ Buffer._avg	|	min	0 B	avg	59.7 MB	max	68.9 MB

Fig. 5. CPU Usage

- Average latency of 7ms between Sensors and Smart Gateway
- 7,86% CPU usage at the smart gateway
- Hardware performance of the cloud server: CPU and RAM usage

These results, compared to those similar architectures[12], [21] and [22] in the literature, show that the latency at the level of the fog computing (between the sensors and the SM) of our experimentation is lower than the one listed

in [12]. Furthermore, our use of the CPU is lower than that of the article cited in [22]. The table below provides comparison between our results and those of other works from the literature (See Table 1).

Table 1. Results comparison

	Our results	Results of [12]
Fog latency	7 ms	21 ms
Fog CPU usage	7,86 %	13,11%

We were able to compare our experimental results with some articles dealing with the implementation of Fog architecture in the field of IoT at the health care level. However, given the difference in the material resources used, the experimental results were not coherent both in terms of data transmission and in terms of material performance. Nevertheless, by eliminating this factor, one can consider that our architecture can produce better results than those presented in [12], [21] and [22].

6. Conclusions

In this paper, we have proposed a Fog-Cloud-IoT architecture which respect GPDR, in particular the local checkup of collected personal data. indeed, the data anonymization and privacy of patient data is respected throughout the communication between the sensor / Fog / Cloud layers. The next challenge would be to strengthen the anonymization mechanism when data is crossed (patient measurements and identification) in the hospital environment, and thus beyond the cloud.

Our system is based on a smart gateway using Samsung Exynos5422: an energy optimized Heterogeneous Multi-Processing technology combining a Cortex^{TM}-A15 Quad Core 2Ghz and Cortex^{TM}-A7 Quad Core 1.4Ghz with Mali-T628 MP6 GPU. Moreover, our smart gateway adapts the collecting frequency in function of the SMAF patient profile eventually corrected in function of his chronic diseases and his actual health state.

In future, we will integrate a Nvidia Jetson Nano to our Smart Gateway to incorporate Artificial Intelligence capabilities, mainly for data filtering, abnormal value detection, drifting sensors but also for abnormal behavior detection by means of machine learning techniques. Currently, personal data of patients are exportable in FHIR format. This format although human-readable remains not understandable for the general public. Others files format without metadata will be proposed such as CSV, Excel or Plain Files. In future, the complete traceability of data patient treatment must again be implemented.

Acknowledgements

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