Remote Health Monitoring and Assistance of Patients with Chronic Diseases: A Big Data Perspective

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Introduction

"*A disease that persists for a long time*" [MDC17], usually more than three months, is known as chronic disease. According to the World Health Organization [WHO17], Chronic diseases (including heart diseases, diabetes, cancer, mental illness, or chronic respiratory diseases), cause 60% of all deaths in the world. In the year 2005, 50% of the 35 million people that died from chronic diseases were under the age of 70. It is considered that the premature deaths caused by chronic diseases influence negatively the economic development of countries. For instance, it is expected that the global costs related only to the chronic mental illnesses will grow to € 5.3 trillion by 2030 [GACD17].

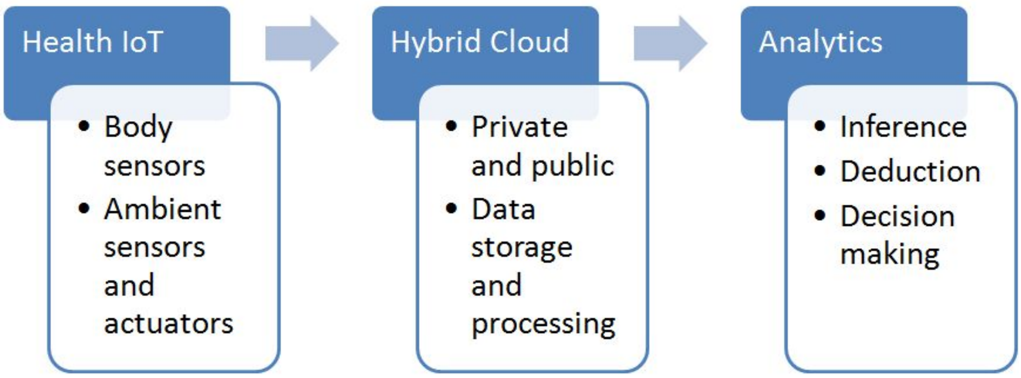

Figure 1. Health IoT generates data that is stored and analysed in the hybrid cloud.

Smart interconnected devices known as the Internet of Things (IoT) may help patients with chronic diseases to live independently at home and avoid unnecessary hospital stay. IoT refers to a network of various interactive physical objects (such as, personal devices, medical devices, industrial machines, or household goods) with sensing, acting, processing, and communication capabilities [Coetzee11]. These interconnected things generate big amounts of data that require extreme-scale parallel computing systems for high-performance processing [Reed15, Abraham15]. Transition from the Internet of computers to the Internet of things creates opportunities for new services and applications in society, environment and industry [Cerf16]. One of the application domains of IoT is independent living [Arbel15, EIP17]. IoT may be used to support elderly [Perez16] in their daily activities with reminding services (such as, time to take the medicament, turn off the cooker, close the window when you leave the apartment, location coordinates of things and persons), monitoring services (for instance, state of the chronic diseases), alarming services (establish a communication link with the nurse or doctor in case of emergency) or social services (help to maintain contacts with other people) [Sundmaeker10].

Cloud computing can be broadly defined as the collection of large scale self-organising architectures using a shared infrastructure that need innovative management approaches for controlling and matching services demand and supply. By exchanging computer and data resources across global networks, it constitutes a new valuable paradigm for network computing, where higher efficiency, massive scalability, and speed rely on effective software development. Cloud computing infrastructure provides a cost effective and easy to use data sharing and access platform which is ideal for the IT enabled healthcare systems [Rosenthal10, Armbrust10]. The requirements of such a cloud-supported health system is high availability of data for healthcare personnel and security of the patients' data. In the context of IoT, the particular benefits could arise from the fog and edge computing paradigms. They represents the model where sensitive data generated by body worn medical devices and smartphone sensors are processed, analysed and mined close to where it is generated, on these devices themselves, instead of sending vast amounts of IoT data to the cloud, that could exhaust network/processing and storage resources and violate user privacy. Only aggregated, context enriched data/events are sent to the cloud for further processing and analytics.

The major focus of this study is on heart-related chronic diseases of professional drivers (such as, taxi drivers). Professional driving is associated with long hours in a single body posture, under exposure to vibration, vehicle exhaust, and noise. Furthermore, the work is performed in an environment that demands constant vigilance. There are, however, many specific diseases for which significantly increased risks of mortality and morbidity have been reported. Professional driving has also been associated with a high relative risk for ischemic heart disease (IHD) [Tuechsen92] stroke, prolapsed lumbar disc, prolapsed cervical disc pain in neck back, gastrointestinal disorders and chronic obstructive pulmonary disease (COPD) [Jensen96].

The study could be extended to monitoring of social, physical and smart-phone based (apps used) activities and conditions, and through correlation with external and environmental data (weather conditions, environment pollution/noise, temperature, city events/crowds, traffic conditions, etc.) and recognition of possible health problem in the future caused by sedentary life and reduced social activities, such as obesity, diabetes, depression, etc. As such modeling, analysis and mining of IoT medical data and external/environmental data could detect potential health problem before they actually occur.

Major contributions of this study include: (1) a state of the art solution for remote health monitoring that is based on body area network, (2) a hybrid edge, fog and cloud computing architecture for health monitoring, disease prevention and assistance of patients with chronic diseases, (3) exemplification of our approach with a case study of taxi drivers that suffer from chronic heart diseases.

The rest of this document is structured as follows. Section 2 describes modern communication standards and devices that enable remote health monitoring. We propose a hybrid cloud based architecture for remote health monitoring and assistance in Section 3. A case study of taxi drives with cardiac issues is described in Section 4. We summarize this document in Section 5.

Advanced remote health monitoring with sensors and personal mobile devices and health assistants

New generation remote health monitoring devices and services are the components of Body Area Networks. A Body Area Network (BAN), as defined by IEEE 802.15, is "*a communication standard optimized for low power devices and operation on, in or around the human body (but not limited to humans) to serve a variety of applications including medical, consumer electronics/personal entertainment and other*" [IEEE802.15]. A typical BAN connects self-regulating nodes attached to the surface of body, implanted in the body, or embedded in wearables for applications in medical, sports, entertainment, military etc. [Zasowski09]. The network's nodes can be implanted medical devices, activity sensors, sensors like ECG electrodes or devices for storage of data etc. [Ryckaert05].

BANs can be used to connect various devices to provide remote monitoring and assistance in cases of accidents and mobile devices can be used to send and receive data to hospitals from the ambulances and other vehicles carrying patients to alert the concerned authorities and to get information about providing first aid to save people's life [Hanson09]. BANs enable a continuous monitoring of patient's condition by sensing and transmitting measurements such as heart rate, electrocardiogram (ECG), body temperature, respiratory rate, chest sounds, and blood pressure etc. It makes BANs to be important tool for diagnosis and treatment of patients with chronic disease, such as hypertension, and diabetes, etc. BANs are also beneficial to hospital patients who receive monitoring at different levels, e.g., pervasive monitoring of patients in the hospital no matter where they are, pervasive in-patient monitoring through implanted devices that enables medical staff to predict, diagnose, and start treatment before the patient reaches to adverse stage of disease [Drude08].

BANs are also highly beneficial for the monitoring and assistance of elderly people, as these conduct to a substantial increase in the quality of life. Eventually, BANs offer a great potential to build up a personalized healthcare system where cure may be provided to the patient at both the monitoring and diagnosis levels [Varshney07].

A Cloud Based Architecture for Remote Health Monitoring and Assistance

The main concept of our approach is based on the interactive hybrid federated cloud with the distributed data-centers, and data servers, integrated mobile devices, agent-based monitoring and data, patients and information management models, and fuzzy-based decision support for patients, patients' monitoring, decisions, data analytics and processing are provided at global and local levels. This system enables a direct integration of the health self-care of the patients with the treatment at clinics and hospitals and remote recovery monitoring supervised by the medical staff. At global level in the public infrastructure, the general patients profiles will be generated through the decision support fuzzy module and based on the anonymous data received from the private clusters. Such profiles are used then for the preparation of the draft programme of the treatment and health care. Patients select the most suitable option and is re-directed to a proper private cloud components, where – in the negotiation and consulting processes – the full personalized care programme (and full personalized profiles) is specified. The results of the monitoring of patients care process can be shared among private (confidential data) and public cloud modules (anonymous data).

We propose to use advanced algorithms to efficiently enable data analytics techniques on diverse structured and unstructured medical data. The framework will carefully marshal data quality and confidentiality as it is expected that data will be collated from multimodal data streams in elderly care, hospital patient records, open data repositories, and other European data sets.

All protocols will be experimentally validated using real medical data sets, ethically extracted from live domains using express consent. Appropriate usability and technical validation experiments will be carried out to assure that the framework complies with the initial requirements.

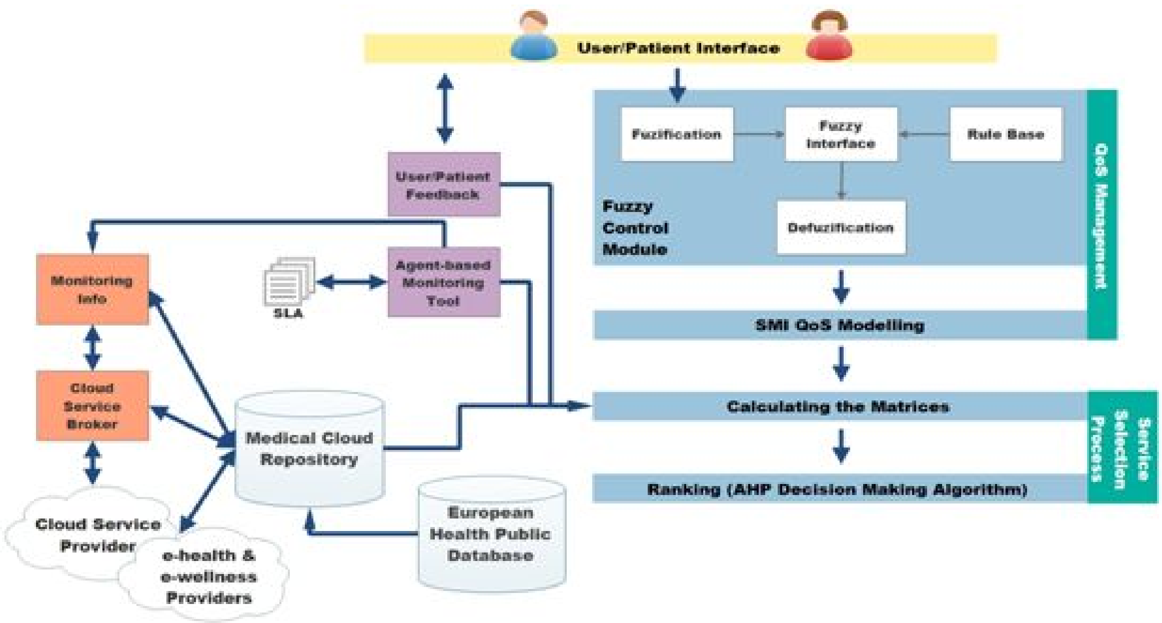

Figure 2. A cloud based architecture for patient monitoring and assistance.

To process data as they arrive, there has been a paradigm change from the traditional “one-shot” data-processing and decision making approach to elastic and virtualized data centre cloud-based data processing frameworks that are able to mine continuous, high-volume, open-ended data streams. The initial processing and analysis are performed at the smart devices within BAN according to edge/fog computing principles. It provides fast response to detected conditions/events, as well as conservation of network bandwidth, minimisation of latency, preservation of privacy and security.

Therefore, we propose a PaaS middleware framework (Core Cloud Library) that enables stakeholders to seamlessly exploit private and public cloud infrastructures for deploying data and event management applications. The main application (SaaS), software (PaaS) and hardware (IaaS) resources of the proposed Cloud are:

- **Cloud application portal (SaaS)**: hosts the application, users interactive interface and users services portal as a web service-enabled system. Users, decision makers, volunteers, and medical staff can access the portal via hand-held devices.
- **Infrastructure as a Service (IaaS):** This layer comprises distributed resources provided by private (small medical clusters) and public clouds.
- **Platform as a Service (PaaS):** This layer provides software, framework and services for building a federated cloud infrastructure, processing streaming data and creating the **Cloud Core Library**.
- **Agent and Fuzzy-based decision support and patients' profiles generator**

To improve resilience, an intuitive solution can be to deploy application components across multiple IaaS providers (data centres). We will exploit the **OpenStack** [OPS17] standardization approach.

To process streaming data from sensors and other sources as they arrive, elastic and virtualized cloud-based data processing frameworks should be developed that are able to mine continuous, high-volume, open-ended data streams. We plan to base the development of our solutions on the following frameworks:

1) NoSQL Database frameworks (MongoDB [Mongo17], HyperTable [Hypertable17], Cassandra [Cassandra17]) allow data access based on predefined access primitives such as key-value pairs; given the exact key, the value is returned;
2) Publish-subscribe and message-oriented middleware, that connect smart medical devices and sensors with fog/cloud computing infrastructure based on message broker paradigm (Apache Kafka [Kafka17], RabbitMQ [RabbitMQ17] and Redis [Redis17], that acts as in-memory data store/cache and a message broker).
3) Data Application Programming frameworks (e.g., S4 [S417], Storm [Storm17], Spark [Spark17], Heron [Heron17], Flink [Flink17]) for writing applications that rapidly process massive and fast data streams in parallel on large sets of machines in cluster/cloud computing infrastructure; Bacth (offline) processing of such data is provided by Hadoop [Hadoop17], Spark [Spark17] and Flink [Flink17], as well.
4) Large-Scale Data Mining frameworks (e.g., Apache Mahout [Mahout17], R [R17], MOA [MOA17], PEGASUS [Pegasus17], Spark MLlib [Spark17], FlinkML & CEP [Flink17] implement a wide range of DM algorithms for clustering, classification, regression (e.g. support vector machines, decision trees, latent Dirichlet allocation, Bayesian approaches, etc.) - such tools are capable of mining datasets in parallel by leveraging distributed set of machines.

It would be interesting to study if the incorporation of Spark (http://spark.apache.org/) in the proposed system can further improve system's performance. Spark is a general engine for large-scale data processing that extends the popular MapReduce model and supports the combination of a wide range of data processing techniques, such as SQL-type querying and data flow processing. One of the main features of Spark is the exploitation of main memory.

It may accelerate an application to one hundred times using memory and ten times using only the disc compared to Hadoop-MapReduce [mavridis2017performance], [mavridis2015log], [databricks17].

Spark can be combined with the most of the above-mentioned frameworks and even to replace them. With Spark will emerge a more unified system architecture with new capabilities and most probably better performance.

There are some studies that compared Spark with several frameworks that plan to be used in the proposed system and they verified Spark's higher performance. For example Meng et al. [meng2016mllib] experimentally evaluated the performance of Apache Mahout and Spark Mlib which are both for machine learning. Their experiments confirmed that MLlib has better performance than Mahout.
In [akgun2015streaming] the authors empirically evaluated the linear regression on streaming data using MOA and Spark MLlib with Spark Streaming support. They concluded that Spark MLlib linear regression performance on streaming data is better than MOA.
In [lim2015graph] the authors found that Spark GraphX outperforms iterative operations like PageRank compared to Pegasus and in [chintapalli2016benchmarking] Chintapalli et al. highlighted that Spark is able to handle higher throughput compared to Storm while having somewhat higher latencies.
Finally Venkataraman et al. [venkataraman2016sparkr] presented the SparkR. SparkR is an R package that uses Spark's distributed computation engine for large scale data analysis.

The application of novel big data stream processing and analysis platforms, such as Flink and Heron, and comparative review of solutions based on these platforms with Spark solution since they differently cope with data streams, i.e. true stream processing vs. micro batch processing. It could give valuable insights for deploying the remote health monitoring infrastructure in real-world settings.

Case Study: Taxi Drivers With Heart Diseases

The experiments will be provided on a representative probe of 100 taxi drivers in Cracow City (Poland) for the period of 4 x 1 month in different months (winter, big sport or music event organized in Cracow, peak touristic season, night). The drivers will be equipped with COMARCH Personal Medical Assistants and additionally Home Medical Assistant. The collected data will be transferred to the COMARCH e-Care Center through the COMARCH Holter application. The main functions of such remote monitoring will be examined according to the individual settings provided by the patient and joint actions coordinated with the medical personnel. In the case of emergency, the patient can press ‘ The Panic Button” at the mobile devices and the reaction time will be measured and optimized.

a) Personal Medical Assistant (PMA) b) Home Medical Assistant

Figure 3. COMARCH e-Care patient monitoring devices.

Remote health monitoring - COMARCH e-Care platform

COMARCH e-Care Platform remotely monitors the health status of patients outside of the hospital. The solution has been designed in cooperation with a team of medical staff of COMARCH iMed24 Medical Center. Based on their medical opinions, optimal functions and development trends of tele-health were identified and have been implemented into the platform.

COMARCH e-Care Platform consists of a medical device for home use HMA (Home Medical Assistant), a portable device for mobile patients PMA (Personal Medical Assistant) and e-Care Center monitoring software (COMARCH Holter, integrated with a local medical cloud cluster as a component of SaaS layer. These devices are integrated with a wide range of medical sensors, facilitating the control of a multitude of vital parameters. COMARCH e-Care Monitoring Center is the nucleus of the system – this is where all the data regarding patient medical incidents are sent instantly from portable devices and processed in order to allow medical personnel to make appropriate decisions and to carry out the correct actions.

The general schema of the e-Care platform is presented in Figure 4. General features of e-Care platform include:

1) acquisition and analysis of medical data from remote patients and mobile devices,
2) 24/7 hours/days patient monitoring,
3) medical Procedures Fulfillment (MedProf),
4) access from anywhere (web-based cloud service and web clients),
5) interfaces to Emergency Services,
6) patient geolocation,
7) examination scheduling,
8) examination on request ,
9) fast medical consultation with doctors (workflow).

Figure 4. e-Care platform model

Methods of communication inside COMARCH e-Care Platform

In the case of health deterioration or life-threatening, communication with the patients can be carried out through voice (integrated phone or HMA VoIP), text (SMS or/and e-mail) and video (with HMA). Also patient, in a case of emergency, can always transfer the health data to the monitoring center (PMA, HMA) or contact by voice and video (HMA).

Security

Secure access to data is equal to the security of access to the application server and the database server. Both servers are placed in the DMZ. Application server in the DMZ is public, and the database server in the DMZ private without direct access from the external network.

PMA - communicates via the GSM network (GPRS), the data goes to the proxy server and are translated into Java objects. Before, however, will go to our proxy server pass through a dedicated APN.

HMA - communication HMA – e-Care is doubly secured. On the one hand it is to use HTTPS encryption transmitted data. In addition, access to the API requires authorization from the unit.

Transmitted data do not have information to uniquely identify the patient. Internal identifiers are used instead of the full data system of the patient. Only name and surname may occur in the transmitted data. However, these data do not indicate directly to a particular person.

Data format

For data transfer are used 2 types of formats: JHDB and frames. The JHBD (JSON Header Binary Data) format is used for transmit ECG data to COMARCH e-Care. This type of data format contains header information, ECG record and information about detected disorders. The frames format is used for sending the rest data to the e-Care center and contains information on the detected alarms, patient location, configuration data. Data transmission is implemented by automatic rules (in a specified time) or data are sending on-demand. Data transmission is performed using a GSM module. For the patient geo-localization GPS module is used.

The PMA device could have 7- or 12- leads modular design. Depending on the construction, one minute ECG generates from 45 kB to 100 kB data.

Summary

Chronic diseases (such as, heart diseases) cause 60% of all deaths in the world, and 50% of those are premature deaths. A timely detection of critical health conditions of patients and proper decision of medical personnel may help to avoid fatal consequences. Modern communication and computation infrastructures such as the IoT and the cloud have the potential for developing proper solutions for remote health monitoring and assistance. IoT may be used for sensing of health conditions and the cloud provides flexible and scalable means for data storage and processing. Advanced data analytic algorithms are used for inference and for supporting the decision making process. A case study that addresses taxi drivers with heart chronic diseases helps to explore the limits of existing technologies and will advance the state of the art based on novel concepts proposed in this study.

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Glossary

- BAN: Body Area Network
- COPD: Chronic Obstructive Pulmonary Disease
- DMZ: Demilitarized Zone; separation of LAN from untrusted networks (Internet)
- ECG: Electrocardiogram
- GPRS: General Packet Radio Service
- HMA: Home Medical Assistant
- HTTPS: Hypertext Transfer Protocol Secure
- IaaS: Infrastructure as a Service
- IHD: Ischemic Heart Disease
- IoT: Internet of Things
- IT: Information Technology
- JHBD: JSON Header Binary Data
- JSON: JavaScript Object Notation

- LAN: Local Area Network
- MOA: Massive Online Analysis
- PaaS: Platform as a Service
- PMA: Personal Medical Assistant
- SaaS: Cloud application portal
- SMS: Short Message Service
- WHO: World Health Organization