D4.3.2 APPLICATION/ SOFTWARE DEVELOPMENT

(Software Engineer -Developer)

«Healthcare Monitoring System Design»

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WP 4 Joint Monitoring System project

IMPROVING HEALTHCARE ACCESS TROUGH A PERSONAL HEALTH MONITORING SYSTEM

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http://www.ehealthmonitoring.eu/

Summary

According to the contract (14/09/2018, Ref. No: 44956) for the project APPLICATION/ SOFTWARE DEVELOPMENT, the particular deliverable «Healthcare monitoring system design» that is being implemented within the frame of WP 4 Joint Monitoring System of the project IMPROVING HEALTHCARE ACCESS TROUGH A PERSONAL HEALTH MONITORING SYSTEM under the INTERREG V-A Greece – Boulgaria 2014-2020 Programme, describes the activities that have been carried out within the period 20/09/2018 – 05/12/2018.

The deliverable describes the design of an integrated system for record and analysis of biosignals that facilitate effective patient monitoring at home. The main contributions of the system are the standardization of biosignals collection and the introduction of Cloud Computing concepts and tools for data managements and analysis utilizing point-of-care decisions. Part of the deliverable is the study that has been conducted for the development of an innovative and interactive integrated service of health monitoring.

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1 Introduction

Direct provision of healthcare and follow-up services, or the so-called point-of-care service, is seen as a key issue for improving the quality of life, especially for older people [1]. Mobile penetrating healthcare technologies can support a wide range of applications and services, including mobile telemedicine, independent living, site-based medical services, emergency response, personalized monitoring and access to healthcare information, providing significant benefits to both patients and medical staff. However, implementation of the management of health-related information via mobile and wireless devices involves several challenges, such as data acquisition, storage and management (e.g. different devices, different communication protocols, physical storage issues, availability and maintenance), interoperability and availability of heterogeneous resources, security and privacy protection (e.g. controlling license, data anonymity, etc.), unified and generalized.

The trend in modern personal monitoring systems is the use of Cloud Computing Template [2]. Cloud Computing provides access to shared resources and shared infrastructure in a generalized and diffused manner, offering on-demand services over the network to perform functions that respond to the changing needs of electronic healthcare applications. In this context, we have developed an integrated homeowner health monitoring system that uses the Cloud Computing infrastructure to manage and analyze data. The proposed solution focuses on the functionality of system decision support, which is implemented both in the smartphone application for temporary analysis and Cloud.

The remainder of the deliverable is structured as follows: Chapter 2 presents the relevant research and discusses basic information about Cloud Computing and BioFilter Collection, while Chapter 3 presents the approach adopted for biosignals life cycle and data modeling. Chapter 4 presents the proposed framework and corresponding software components, while in Chapters 5 and 6 we describe the system and technologies on which it is based. Finally, Chapter 7 contains the conclusions.

2 Related Research

Various health information systems have already been identified and established to monitor and assist chronic patients, the elderly and people with disabilities [3]. The use of biosignals is considered necessary to understand the health status of a person in such systems [4]. In this context, the credible acquisition, gathering, and safe transfer of biosignals data or any kind of medical data to remote computing infrastructures are the greatest challenges during the installation of a point-of-care system. The widespread use of mobile devices with significant online and computing capability has allowed them to be used as intermediate nodes or nodes - portals limiting the need to integrate sophisticated networking technologies into specialized medical devices. The three-tier model, consisting of i) biosignal sensors, ii) biosignal gates and circuits, and iii) the Cloud infrastructure allows efficient hardware utilization and low-cost communication.

Sensor device makers focus on acquiring effective biosignals while using standard wireless short-range technologies to transmit data. Biosignal portals and circuits can be implemented using mobile or embedded platforms with off-the-shelf operating systems based on sophisticated technologies such as REST services and TLS security for reliable and secure transmission to the cloud infrastructure. An important issue is the compatibility between health devices and gateway nodes, which introduces complexity especially in the design of the gateway node.

Extensive biosignal analysis goes beyond the scope of this document, but we are addressing some key issues to highlight the diversity of communication methods, including media and protocol specifications, data exchange styles and available APIs for managing sensors.

Biosignal sensors mostly transmit their data via Bluetooth and USB, and the use of the mini-jack is also seen for some types of sensors, such as glycosylates. However, even in the case of using Bluetooth, different Bluetooth protocol specifications are available and only a subset of them is applied by sensors and computer and receiver devices. The two main versions of Bluetooth communication can be described as (a) the classic Bluetooth standardized by IEEE 802.15.1 as well as b) Bluetooth Low Energy - BLE (or Bluetooth Smart) [1]. The BLE, derived from the Bluetooth 4.0 version, is considered to be a major breakthrough that allows for more efficient data transmission, lower power consumption and simplest communication processes compared to classic Bluetooth that needed to match finds and prepare before biosignal data exchange. The BLE software model introduces the concept of Generic Attribute Profile (GATT), which is a general API for communication with any BLE device. The model also offers a number of special profiles for certain types of devices and communication purposes such as placement, healthcare, headset communication, etc. [2].

The ISO / 11073 IEEE [3] standard provides a framework for the connectivity of health devices to the use of wired (USB) or wireless short-range communication technologies (Wi-Fi, Bluetooth, Zigbee) on gate devices. Nonetheless, healthcare device makers have built up short-range wireless connectivity relatively recently and practically, many still use proprietary protocols to transmit cloud data through apps that run on Android or iOS platforms via cable (USB) or wireless (Bluetooth) physical layers.

Continua Health Alliance [http://www.continuaalliance.org] has proposed a framework to promote interoperability between ISO / IEEE 11073 and BLE devices. However, the use of specific communication profiles and healthcare standards for the time being is limited.

Instead, manufacturers often use proprietary GATT protocols to communicate with BLE sensors, or low-level messages to communicate with classic Bluetooth sensors.

The abundance of available devices, where each manufacturer follows different communication standards and implements non-standard data formats, gives tremendous complexity to third-party tools and applications for the communication and use of such sensors. In addition, different types of biosignals and different measurement techniques raise additional challenges for communicating with sensors and acquiring and managing biosignals data. For example, pulse oximeters provide streaming data, while blood pressure monitors provide uniform results of measurements, and in this sense, the devices connected to them should provide different detectors for acquiring and managing data.

It is well known that sensor manufacturers provide specific APIs to communicate with their products by breaking access to Bluetooth components to provide better control and communication performance to them. However, incorporating multiple protocols and APIs from manufacturers into the same software as a smartphone app is not always easy due to compatibility and aggressive use of resources and services from each API library.

A variety of architectural systems have been presented in the literature and different aspects of these systems have been evaluated. More specifically, the research of wireless interconnection protocols is presented in [4], and can be used for common health devices such as blood pressure monitors and pulse oximeters and various machine-to-machine (M2M) architectures and collection health data.

Researchers [5] also propose an IEEE 11073-based architecture that uses "Personal Health Managers-PHI" and works close to the user and also suggests "Internet Health Managers" based on cloud infrastructures and communicates with PHIs by evaluating the use of CoAP for transactions. Bluetooth health sensors (pulse, oximeter, and ECG) are also used to communicate data with an Android device, which then transfers to the server with the MQTT connection protocol [6]. The ability of Android mobile devices, such as resource gates and battery life effects, is estimated at [7].

The findings highlight that mobile devices can play this role, however battery life can be greatly affected. Finally, the present deliverable evaluate home screening technologies with clinical trials and identify key performance characteristics and regulatory requirements in a home-based telemonitoring platform [8]. The bibliography highlights the need for greater accuracy of health devices and suggests online support by trained specialists for filtering and interpreting data collected.

As far as decision support is concerned, there are several techniques for identifying patterns and sorting data for biosignal analysis [13-17]. More specifically, there is a variety of classification methodologies ranging from classic statistical methods, such as linear and accounting regression or Bezijski networks, to more sophisticated artificial intelligence techniques, such as neural networks and genetic algorithms, or the latest support vector machines. Other types of hybrid intelligent systems are neuro-fuzzy adaptive systems, which may consist of an adaptive fuzzy controller and an internet-based predictive marker. More information about data sorting techniques can be found at [18]. The challenge for such smart systems lies in the complexity of capturing, representing and processing biosignals data to produce knowledge.

In addition to presenting the information, we want the orders to be executed automatically as well as to reform the system on behalf of the user, depending on the changes in the decisions.

For example, in the event of a user's health deterioration, the intelligent system needs to be able to respond by activating an appropriate alarm and providing corresponding indications that explain why the corresponding alarm is triggered. Appropriate training and calibration of artificial intelligence modules is required in advance.

The basis for the proposed decision-making approach is illustrated in Figure 1. The proposed platform allows the creation of a patient-centered health care support network and also provides the framework and required services for the effective communication and management of a wide range of device and sensor wearers that allow for the continuous monitoring of patient's activities.

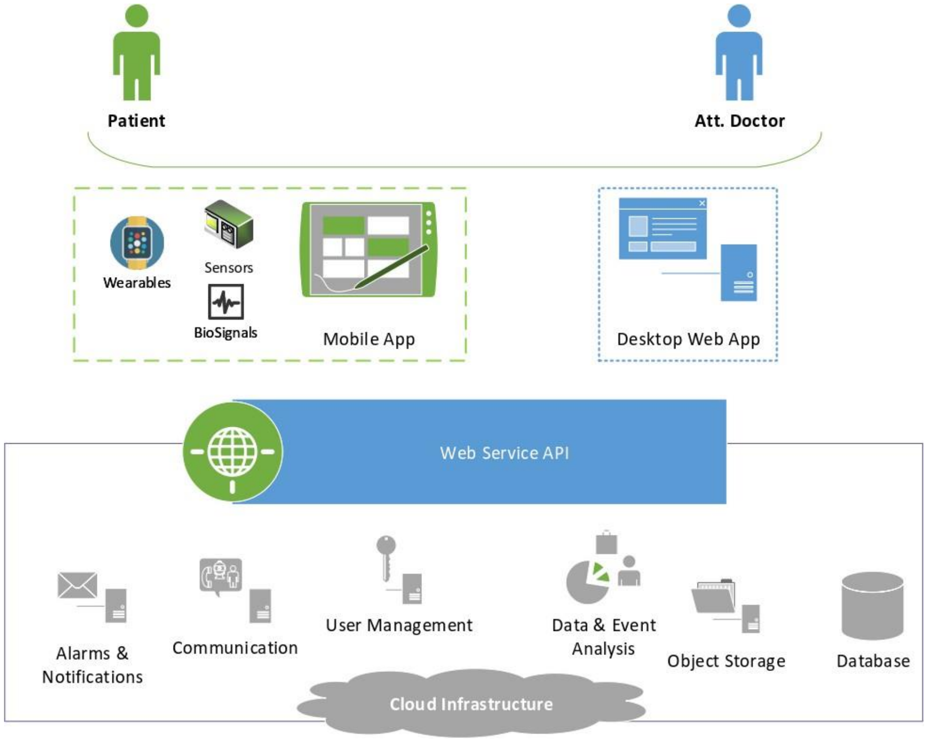

Figure1 Biosignal Logging Platform

3 Life Cycle and Data Modeling

In order to design and implement a framework for the measurement, management, storage and analysis of biosignals, it was necessary to first study the lifetime of a biosignal once it is taken for permanent storage in a repository of a base data. This life cycle extends to various frame components, both in the patient environment and cloud computing (Figure 2).

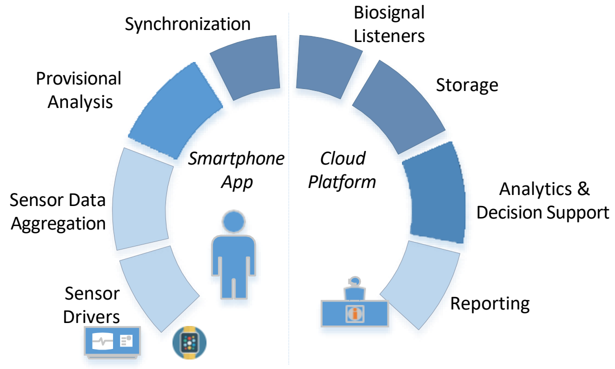

Figure 2 Biosignals' Life Cycle

The various functions on the patient's side are performed in an application that is responsible for:

1. the capture of biosignals by the various sensors using specific movements applied to each sensor,
2. aggregating the metrics and converting them into a common model and common format,
3. performing a temporary analysis to evaluate the quality of each measurement and
4. periodic synchronization of measurement data with the cloud platform.

In the suggested framework, we have chosen to use only sensors with a Bluetooth network interface. The thought behind this option is as follows::

- ✓ Bluetooth is available on all modern computing devices, smartphones and tablets,
- ✓ is easy to use,
- ✓ does not require additional wires or equipment, greatly improving the user experience and
- ✓ provides the required performance and capacity to manage biosignal data.

From the cloud computing side, platform components perform heavy computational operations for all patients, focusing on:

1. the acquisition of biosignals for applications,
2. their storage,

3. analysis that consolidates multiple parameters, models and real-time bio-data or historical data, and finally,
4. the reporting of the results of analyzing and supporting decision-making in emergencies and communication with appropriate services and staff.

One of the main concerns during the planning and implementation of the integrated system was the use of a single format and a common model for all biosignals in order to simplify all functions in the biosignals life cycle and all components of the platform. Instead of using an ordinary approach, we use the FHIR [19]. This special approach simplifies not only component development, but also improves the platform's operating procedures and performance, resulting in the promotion of the quality of the analysis processes.

In addition, the implementation of communication with any external providers is standardized in this sense, allowing for smooth integration with their systems, based on a common message structure and common use of words to avoid unnecessary transformations that lead to congestion of performance.

In addition to the aforementioned advantages, the use of FHIR Observations as a single form of biosignals platform introduces both technical and operational benefits as it provides Java and JavaScript model applications (such as JSON shapes), which can easily integrated into any environment and development framework.

4 Biosignal Acquisition and Framework Management

The proposed system covers the full life cycle of a biosignal from its measuring using a sensor for analyzing and storing it in a cloud environment, focusing on the use of standards in order to achieve the greatest possible compatibility with other systems and the scalability for integration of future biosignals and analysis tools. The system (Figure 3) consists of two basic elements:

1. a smartphone application for the communication with biosignals sensors facilitating the initial data assessment
2. a cloud-based platform for the storage and analysis of biosignals.

At the same time there is the potential of communication with other services in case of abnormal situations or emergencies.

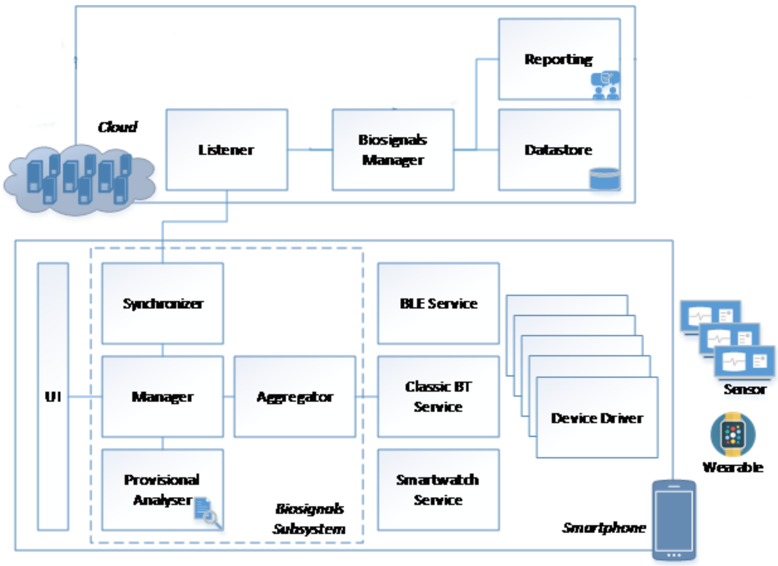

Figure 3 System's architecture

The smartphone application operates in Android and requires devices with a Lollipop version (API 21) and above, which inherently support BLE. The application has been designed and developed to enable multiple biosignals-device communications with minimal customization. Conceptually, this was accomplished by implementing three basic services

i. using the BLE,
ii. using Bluetooth for sensor pairs and
iii. the exclusive APIs manufacturers for other sensors (eg smartwatches).

For BLE and sensor pairs, it is planned to design the appropriate drivers to perform the various communication actions with the sensors based on the communication protocol of each device while API libraries will be used by the manufacturers whenever they are available.

The driver approach allows for a general design for BLE and typical Bluetooth services. Each driver is put in place according to each manufacturer's communication protocol for message exchange and biosignals' data acquisition by the sensor. In particular, each driver will be able to take action with regard to:

1. the start of the communication,
2. the pre-measurement setup,
3. the processing of measurement data; and
4. the post-measurement and the finalization.

The measurement process is controlled by all means of communication services, which allows detection of available sensors, loads the appropriate drivers, and retransmits the results of the measurements to the Bioscience Subsystem. In addition, sensor drivers and the services that control them are designed to support the different measurement method of each sensor. The system can communicate effectively with sensors that provide either a single measurement result, such as pressure gauges and saccharimeters, or real-time flow data from sensors such as pulse oximeters to correctly capture bio-data. It should be noted that in the case of bioluminescent flow, the periodicity of the measurement may also vary significantly from a few milliseconds (eg ECG data) to seconds or even minutes (eg in body temperature and arterial temperature sensors pressure). This adds extra complexity to the process of gathering, managing and analyzing data.

A key element of the smartphone application is the biosignals subsystem, which facilitates data management, monitoring, analysis and synchronization procedure. After the biosignals life cycle, each measurement result is taken by the driver and relayed to the biosignals subsystem.

Data summary component allows for combining the different types of biosignals and convert primary data from the sensors into a structured document that represents single or multiple measurements under specific frameworks and specifications. These documents are used for all the following operations in the biosignals life cycle and on all platform systems and components. In addition, measurement documents are merged with additional user-specific information, sensor, time stamps, and other metadata that may be valuable for analysis and evaluation.

The temporary analysis component is a tool based on a single decision support rule, with the aim of performing an initial assessment of the quality of each measurement. This element is configured with general rules for each device type to inform the system and the patient if the last measurement should be considered acceptable or if the measurement procedure should be repeated. Examples of such rules refer to the indication of blood pressure measurement or continuous flow data from a pulse oximeter. Additionally, customized rules can be set up, which consist of the thresholds for the results of measurements that present unreliable biosignal values. These rules are determined by the medical staff or the system itself, based on the analysis of the patient's biosignals history. In such cases, the system may propose additional measurements before generating cases that indicate abnormal situations or emergencies.

The management components, respectively, have the roles of coordinating the biosignals subsystem and controlling the cloud platform communication. Finally, the user interface data is provided in the application for interaction with patients and process control.

The main analysis of biosignals measurements is carried out in the system's cloud environment, where the required computational resources are available and where all patient health records are accessible. The platform provides components that listen to communication with biosignals sources. The effort in this deliverable focused on acquiring biological signals from sensors through an intelligent phone application, but also on manual submission of measurement results. General coordination in the cloud environment is performed by the biosignals manager who acquires the data from the listeners and stores them permanently in a database.

As part of this process, biosignals are continuously analyzed by the decision analysis and support component, and any events identified they trigger appropriate mechanisms.

These actions may vary, ranging from patient classification to a high-risk group, to emergency services notification if the life of the patient is at risk. Users can access their profile, historical measurement data, and analysis results through an online application that is also available as part of the proposed cloud-based solution.

Technically, the platform's internal and external integration units are implemented as REST APIs through which JSON messages are exchanged. To this end, the data is also JSON in data storage systems based on the proposed platform, which is MongoDB [20]. For biosignasl data, JSON messages are structured as FHIR Observations (Figure 4) [21].

```
{
  "resourceType": "Observation",
  "id": "heart-rate",
  "meta": {
    "profile": [
      "http://hl7.org/fhir/StructureDefinition/vitalsigns"
    ]
  },
  "text": {
    "status": "generated",
    "div": "<div xmlns=\"http://www.w3.org/1999/xhtml\"><p><b>Generated Narrative with Details</b></p><p><b>id</b>: heart-rate</p><p><b>meta</b>: </p><p><b>status</b>: final</p><p><b>category</b>: Vital Signs <span>(Details : {http://hl7.org/fhir/observation-category code 'vital-signs' = 'Vital Signs', given as 'Vital Signs'})</span></p><p><b>code</b>: Heart rate <span>(Details : {LOINC code '8867-4' = 'Heart rate', given as 'Heart rate'})</span></p><p><b>subject</b>: <a>Patient/example</a></p><p><b>effective</b>: 02/07/1999</p><p><b>value</b>: 44 beats/minute<span> (Details: UCUM code /min = '/min')</span></p></div>"
  },
  "status": "final",
  "category": [
    {
      "coding": [
        {
          "system": "http://hl7.org/fhir/observation-category",
          "code": "vital-signs",
          "display": "Vital Signs"
        }
      ],
      "text": "Vital Signs"
    }
  ],
  "code": {
    "coding": [
      {
        "system": "http://loinc.org",
        "code": "8867-4",
        "display": "Heart rate"
      }
    ],
    "text": "Heart rate"
  },
  "subject": {
    "reference": "Patient/example"
  },
  "effectiveDateTime": "1999-07-02",
  "valueQuantity": {
    "value": 44,
    "unit": "beats/minute",
    "system": "http://unitsofmeasure.org",
    "code": "/min"
  }
}
```

Figure 4 FHIR Observation example

In addition, with the simplification of communication procedures, APIs are available for biosignals data consumption by all popular biosignals activity providers and platforms (eg HealthKit and Fitbit). Therefore, biosignals and activity data are easily manageable by creating efficient and transformed data in FHIR format. At the same time, Electronic Medical History in HL7 is also partly supported.

Finally, the specification provides well-defined expansion points for the models, as well as standards for creating additional quantitative measurement schemes, which are not yet inherently supported. In the case of the proposed solution, this is particularly useful for defining the new models for Oxygen Peripheral Capillary Saturation and PPG [22] which are measured by pulse oximeters. Similarly, data point headers have been expanded to include information for identifying the sensor that was the source of each measurement, using as the identifier the MAC address of the sensors. The latter allows extensive analysis of the various measurements by correlating patient and sensor information. To this end, the platform's decision support system is able, besides providing a general picture of the health status of patients, to identify potential sensor malfunctions at the same time.

5 System of Biosignal recording

The proposed platform offers high quality health monitoring through instant messaging services, accurate recording of biosignals and other critical information, in order to meet the ever-changing needs of elderly and chronic sufferers in the so-called mhealth service sector. Through supportive services, it is intended to strengthen end-user compliance with care obligations and increased safety for the patient himself and his family. In addition, the system is minimally invasive, offering an unparalleled user experience.

Moreover, the platform facilitates the creation of a human-supportive network of health professionals, relatives and friends of patients and also provides the framework and services required for effective communication and management of a wide range of wearable devices and sensors, which make possible uninterrupted monitoring of user bioesignals and activities.

The end-user can use devices and/ or wearables for the recording of the biosignals, while the mobile application requires merely a tablet. The assistant doctor may be connected to the system from his computer and make an assessment of the patient's state of health and of his Electronic Medical History (demographics, medical history, laboratory tests, medication, allergies, etc.) using platform analysis and imaging tools, and hence can determine the tracking characteristics and the treatment pattern that suits the patient profile. The system allows for the creation of a customized timetable of measurements which should be received and entered into the system on a daily basis, either manually by the patient or automatically by the sensor network, the respective permissible limits of the emergency biosignals for each emergency, as well as the prescription and the treatment schedule. Compliance with the treatment schedule and the personalized follow-up program is implemented through reminders on the tablet.

The system processes data related to cloud timetable and whenever a measurement exceeds the limit set by the attending doctor, he is being informed via a pre-selected push channel (push notification, e-mail, etc.) facilitating direct communication with the patient. This is achieved by exploiting the functionality of video conferencing that offers the possibility of social networking with the user's "care circle", either in the form of communication with friends and relatives or with medical staff not only in every day cases but also in emergency situations.

6 Technology

The Integrated Health Monitoring System consists of four main sub-systems that realize the required functionalities, as well as a cloud back-end platform, which supports all other subsystems. These subsystems have been designed and developed utilizing a rich set of state-of-the-art technologies and tools, in order to secure optimal levels of robustness, security and extendibility and the finest user-experience.

The system follows a service-oriented architectural design, exploiting the advancements and flexibility of cloud offerings, and implements modern UIs for all types of users. Cloud Computing allows for ubiquitous access to shared resources and common infrastructure, offering services on-demand, serving the constantly changing needs of the health-centric digital services. To that end, is being developed an integrated system for patient monitoring at home, utilizing Cloud Computing concepts and tools for data managements and analysis. The proposed solution focuses on the system decision support functionality, which is utilized within the smartphone app for initial assessment, as well as in the Cloud.

A combination of Java and JavaScript technologies and frameworks are used for implementation and communication of the various application components and services. A cross-layer technology that has a key role on the realization of the communication and videoconferencing functionality is WebRTC, which is used both for the desktop and mobile applications.

6.1 Android App

For a simplified, flawless and ubiquitous access to the system, a mobile app for Android devices has been developed. Besides the core functionality for communicating with the backend, the mobile applications allow for the integration of Bluetooth devices, sensors and wearables. The native android application targets (API) Android 21 / Lollipop.

The application incorporates the required functionality for communicating with the cloud-based platform services and also acts as a platform gateway to the various Bluetooth devices (biosensors και wearables).

6.2 Web App

The web app includes the core functionality for interacting with all user types. In contrast to the mobile application, which is lightweight and simplified so as to ease the interactivity with the elderly users and patients, the web application has rich user interface for configuring the user and application parameters, and also for visualizing the biosignals and health records. WebRTC based communication is also provided through the web application.

6.3 Cloud Platform

The back-end platform is set of several cloud-based services and components. The main technology used for the platform is JEE and most of its features are exposed to the aforementioned applications through web services. In addition, it is possible to implement communication with external healthcare providers for updating the patient's PHR in case data are available.

7 Conclusions

The deliverable describes the design of an integrated system for record and analysis of biosignals that facilitate effective patient monitoring at home. The main contributions of the system are the standardization of biosignals collection and the introduction of Cloud Computing concepts and tools for data managements and analysis utilizing point-of-care decisions. In addition, it is presented the study that has been conducted for the development of an innovative and interactive integrated service of health monitoring.

8 References

[1] World Health Organization mHealth: New Horizons for Health through Mobile Technologies: Based on the Findings of the Second Global Survey on eHealth. Available online at: http://www.who.int/goe/publications/goe_mhealth_web.pdf

[2] Doukas, C., Pliakas, T., & Maglogiannis, I., Mobile healthcare information management utilizing Cloud Computing and Android OS. In Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE (pp. 1037-1040). IEEE.

[3] Charalampos Doukas, Vangelis Metsis, Erick Becker, Zhengyi Le, Fillia Makedon and Ilias Maglogiannis, “Digital cities of the future: Extending @home assistive technologies for the elderly and the disabled”. Telemat. Informat. (2010)

[4] Da Silva, H.P., Fred, A., Martins, R. Biosignals for everyone (2014) IEEE Pervasive Computing, 13 (4), art. no. 6926682, pp. 64-71

[5] Gomez, Carles, Joaquim Oller, and Josep Paradells. "Overview and evaluation of bluetooth low energy: An emerging low-power wireless technology." Sensors 12.9 (2012): 11734-11753.

[6] Bluetooth adopted specifications: https://www.bluetooth.org/en-us/specification/adopted-specifications

[7] Yao, J., & Warren, S. (2005). Applying the ISO/IEEE 11073 standards to wearable home health monitoring systems. Journal of clinical monitoring and computing, 19(6), 427-436.

[8] Kartsakli, Elli, et al. "A survey on M2M systems for mHealth: a wireless communications perspective." Sensors 14.10 (2014): 18009-18052.

[9] Santos, Danilo FS, Angelo Perkusich, and Hyggo O. Almeida. "Standard-based and distributed health information sharing for mHealth IoT systems." e-Health Networking, Applications and Services (Healthcom), 2014 IEEE 16th International Conference on. IEEE, 2014.

[10] Barata, Daniel, et al. "System of acquisition, transmission, storage and visualization of Pulse Oximeter and ECG data using Android and MQTT." Procedia Technology 9 (2013): 1265-1272.

[11] Morón, María José, Rafael Luque, and Eduardo Casilari. "On the capability of smartphones to perform as communication gateways in medical wireless personal area networks." Sensors 14.1 (2014): 575-594.

[12] Celler, B., and R. Sparks. "Home telemonitoring of vital signs-Technical challenges and future directions." (2014).

[13] Chao, S., Wong, F., Lam, H.-L., Vai, M.-I. Blind biosignal classification framework based on DTW algorithm (2011) Proceedings - International Conference on Machine Learning and Cybernetics, 4, art. no. 6017023, pp. 1684-1689

[14] Benmalek, E., Elmhamdi, J. Arrhythmia ECG signal analysis using non parametric time-frequency technique (2015) Proceedings of 2015 International Conference on Electrical and Information Technologies, ICEIT 2015, art. no. 7162958, pp. 281-285.

[15] Wu, P., Jiang, D., Sahli, H. Physiological signal processing for emotional feature extraction (2014) PhyCS 2014 - Proceedings of the International Conference on Physiological Computing Systems, pp. 40-47.

[16] Phinyomark, A., Quaine, F., Charbonnier, S., Serviere, C., Tarpin-Bernard, F., Laurillau, Y. Feature extraction of the first difference of EMG time series for EMG pattern recognition (2014) Computer Methods and Programs in Biomedicine, 117 (2), pp. 247-256.

[17] Li, Q., Rajagopalan, C., Clifford, G.D. A machine learning approach to multi-level ECG signal quality classification (2014) Computer Methods and Programs in Biomedicine, 117 (3), pp. 435-447

[18] Jun-Hai Zhai, Su-Fang Zhang, Xi-Zhao Wang: An Overview of Pattern Classification Methodologies, In Proceedings of the Fifth International Conference on Machine Learning and Cybernetics (2006) 3222 – 3227.

[19] FHIR: http://hl7.org/fhir/

[20] MongoDB: https://www.mongodb.org/

[21] FHIR Observation: https://www.hl7.org/fhir/observation.html

[22] K. Shelley and S. Shelley, Pulse Oximeter Waveform: Photoelectric Plethysmography,in Clinical Monitoring, Carol Lake, R. Hines, and C. Blitt, Eds.: W.B. Saunders Company, 2001, pp. 420-428.