A Medical Cloud

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***Abstract*—Recent trends and development in the production of various wearable biosensors enable a lot of medical and environment information to be available for each human being. Processing of data coming from these sensors, extracting valuable information and analyzing the electronic health record with a sufficient expertise is a complex processing task, which requires more resources than an ordinary mobile device or personal computer can perform with the available technology today.**

In this paper, we propose a cloud-based solution to deal with these challenges. The design includes use of wearable biosensors, personalized medical devices as transmitters of sensor data and the cloud that delivers various healthcare services over the Internet. A medical cloud hosts a specially developed application, which communicates with medical devices and sensors from one side and caregivers, such as a medical institution. The services include analysis by an expert ICT system, and also by a medical expert in case of an alert for detected problems analyzing the current state by received sensor data.

***Index Terms*—cloud computing, mobile healthcare, biosensors, cloudlet, fog computing**

I. Introduction

Although cloud computing [1] is not a new concept to the technological advancement, its potential use in healthcare is rising on the horizon. One can witness the benefits of this technology that recently is taking into practice, especially in cases when the personalized mobile devices, such as smartphones, tablets or laptop computers can not manage with complex computations and storage needs.

Recently, a variety of biosensors [2] is produced as wearables on a human body [3], such as ECG monitors, heart rate monitors, glucose monitors, pulse oximeters, body temperature, humidity and blood pressure monitors, SpO2 and various hemodynamic parameters of the patient. Additional information is gathered by various motion and position sensors, including GPS, accelerometer, gyroscope, step meter, etc. They can form a Medical Body Area Network (MBAN) which is a small-scale wireless communication network [4] used as a technology to provide medical-related raw data from attached sensors.

The trends show that in near future all these sensors will be realized on a smaller scale to provide continuos medical diagnosis, including micro and nano chemical smart sensors [5].

A lot of research is conducted aiming at provision of mobile healthcare systems, and most of these designs are using clouds for computation offload. For example, Doukas et al. [6] present an implementation of a mobile system based on Android that uses a cloud for electronic healthcare data storage, update, and retrieval.

Many services have to be realized in order to deal with multimodal and heterogeneous physiological signals and provide persistent personalized services. They require complex computations and need offload to a cloud. However, most of the current designs refer to a cloud as a storage system for Electronic Health Records (EHRs). All current solutions are based on static information and their design involves a data processing server. In this paper, we introduce a medical cloud that is capable of dealing with streaming and static structured data from EHRs.

The rest of the paper is organized as follows. Section II describes the architecture and functional description for building a medical cloud. Several design aspects of such a medical cloud are presented in Section III along with an analysis of essential application characteristics, such as elasticity and scalability, security and privacy, quality of service, etc. Section IV discusses the applicability, benefits, pricing and other non-functional issues and challenges. Related work of various approaches for dealing with personalized healthcare and a comparison of other approaches to the proposed medical cloud are given in Section V. The conclusions are presented in Section VI.

II. Organization of a Medical Cloud

In this section, we will discuss the architecture of the proposed solution, data communication issues, an organization of data processing and an overview of functions of the medical cloud.

A. Architecture design

The three-tier architecture of a medical cloud is presented in Figure 1. Various biosensors attached to a person can stream raw data to the nearby mobile device. Most of the sensors form the MBAN, they can also be independent sensors made as a very small wearable units that can stream data wirelessly to a receiver, which is positioned at a very close distance. This saves energy and the battery life of the biosensors, that are not easily detachable and can be re-charged. It will make them last for a longer period without any interruption in streaming data.

B. Data communications

If we analyze a given sensor as a transmitter in our design, then the receiver needs to be at a very close distance. Typically, the solutions offered by various researchers in the literature

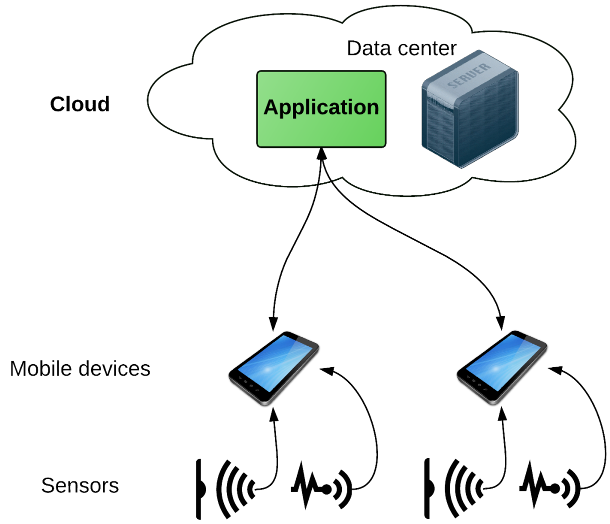

Fig. 1: Three tier architecture of a medical cloud

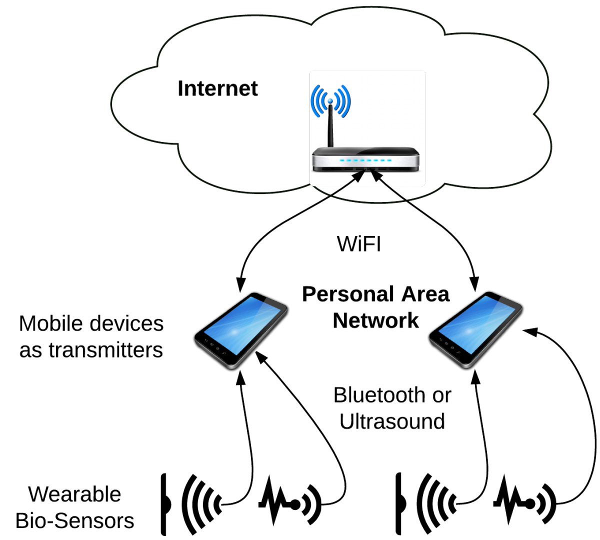

Fig. 2: Signal description of the proposed design

include gateways or similar devices, which are positioned in a home environment. These solutions need sensors that transmit more powerful wireless signals at an average distance of 5-10m.

Analyzing the new trends in production biosensors on a micro scale, that are very small and can transmit to distances that are at most 1m, and on average at a 0.5 m. Therefore, our solution uses a nearby device capable of receiving these signals and then forwarding them with the use of WiFi integrated in the smart mobile device to the cloud. This concept of using a mobile device just as an intermediator that receive weak signals and transmits them to the cloud via Internet is new and is not used in the solutions proposed as prototypes or a limited number of realized commercial products.

This idea is presented in Figure 2. Instead of using WBAN or WSN, where the sensors are powerful enough to transmit WiFi over 5m range, this design is based on the use of wearable biosensors that can transmit signals with a very low emitted power at 10 times fewer distances. For example, these wearable biosensors can communicate with ultrasound or low-power Bluetooth to the personalized devices in the Personal Area Network (PAN). These mobile devices can transmit received signals to the Internet using the WiFi router.

This design also solves the mobility problem. In case the person that uses wearable biosensors and PAN is not in an area that uses known WiFi network, then the mobile device can use its connectivity to the mobile network, such as 4G or similar. It is advised to avoid these situations as much as possible since the achieved speeds usually are higher on WiFi connected to an optical cable operator instead on Internet connectivity through mobile operator.

The mobile device can also contribute to the determination of other environmental data using the built-in sensors, such as GPS, accelerometer, gyroscope, step meter, motion sensors etc. These environmental sensors can provide sufficient information, such as the position of the person, its motion, and physical activity.

C. Data processing

Although this design does not include any processing on the mobile device, there are at least two occasions when this can be realized. The first case happens when the mobile device can not establish a communication to any of the WiFi or mobile operator. For example, it is happens in planes or other situations when there is no service by a mobile operator or WiFi. In this case, the raw data storage and initial data processing should be realized on the mobile device itself.

The second occasion is initiated by the necessity to react as fast as possible. This includes initial stream processing with the determination of abnormal situations that need further alerting. For example, in the case when received values of sensor data exceed the extreme values set as a normal physiological condition, then there is a need for an alert, as soon as possible. This processing is usually done on-the-fly, whenever the stream data arrives at the mobile device, with a small number of instructions performed on each received data item, to keep the battery life of the mobile device as long as possible. Usually, this processing is based on a comparison of the incoming data item with pre-defined low and high levels. Alerting is a consequence of detecting an abnormal physical condition and can include sending messages to the user, and also to its caregivers, such as medical institutions or close relative or friend subscribed to it.

Although the solution initially proposed by Chen et al. [7] is a three-tier architecture, it is different from our approach since it is using a smart gateway as an intermediator between the sensors and the server, instead of using a mobile device to transmit relevant information from sensors to the cloud.

Fog computing concept also includes a three-tier architecture, but in this case, all communication and processing goes to an infrastructure offered by the mobile operator. However, these solutions are almost always vendor lock-in situations, when the user can not transfer its data and processing to another provider.

D. Functions of the medical cloud

The medical cloud can support several information-based services used for delivery of personalized healthcare:

- receiving streaming raw data from sensors,
- storing unstructured received sensor data,
- pre-processing for abnormal physical condition,
- initiating alerts and messaging to caregivers,
- processing the raw data to extract relevant information,
- storing the structured information in EHR, and
- processing of latest physical state by an expert system.

The medical cloud is capable of receiving multiple streams of sensor data and storing them in a sequential record structure. As a part of the stream processing when each data item arrives, the system is capable of determining if its meaning is in a range of predefined values, or if it in combination with another relevant information exceeds the predefined normal values. In the case of detecting an abnormal physical condition, then a proper alert is initiated along with further actions that deliver this message to the person itself or to the caregiver (medical institutions or close relatives or friends) subscribed to receive such messages. Note that this pre-processing and storage of unstructured raw data can be done in a more efficient way, as presented in the next Section.

Extracting the relevant information from the received raw data is another important function of the medical cloud. Raw sensor data needs to be processed and only the significant values should be transferred for further determination of the physical condition of the person. This structured data needs to be stored in a database as EHR. For example, if a sensor is transmitting ECG values from attached ECG wearable sensor, then the processed information may include heart rate, any abnormalities, such as arrhythmia. If this is the first occurrence of such a diagnosis, then the complete ECG is stored in the EHR with the detected diagnosis. If this is already detected, then only small relevant information that detects a change in a physical condition should be updated in the EHR.

Note that the current physical state is always matched to other environmental conditions received by other sensor data. For example, in the case of a physical exercise detected by the motion sensors and step meters, it is normal to expect increased heart rate.

In addition to these functionalities from ICT aspects, the medical cloud is capable of realizing a healthcare monitoring service. This means it is capable of presenting the relevant information from the EHR, including the latest information or the history of previously recorded values. Besides presenting values, it is also capable of presenting graphical medical images, such as any ECG data, MRI, X-ray or other images. Data can be presented only to subscribed caregivers.

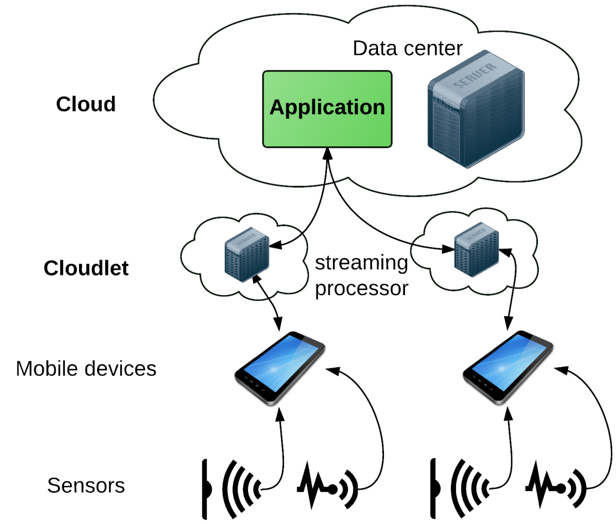

Fig. 3: Upgraded four tier architecture of a medical cloud

III. ICT Challenges in the Design of a Medical Cloud

In this section, we will analyze the several design aspects of the medical cloud, such as the elasticity and scalability, security and privacy, quality of service, availability and disaster recoverability.

A. Improved design

One huge challenge is to solve the communication demands in case of streaming data from multiple sensors. The initial problem, in this case, is the huge amount of received data, that needs to be received and processed, which creates a communication bottleneck or computation overload, which cause an inability to accept and process all received data.

In such a case the architecture of the medical cloud needs an upgrade by inserting another cloudlet tier, as presented in Figure 3. Cloudlets are local nearby servers that can process of streaming data and send processed information to the medical cloud. This design distributes the pre-processing of sensor data streams to several smaller and nearby servers situated in cloudlets.

Some IoT-based health monitoring solutions use smart gateways and local data center as an intermediate to transfer and process sensor data prior to their final storage and processing at the remote healthcare center, such as the solution proposed by Rahmani et al. [8]. Although, this is also a 4 -tier solution, it differs from ours solution. Instead of using mobile devices for transmission of sensor data to the cloudlet and afterward to the cloud, they use specialized gateways and local data centers.

B. Elasticity and Scalability

Scalability and elasticity are one of the main features of the medical cloud. The idea is not to be used only for storage of EHRs, but also to offer various services that diagnose the medical records and setup a diagnosis.

The improved design presented in Figure 3 is a highly scalable solution. When a given cloudlet is servicing numerous streaming sensors it may be a victim of a communication bottleneck or can face more processing demand than it can support. In these cases, scalability is solved by starting a new cloudlet instance and transferring some sensors from the existing cloudlet to the new one.

The need for porting a sensor from one to another cloudlet can be solved by conventional or specialized solutions that transfer all relevant data from the sensor to another location. In the case of having a system monitor that checks the state of existing computing and communication capabilities of a given cloudlet, this can be realized by an automatic procedure that leads to an elastic design. Of course, this process has also a downgrade component, meaning that to enable sufficient efficiency of the cloudlet, one has to optimize the number of tasks a cloudlet is performing. It means that the elasticity can both decrease and increase the workload of a given server in the cloudlet.

C. Security and Privacy

Security and privacy are very important for the existence of the medical cloud. Personal medical records have to be secured and available only to authorized users, such as responsible medical staff. The medical records are processed and stored in the cloud with sufficient security. This processing is also a matter of several legislations in various countries over the world, and the user of the medical cloud has to sign a contract to whom should the medical records will be available with transferring all reliability and trust to a medical institution or staff. The provider of the medical cloud should also guarantee that all known measures will be taken for data protection according to the available legislation and there will be no abuse of data.

Analyzing the overall solution, our proposal provides sufficient security and data privacy.

When a sensor transmits the streaming data to the nearby mobile device, the raw data is not encrypted or protected. Raw data is usually a stream of bytes without any identification of their meaning. The range of signal communication is very close and only devices that are very close the person can detect those signals. Only those devices, which are positioned very close to the person can damage these signals and initiate various intruder attacks. These devices are easily discoverable and can, therefore, be eliminated to prevent such situations.

When the mobile device transmits data to the cloudlet or cloud, it sends sensor id, and raw data, along with the date and location stamp. This data is still not encrypted to prevent any additional pre-processing on the mobile device and save its battery life. However, the established communication can be realized as a secured transaction, such as https. This prevents any data intrusion attacks and disables immediate capture of sensible data. Even in the case of capturing data, it is still not known for whom this data correlates, or what kind of raw data is sent, it is just a sequence of data bytes.

Data in the EHR stored in the cloud is protected according to the well-known data storage techniques. Data identification of the person with a corresponding EHR is kept on the level of the medical cloud and its provision of monitoring services.

Only authenticated and authorized users classified as caregivers can access the monitoring service offered by the medical cloud.

IV. Other challenges

This section discusses the applicability, benefits, pricing and other non-functional issues and challenges

A. Quality of Service

The quality of service is another important challenge. The provider of the medical cloud should guarantee that there will be no interruption in the provision of availability of offered services, and all measures will be taken to provide an alternative communication and processing server if there is an incident with the current server. The cloud provider has to guarantee that a proper disaster recoverability is enabled to keep the records of all interactions with the customer.

The improved design allows high performance since in case of increased utilization of a given server in the cloudlet over its capabilities, the system allows distribution of the workload to another server or cloudlet.

B. Benefits, pricing and other non-functional issues

The overall benefit of using a medical cloud are numerous. The users can obtain a personalized healthcare system, which is based on sensing some physiological parameters that can determine the overall physical condition. A huge benefit is using an expert ICT system that recognizes the sensing health related data and processes it by analyzing all related environmental and physical conditions. These systems can understand whenever some parameter is out of a predefined range of normal behavior and can initially alert in case of detection of an abnormal situation. In these cases, a medical expert from a caregiver medical institution can react and establish a more precise diagnosis. This concept gives the user healthcare protection.

The pricing strategy of using a medical cloud is based on the concept of provision of a Personalized Healthcare As A Service (PHAAS). This means that the users will pay a monthly subscription fee to have a constant monitoring of relevant wearable biosensors. The physical condition is matched upon other environmental information captured by the sensors built on the mobile device. An expertise system checks if the scanned data is in a predefined range assuming the complete physical condition of the user. If there is abnormality detected, such as exceeding a maximal value of some measured or calculated parameter then an alert is raised and several actions are initiated. Messages are sent to authorized caregivers in a form of an alerting service. A typical monitoring and check are started if an expert from a medical institution registered as a caregiver receives such an alerting signal. This expert has the task to analyze what caused the alert and monitor the overall scanned physical state provided by the sensors. The expert can additionally get more information by establishing a direct mobile phone conversation with the user and in a case of emergency to call an ambulance or give and healthcare advice.

This solution solves a lot of challenges in establishing ubiquitous healthcare systems such as energy efficiency, scalability, and reliability issues. Our approach is a highly energy efficient solution, saving the battery life of both the sensors and mobile devices. Scalability and elasticity are solved by the improved design with distributing the stream processing to the nearby server in the cloudlet tier. The overall goal of the improved design is the provision of relevant Quality of Service and keeping the performance at high levels.

This solution also offers easy attaching of different wearable biosensors, by keeping the independence of any platform or operating system. Interoperability issues are also important in the design of new sensors and solutions to support the available technology and communication standards.

V. Related work

The technology used is based on concepts of cloudlets and fog computing.

Cloudlets have been proposed as a solution for various problems, such as face recognition at airports [9], based on early designs presented by Satyanarayanan et al. [10]. More cloudlet challenges are discussed in [11]. Fog computing [12] is also an alternative solution to this design by extending cloud services to the edge of the network [13].

Next, we will compare our design of a medical cloud with the existing approaches.

There are several patents that address a cloud-based solution for a healthcare provided by a mobile device. For example, the Patent US2014275928 by Acquista et al. describes a system and method for monitoring and diagnosing the patient condition based on wireless sensor monitoring data [14]. However, the main intention of the patent invention relates to one or more wireless sensors and a network of wireless sensors for monitoring of vital signs. Additionally, it provides improved diagnosis, monitoring, and treatment of medical conditions, based on the integration of wireless sensors with an electronic medical record and management system for patient healthcare. The cloud in this context is used as a monitoring device, or as a device that connects to the electronic medical record or patient health record. This invention does not cover our definition and architecture of a medical cloud.

He et al. [15] designs a novel efficient cloud platform for ubiquitous healthcare services. Their architecture consists of six layers according to the specific requirements. This platform utilizes message queue as a cloud engine aiming at a prototype cloud platform, with robust, stable, and efficient features, that can satisfy high concurrent requests from ubiquitous healthcare services.

Medcloud [16] is a healthcare cloud computing system, designed to enable scalability of patient's data storage. Moreover, the authors provide an architectural design of a personal health record system that utilizes and integrates services from Hadoops ecosystem. Their design presents data layer, server management layer (coordinator manager, query manager, concurrency manager, data storage manager, jobs manager) and application layer (authenticator, authorizor, request receiver, data integrator, NPP registry, authorizers registry, service registry, disclosure tracker).

Chen et al. [7] design a smart gateway for health care system using a wireless sensor network (WSN). They analyze the challenges of transmitting big quantities of sensor data to a remote server or to a cloud for data processing, healthcare decision making and sending emergency messages. To avoid communication delays and bottlenecks they have designed a prototype of a smart gateway dedicated to WSN health care systems at home environment. Their smart gateway consists of a central control unit, database (DB), WSN module, WLAN AP, and GSM module.

Rahmani et al. [8] also analyze a Smart e-Health Gateway gateway solution, where the smart gateways are considered as devices with beneficial knowledge and constructive control over both the sensor network and the data to be transmitted through the Internet, and also as devices that offer several higher-level services such as local storage, real-time local data processing, embedded data mining, etc.

Instead of having a specialized gateway, our solution is based on using available nearby computing and storage infrastructure capable of receiving and analyzing streaming data.

Suciu et al. analyze several new trends in IT, such as Big Data, Internet, and Cloud convergence, and propose an architecture for secure e-Health applications [17]. Their design is a typical Internet-based solution, where all relevant actors communicate via Internet. Sensors are connected to Internet via a remote telecommunication unit (RTU) that is usually connected with an assistance of a mobile network provider. This solution is a typical solution of the edge/fog computing model.

Fernandez and Pallis discuss the system engineering space [18], analyzing the business model, nonfunctional requirements, application context, physical environment and characteristics, and other relevant aspects. Kanth et al. [19] also present technological development towards personalized and pervasive healthcare systems. Their solution also addresses sensors, access points, and cloud to deal with patient-oriented services that transfer medical checks and healthcare services from hospitals to a home environment.

Ferrucci et al. [20] discuss how the IBM Watson technology can be applied to health care and describe a vision for an evidence-based clinical decision support system. It is based on the DeepQA technology, that affords exploration of a broad range of hypotheses and their associated evidence, as well as uncovers missing information that can be used in mixed-initiative dialog. It has been efficiently used in oncology decision making [21], [22].

VI. Conclusion

We designed a medical cloud that collects data from personalized biosensors for a human being and other related environmental sensors, communicates with personalized mobile devices, processes the available information, analyzes complex algorithms to determine the health state of the analyzed person and eventually set a medical diagnosis. The cloud communicates also with a medical service for extended consultation about the diagnosis and in a case of detecting a malfunction or a health problem, alerts the medical expert.

The functions that provide a personalized healthcare are rather complex to be realized by a personalized mobile device, so the suggested design to use a medical cloud is the only alternative. A three-tier architecture that consists of a medical cloud at the top level, mobile devices at middle tier and various wearable or environmental sensors on the lower level can be upgraded by a four-tier architecture, setting a cloudlet between the cloud and mobile devices. In this case, the cloudlet can be used for stream processing functions, since transmitting stream data on a distant cloud can be inefficient and cause communication bottleneck.

Our design is based on personalized mobile devices as an intermediator in the PAN with tasks to communicate with the wearable biosensors from one side and WiFi from the other side. Typical solutions found in the research literature or prototypes in labs use WBAN or sensors that use WiFi to communicate directly to the cloud or use a specially designed smart gateway that not only accepts the sensor data, but also processes it locally. These designs lack mobility if the gateway is situated in a home environment. If the concept of fog computing is used, then everything is set on the mobile operator infrastructure and there is no flexibility of the user to choose a solution, nor availability to avoid lock-in situations. Therefore, our design offers more benefits compared to other solutions.

Presented design of a medical cloud as an IoT-based health monitoring system offers enhanced overall system energy efficiency, performance, interoperability, security, and reliability. Following the advances in the realization of expert diagnosis and recommender systems, one can expect that in near future the medical cloud will offer full healthcare services, even without the expert help of a medical institution.

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