Medical Tele-Monitoring and Tele-Assistance for Diabetics Patients by Means of 5G Cellular Networks

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Abstract. This paper deals with the description of an effective solution for tele-monitoring and tele-assistance of diabetics patients which resorts to the use of the recently launched 5G cellular networks. The proposed solution allows the provision of a tele-monitoring service for chronic diabetic patients, which provides proactive remote interaction of the patient with a “Healthcare center”. Moreover the paper shows the results of a recent experimentation which is based on the use of 5G network and has been realized in the town of Prato, Italy by presenting the results in terms of main performance indicators and describing the implemented e-health routines. Since these activities are achieved in the framework of one of the recent Italian pilot experimentations of the 5G networks, the presented e-Health services are one the first implementation that is based on this cellular system and take benefit of its outstanding performance.

Keywords: 5G cellular networks · E-health services · Tele-assistance · Telemonitoring

1 Introduction

Thanks to its remarkable performance the fifth Generation (5G) cellular networks will represent an enabling factor for different applications concerning the quality of life of the community of the territories by providing several advanced services. Focusing on the healthcare sector, the adoption of 5G networks will improve the citizen’s health assistance system: e-health services, such as tele-assistance, tele-consultation and

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remote monitoring of patients and fragile subjects, will guarantee continuity of care and assistance and will push towards transition from the specialized hospital-based care models to patient-centered ones. These services and the introduction of the 5G networks will make the medical service more effective, reduce its costs and increase the quality of life of patients [1–3]: it is important to note that the Tele-Assistance/Tele-Consultation applications will take particular benefit from the distinctive features of the upcoming 5G networks, namely the ultra-low latency and very high bandwidth.

This new paradigm will allow the design and development of innovative solutions addressing some of the main problems related to the management of multiple patients in a care environment (hospital, rehabilitation structure, etc.) during all the different phases and to the remote assistance of convalescent or home patients (for diseases such as diabetes). The patient can be assisted "transparently" at any time through adaptive interactions among smart objects (sensors, drugs, doctors' terminals, patients, relatives, and pharmacies): the monitoring of some of the main parameters will afford immediate assistance in case of necessity. The transparency to the user, the flexibility, and the cooperation between the patient, the objects, and the network are of utmost importance in the disease context and can be specifically tailored to the assistance of patients affected by specific problems or pathologies [4, 5].

In this paper an effective solution for tele-monitoring and tele-assistance of diabetics patients is presented, which resorts to the use of the recently launched 5G cellular networks [6–8]: this solution allows the provision of a tele-monitoring service for chronic diabetic patients, which provides proactive remote interaction of the patient with a "Healthcare Center".

The proposed solution resorts to the adoption of an innovative 5G architecture that affords to experience the outstanding Key Performance Indicators (KPIs) of the upcoming cellular network. The interactions between the Patients, the Doctors and Healthcare Center are permitted by an original web app that has been specifically designed for the Use-Case experimentation: the application allows patients to monitor the status of their diabetes pathology and to be remotely monitored through frequent blood glucose and weight measurements. Measurements are performed by consumable and wearable devices and their results are automatically stored in the patient clinical records and made available and accessible at anytime and anywhere. Moreover, the connection to the H24 operating center permits medical monitoring of the measurements and the support in the decision-making process related to the management of their pathology. The adoption of the 5G network enables high quality tele-Assistance and represents a performance breakthrough with respect to current LTE/LTE-A (Long Tem Evolution/Long Term Evolution - Advanced) networks. Since the latency and the data-rate are both essential for this service, their values have been measured alongside the preliminary tests of the Use-Case: the measured values are also reported in the paper.

The article is organized as follows. The next paragraph presents an overview about the Diabetic Pathology with figures about number of patients and control routines. Then the main requirements of tele-monitoring services for diabetics patients are reported. In the successive paragraph the proposed solution for tele-monitoring and tele-assistance is introduced by describing the network architecture and the benefits that are due to the 5G exploitation. Then, the results of a recent experimentation which is based on the use of 5G network and has been realized in the town of Prato, Italy is presented by showing the results of the main performance indicators and describing the simulated e-health routines. Finally, conclusions and future developments are drawn in the final section.

2 An Overview of Diabetic Pathology: Some Figures About Number of Patients and Control Routines

The slow but inexorable increase in life expectancy of the world population and the equally significant decrease in some of the most widespread pathologies has made the growth of the incidence of diabetes in the world population evident. International Diabetes Foundation has recently revealed that while today one in 11 adults has diabetes, in 2040 the diabetics will be one in 10. This means that while today 415 million people have diabetes, this number will raise to 642 million in 2040. Moreover it is worth recalling that in 2015, around 5 million people died of diabetes-related causes (1 every 6 s) and that 193 million people live with undiagnosed diabetes, that is to say one in two adults [9].

The reasons for this diabetes epidemic are manifold and mainly attributable to a profound change in lifestyle, to increased life expectancy and ongoing social changes:

- the population of over-sixties is constantly growing;
- increased calorie intake and reduced physical activity led to the rapid increase in obesity and overweight.

Moreover, diabetes tends to be more common in the less well-off socio-economic groups and also in some specific ethnic groups. As a matter of facts, an ever-increasing number of people will have to live with diabetes and with the serious complications that it causes with a growing demand for assistance, social support, economic investments and reorganization of care. Therefore, the growth in health expenditure will risk to jeopardize the principle of equality of access to care with the consequent widening of poverty and fragility. Therefore, our societies will need a deeper attention and bigger resources to be dedicated to the prevention that, as it is known, tends to reduce the subsequent costs for the treatment of complications.

3 Monitoring Diabetic Patients: Main Requirements

The efficient management of diabetic patients requires a continuous monitoring of different parameters. The main ones are: glycaemia, weight, eating habits, physical activity, pre-scribed therapy adherence. By correlating the information coming from the monitoring of these parameters and analyzing the results that are achieved by taking also into account the history of the patients' health, the medical staff can evaluate the actual status of the patient and activate the adequate care path.

On the diabetic patient's side, the main identified needs:

- to increase the frequency of specialist visits;
- to easily store the glycaemia measurements and report them to the specialist (clinical history);
- to reduce the waiting times to schedule a visit;
- to be home-monitored due to both logistic difficulties in accessing public health facilities (e.g. long distances) and motor difficulties (e.g. complications of diabetes);
- to be motivated to improve his/her lifestyle (eating habits, physical activity);
- to be supported by qualified staff in the daily management of diabetes (e.g. lack of social and family support network);
- to be guided and motivated to improve adherence to therapy.

In this context, the adoption of ICT (Information and Communication Technologies) and of wireless and wearable medical devices affords the implementation of advanced tele-monitoring systems that are able to address most of the previous listed requirements. Although a large variety of services can be defined, the main components that should be considered in the design of such services are:

- Qualified tele-assistance for medical consultation or guidance;
- Tele-monitoring and information collection of the main critical parameters that are required for the assessment of a diabetic patient;
- Feedback mechanisms for motivating patients, improving patient's lifestyle, monitoring the adherence to therapy, activating corrective actions in case of anomalies, etc.

4 Proposed Solution

Starting from the main requirements for the monitoring of diabetic patients, the proposed solution relies on the usage of a simple app that allows patients to record and monitor their health parameters and receive qualified medical advice anywhere and anytime by phone or video call.

4.1 The Service: Integrating Tele-Monitoring and Tele-Assistance

The proposed service consists of two main components: tele-monitoring and tele-assistance.

Tele-Monitoring Component. It enables patients to monitor the status of their pathology and to be remotely monitored through:

- frequent blood glucose and weight measurements, which automatically are stored in the patient clinical record and are made available and accessible anytime and anywhere;
- a H24 operating center for proactive medical monitoring of the measurements performed by patients and for supporting them in the decision-making process related to the management of their pathology.

The patients will be equipped with a kit for measurements including a NFC (Near Field Communication) glucometer, a Bluetooth weight scale and a blood glucose lancing device.

Tele-Assistance Component. It enables patients to contact the Operating Assistance Center for:

- having a teleconsultation with medical staff;
- booking and having a tele-visit with a general practitioner or a specialist;
- being supported in coping with technical or administrative problems regarding the service itself.

In order to describe the proposed service a brief description of a use case integrating the two service components is provided in the following.

4.2 The Network Architecture

The objective of this section is to describe the network architecture that supports the proposed Service, highlighting the involved devices and communication technologies.

Figure 1 depicts the main components of the network architecture, showing the interactions among the three main players of the Service: the patient, a member of the medical staff and the Operating Assistance Service operator.

The data exchange among them are enabled by different communication access network technologies and by customized software applications (both as a mobile and a web versions) representing the interface with the Cloud Service Platform.

In the following the way each Platform user can access the Service is analyzed and the main functionalities of the Cloud Service Platform are presented.

Patient Side. The patient is equipped with a 5G smartphone running a customized App for accessing the tele-monitoring and tele-assistance Service and with a kit of smart devices for the measurements acquisition. In detail, the developed App is able to interface with the weight scale through a Bluetooth connection and with a glucometer with an NFC connection and to acquire automatically the results of the measurements. Once the measurement values are acquired by the smartphone, they are sent through a 5G link (eventually relayed by a 5G modem) to the Cloud service platform and stored in the patient health record.

Service Platform Side. The cloud platform allows the storage, processing and sharing of the uploaded measurements, which can be accessed and visualized (e.g. historical text or graphical output) by patients, medical staff members and Operating Assistance Service operators. In fact, all the patients' measurements are stored together with some additional diagnostic images and clinical reports (eventually integrated) in the Cloud Platform and they are always available and shared with the authorized people. Moreover, Tele-assistance sessions (e.g. videoconference) between patient and medical staff or patient and Assistance Service operator are allowed for medical and technical assistance, respectively. In case of anomalous measurements (alert mechanism) the patient will be called by the Operating Assistance Service operator with the aim to further investigate on the patient's health status and, if needed, a tele-visit with a general practitioner or a specialist is booked.

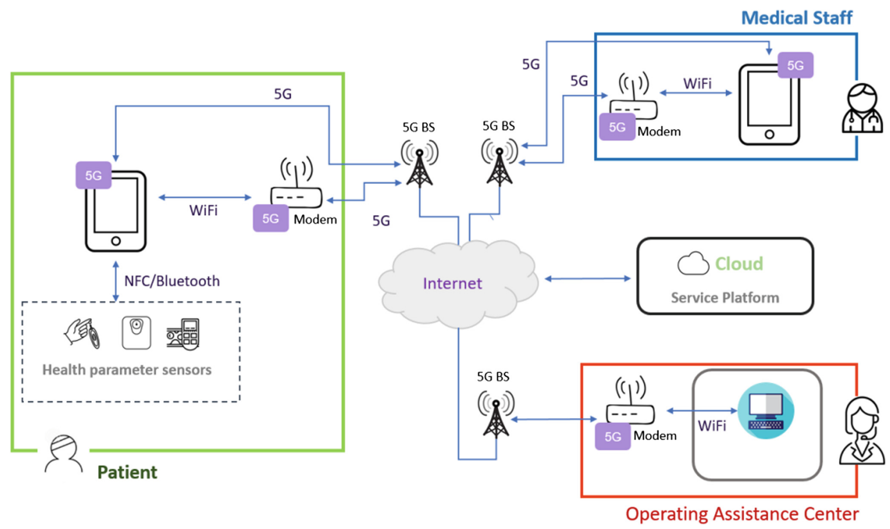

Fig. 1. Network architecture

All these interactions are enabled by the definition and development of a Platform web interface and a mobile interface, which allows patients, medical staff and operators to access the Service.

Medical Staff Side. Each member of the medical staff can run the customized Web App on his computer for remotely accessing patient health record and real time monitoring the patient's performed measurements. The historical health records and therefore the possibility of evaluating the trend of the patient's health status allow them to activate the proper countermeasures (e.g. tele-consultation, therapy calibration, etc.), if required.

Operating Assistance Service Side. The continuous monitoring of the uploaded data is guaranteed by the Operating Assistance Service operators, who access the Platform through a Personal Computer Wi-Fi connected to a 5G modem. In particular, the developed web interface allows an efficient patient management and monitoring.

4.3 The Benefits of 5G

Thanks to the flexibility that is guaranteed by new features such as the network slicing, the 5G networks will enable new business models in which operators, suppliers, end users, industry, companies, service providers, suppliers and other players in general will collaborate differently than today [6].

The evolution of business models will lead to the birth of new services or to the evolution of those that characterize the current telecommunications, which are mainly focused on personal communication (voice), on the interconnection of people between them (Instant Messaging and Social Networks) and on the use of multimedia content (Streaming and Internet browsing). These services will evolve both due to the increasing use of multimedia contents and to the interaction of "things" between them and the Web world. Moreover, unlike previous 3GPP mobile communication systems that are characterized by a single system configuration for all services, the 5G system will be able to provide differentiated and optimized support for a variety of deeply differentiated services, that are targeted for user communities with different needs. The 5G is therefore a multifunctional system capable of simultaneously supporting various combinations of performance characteristics, such as transmission speed, latency, positioning, reliability and availability.

As a consequence new and more stringent performance indicators such as: high data rate, very low latency, high reliability and availability, greater positioning accuracy, new minimum coverage requirements, connected device density and network capacity will have to be met.

As far as the e-Health use case is concerned, the use of 5G technology is especially required by tele-monitoring and tele-assistance services in order to guarantee the necessary network capacity (e.g. up to 200 Mbps per single stream, necessary for the transmission of HD video in case of videoconference between doctor and patient), and a reliability of at least 99% that is requested to ensure the correct continuity of the service.

More generally the considered services require the use of 5G technology to allow a more efficient realization than the ones that are possible with the current network technologies. Key features of 5G with a direct impact on the performance of the services developed in this eHealth trial are:

- the stability of the network to ensure continuity of service;
- the low latency required by monitoring and control applications;
- the high throughput required by video/teleconsultation applications.

Moreover it is worth recalling that 5G cellular networks will resort to the introduction of the Network Slicing, through which various eHealth services will be instantiated with isolation characteristics between different Customer traffic flows and performance guarantee in each slice.

5 Experimental Activities and Use Case

On March 16, 2017, the Ministry for Economic Development published a call for tenders for project proposals for pre-commercial testing of the 5G cellular network in the spectrum portion of 3.6–3.8 GHz. This call for proposals responds to the request of the European Commission for a 5G timely deployment as a strategic opportunity for Europe, with a coordinated approach and a common calendar among Member States.

This is the context of the joint initiative that has been promoted by the lead companies OpEn Fiber and Wind Tre, which combined their skills, infrastructures and investment capacity with the common goal of promoting a “5G City” project in which they are provided innovative services with a strong impact both in terms of social and economic utility. The initiative concerned the city of Prato while presenting characteristics of replicability and usability either on a National, an European and more generally, an International scenario. Therefore, a series of use cases were identified for which applications and services are intended with certain performance requirements, analyzing the strategic role of the 5G networks and the related economic and social impacts expected in the Prato area; among others, experimentation activities related to the improvement of the citizen's health care system have been launched.

As part of the activities planned for the Use Case 1 of the 5G Experimentation project promoted by the Italian Ministry of Economic Development (MISE), Enel is setting up a tele-monitoring service for chronic diabetic patients, which provides for proactive remote interaction of the patient with a "Healthcare center".

Enel aims to establish a Proof-of-Concept (PoC) test in Prato (which is the site selected for testing activities within Project 5G), to simultaneously determine the values of the main KPIs and perform tests on the integrated service. In order to provide further details on the KPI measurement link, Fig. 2 shows the protocol architecture of the segment of interest of the 5G network; the entities that are represented in this figure are the Customer Premise Equipment (CPE), the Evolved Radio Access Network (E-UTRAN), the Serving Gateway (SGW) and the Packet Data Network Gateway (PDN GW) that is also the point of connection with the Internet. The layers of the protocol stack and the interfaces are depicted for all the involved entities.

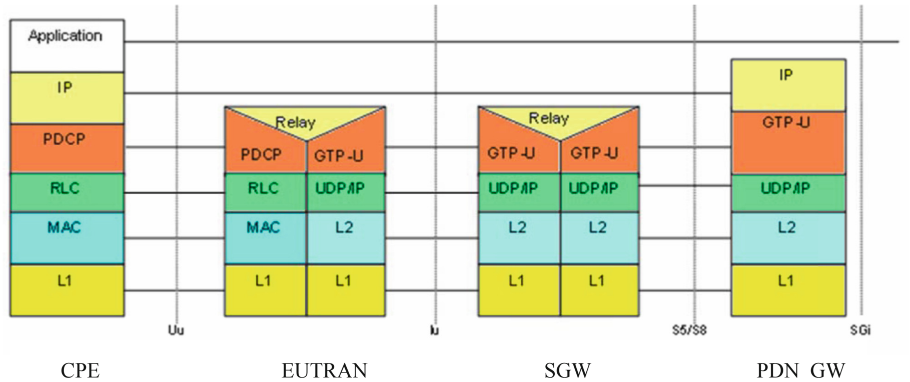

Fig. 2. 5G network architecture: network segment subject to measurement for KPI verification.

As for the KPIs, the following Tables 1 and 2 give a summary of the results that have been achieved in the preliminary tests: the entities that are mentioned in these tables are the CPE, the Base Station, the Evolved Packet Core (EPC) Network and the PDN). Multiple tests have been performed for all the considered parameters: particularly the bandwidth has been measured both for the UDP (User Datagram Protocol) and the TCP (Transmit Control Protocol) cases.

Table 1. Results of latency tests.

Latency (CPE - Base Station - EPC Core - PDN)					
	Measured values [ms]			Requirements [ms]	Test result
	Min	Mean	Max	Range	
Round trip time	**9**	10	12	20–100	Passed
One way delay	**4.5**	5	6	10–50	Passed

Table 2. Results of bandwidth tests.

Bandwidth (CPE - Base Station - EPC Core - PDN)					
	Measured values [Mbit/s]		Requirements [Mbit/s]		Test result
	DOWN	UP	DOWN	UP	
UDP	170	60	100	50	Passed
TCP	155	55	100	50	Passed

As regards the measured values, it has to be noticed that both the latency and the bandwidth satisfy the requirements that have been identified for the monitoring service of diabetic patients, namely the high data transmission speed (50 ÷ 100 Mb/s) and the moderately low latency (10 ÷ 50 ms, one way).

As for the service, Enel X and A. Menarini Diagnostic have developed an innovative solution that allows to record and monitor health parameters and to receive qualified medical advice anywhere, anytime, by either phone or video call. This solution is based on the implementation of the previously described network architecture, the use of suitable medical devices and the design of a simple app. Particularly, the parameters telemonitoring protocol allows to synchronize glycemic and weight results directly from the smartphone. The patient can view the measurements and get a graphical and organized view of the trend over time, with notifications in the event of values out of range. On the other hand the telephone and video-consultation assistance with a Diabetologist permits to request, 24 h a day, telephone assistance with doctors of the Operational Center and book a video-consultation with a Diabetologist, by simply clicking on mobile, comfortably at home.

As depicted in Fig. 3, a diabetic patient will program the daily measurement routines with the considered devices. During one of these probes, the glucometer will detect high/low glycaemia values. This condition will trigger the emission of an alert towards the smartphone with a callback request; on the same time, a Doctor in

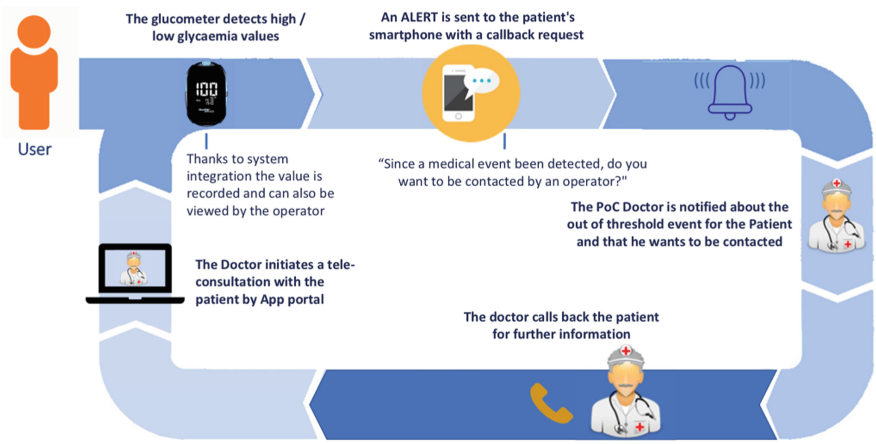

Fig. 3. The proposed tele-monitoring and tele-assistance routine.

Healthcare Center will be notified with the report and pre-alerted for a possible call by a patient. If the patient will proceed with the call, the Doctor will contact him to clarify the situation by means of a specific Teleconsultation through the app portal.

6 Conclusions and Further Works

An effective solution for tele-monitoring and tele-assistance of diabetics patients which resorts to the use of the recently launched 5G cellular networks has been presented. The results of a recent experimentation, which is based on the use of 5G network and has been realized in the town of Prato, Italy have been also shown by presenting the results of the main performance indicator and describing the simulated e-health routines. Future activities encompass further tests for the validation of the application and evaluation of the User Experience over a restricted set of real patients.

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