Health Monitoring of People with Diabetes using IoT and 5G Wireless Network Infrastructures

Vasileios Tsoulchas, Nikolaos Tsolis, Eirini Zoumi, Emmanouil Skondras, Dimitrios D. Vergados
Department of Informatics, University of Piraeus, Piraeus, Greece,
Email: {tsoulchas, tsolis, skondras, zoumi, vergados}@unipi.gr

***Abstract*—During the last years, Internet of Things (IoT) is evolving rapidly, providing a vast range of equipment that fits in all aspects of modern life. Indicatively, wearable devices can be used for monitoring people's health, since several people need continuous medical supervision due to health problems they face. Meanwhile the continuous monitoring of their health status with traditional ways, such as with daily visits at hospitals, brings several limitations to their daily lives while at the same time it does not provide supervision on a 24-hour basis. This paper proposes a model to monitor the health of people with diabetes melitus, a disease with high incident rates mainly at the elderly but also in younger people. Specifically, a study about the existing medically approved technologies for continuous measurement of diabetes is described. Subsequently, the model for monitoring patient's blood glucose levels is descibed. Whenever a patient's blood glucose levels are Low or High, the model triggers an alarm to a Cloud infrastructure in order remote medical staff to provide immediate cure to the patient. Furthermore, in order to assure the immediate response of the remote medical staff, the proposed model is deployed upon a 5G wireless network architecture.**

***Index Terms*—Diabetes Melitus, Health Monitor, Patient Consciousness, Internet of Things (IoT), 5G, Cloud**

I. Introduction

Medical technology has managed to increase life expectancy. The elderly have increased also [1] mostly in the developed world. According to Eurostat, 19.2% of Europe's population corresponds to people aged over 65. After the age of 65, the life expectancy is 11.73-16.35 years for men and 18.18-20.21 years for women [2], usually with increased health problems. This means that the 47.5% of the expected life over 65 for men and the 55.6% of the expected life over 65 for women, will have health problems. Also an increasing number of the elderly in Europe live alone.

Diabetes is a very common disease among the elderly and not only. Worldwide, people suffering from diabetes is estimated to be increased from 285 million in 2010 to 440 million in 2030 [3]. It is the main cause for blindness, kidney failure, heart attack, stroke and leg amputation. It has been calculated that in the year 2015 there were 1,6 million deaths caused directly from diabetes and another 2,2 million deaths that are caused due to high blood sugar (hyperglycemia) concentrations. In general, people suffering from diabetes are at least 56 million in Europe [4]. Furthermore, patterns of disease differ by ethnic group: type 2 diabetes is up to six times more common in people in south Asian descent and up to three times more common among people with African and African-Caribbean origin [5].

If diabetes is not addressed immediately and correctly, over time can damage the heart, blood vessels, kidneys, eyes and nerves. 50% of people with diabetes die of cardiovascular disease (primarily heart disease and stroke), while at the same time approximately 10-20% of people suffering from diabetes, die due to kidney failure [6]. There are many papers and research work for monitoring people's health and activities [7]–[11]. Most of them are focused on monitoring people when they are at home [12]–[16], monitoring their activities and health using a variety of medical equipment, depending which medical parameters must be monitored [17]–[19].

In this paper, an Internet of Things (IoT) device for monitoring patients' blood glucose levels is used. This device periodically measures the patient's blood glucose levels and transmits them to a smart device (e.g. a smartphone) of the patient. In case where the patient faces an increase or decrease in the glucose measurement, the smart device communicates with remote medical infrastructure using the appropriate communication equipment, and triggers an alarm. For assuring the immediate response of remote medical staff in emergency situations, the proposed model is deployed upon a dense 5G [20] wireless network architecture. In general, Ultra Dense Networks (UDN) [21] aim at the support of high data rates produced by an increased number of users. Accordingly, a large number of small cells, such as Femtocells, is deployed in-side the network coverage area in order to increase the overall capacity of the access network [22]. In addition, heterogeneous network access technologies, such as 3GPP Long Term Evolution Advanced (LTE-A) [23] or IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX) [24] Macrocells and Femtocells, as well as IEEE 802.11p Wireless Access for Vehicular Environment (WAVE) [25] RSUs, are used for the interaction between the medical IoT devices and Cloud infrastructures. Through this infrastructure, the medical staff can immediately provide the required care or advice remotely each patient.

The remainder of the paper is organized as follows: Section II describes the existing techniques available for measuring diabetes. Subsequently, Section III describes the proposed model and Section IV presents a case study. Finally, Section V concludes the discussed work.

II. Measuring Diabetes

This section describes the available techniques for measuring diabetes. Firstly, regarding the Self Blood Glucose Monitoring (SBGM) technique [26], a person who suffers from diabetes has to measure the glucose concentration in his blood, several times a day, depending on the severity of diabetes, by puncturing a finger and get one drop of blood. This drop of blood is inserted in a special sensor attached on a device, and after a period of approximately one minute, the patient gets the result. The device stores the value with the corresponding date and time for monitoring the course of the disease. This method is accurate but painful and not very comfortable in case the patient needs to carry out many measurements during the day. Also, the patient must have his consciousness to complete the measuring procedure.

During the last years a new method has introduced, namely the Continuous Glucose Monitoring (CGM) [27]. A body sensor attached to the patients' body for approximately 15 days is used. After this period the sensor must be replaced for the patients' safety as well as for battery replacement. The sensor measures the glucose from the interstitial fluid, which is not different from the glucose measurement from blood, except a 10 minutes delay. The sensor communicates wirelessly with a mobile device or a smartphone using an application. The application receives the measurements from the sensor and notifies the patient if the glycose measurement is out of range. The application stores the measurement, giving the opportunity to the patient and the doctor to examine the glucose variations for a selected period of time.

Internet of Things (IoT) is mainly a network of interconnected devices that communicate one another by sending and receiving data. Every day devices convert into IoT devices with the addition of various sensors. Indicatively, the CGM sensor for the continuous glucose measurement is an IoT device that measures glucose and through a communication network, send the measured values to a smart device or smartphone. The communication protocol could be any available in the market of the IoT. Bluetooth, NFC, Wi-Fi, ZigBee, 6LoWPan, Thread, Sub1Ghz, WirelessHart. But for the patient's comfort (not to carry many devices with him), the best solution is the Bluetooth, since all the smartphones support this kind of communication. Bluetooth protocol can cover the range that is needed for the connection of the body sensor and the smartphone which will be near the patient.

For the moment, two companies have CE certification for the medical use of their CGM based systems and these results can be used for medical evaluation. The models are the Abbott Freestyle Libre [28] and the Dexcom G6 [29]. The first one uses Near Field Communication (NFC) [30] with a few centimeters distance to achieve communication, and the patient must be conscious to get the measurement. The second system uses Bluetooth [31] communication which gives approximately 8 meters distance for communication and there is no need for the patient to be conscious to get a measurement.

The sensor that the Abbott Freestyle Libre [32] is using, communicates with a proprietary device using the NFC technology. The user must bring the device near the sensor (less than 4 cm) to get the measurement. The device then notifies the user about the measurement value (Low, High or Normal) and stores the value for monitoring the variation of the glucose for a period. On the other hand, the sensor that the Dexcom G6 [33] is using, communicates through Bluetooth technology, either with a proprietary device or a smartphone that uses an application designed from Dexcom. The device needs to be near the sensor (6,5 meters) and the sensor sends the measurement values in predefined periods. The proprietary device or the smartphone, notifies the user about the measurement value (Low, High or Normal) and stores the value for monitoring the variation of the glucose over time. For both Abbott Freestyle Libre and Dexcom G6 systems, the user/patient must either have his consciousness to act according to the measurement value, or in case of unconsciousness he must get immediate medical attention.

III. The proposed Model for Blood Glucose monitoring

The system architecture of the proposed model is presented in figure 2. For each patient, a Dexcom G6 CGM device is used, whose design is presented is figure 1. As it can be observed, the CGM device is equipped with a filament for performing the glucose measurements, which is less than 0.4mm thick, as well as with a Bluetooth transmitter which is used for sending the measured values to nearby smart devices, such as smartphones, tablets or vehicular On-Board Units (OBUs) [34]. Furthermore, a mobile application which is deployed to patient's smart device is also used. Both the CGM device and the patient's smart device are interconnected using the Bluetooth technology.

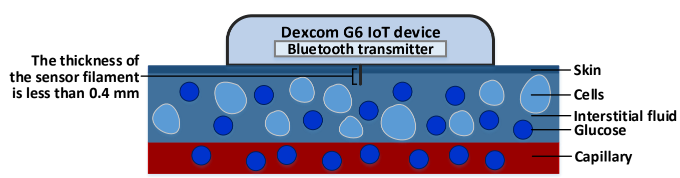

Fig. 1: The design of the Dexcom G6 IoT device.

Algorithm 1 presents the measurement procedure, where the CGM device periodically monitors the patient's blood glucose levels. Specifically, during the initialization of the proposed model, the patient (or a person who oversees the patient) sets a time interval for the measurement of his blood glucose levels, depending on the severity of his health status. Furthermore, since not all patient cases are the same and not all people respond similarly to the same medicine, personalized thresholds for Low (*T_Low*) and High (*T_High*) blood glucose level should be set for each patient, according to medical staff conclusion about each specific case.

When the time interval becomes equal to 0, the CGM device performs a measurement about the blood glucose levels of the patient. Subsequently, the CGM device transmits the measured values to the smart device of the patient, while at the same time the time interval obtains its initial value and start again the countdown for the next measurement.

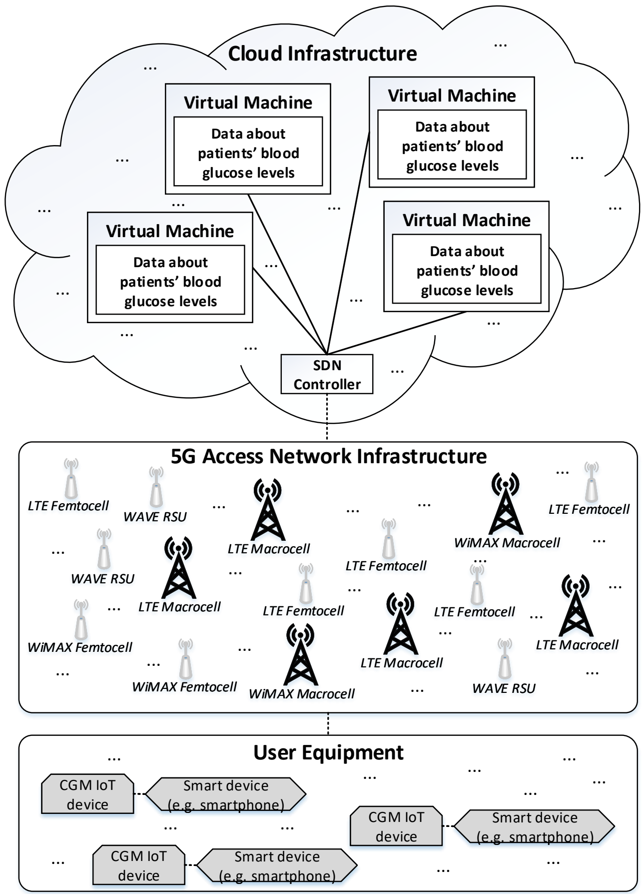

Fig. 2: The network topology where the proposed model is deployed.

The patient's smart device stores the received measurement data and compares them with the *T_Low* and *T_High* thresholds. When the smart device of the patient recognizes either High or Low glucose levels, it transmits the collected information to a Cloud infrastructure which is used from remote medical staff. Thus, an alarm about the health status of the patient is triggered. Also, the smart device displays a questionnaire to the user with questions about his current health status in order additional useful information to be collected. If the user answer in the displayed questions, the additional information is also transmitted to the Cloud, to further assist the remote medical staff to perform a diagnosis.

Specifically, if the measured glucose level is Low, then the patient's smart device displays the questionnaire for Low Glucose to the patient (Algorithm 2). The patient has to answer all questions in $T_{countdown}$ = 60 seconds. If all answers are negative and within the time frame of 60 seconds, the result of the procedure will be "Negative". Accordingly, if at least one answer is answered positively or the time frame of one minute expires, the result of the procedure will be "Positive".

Algorithm 1 The pseudocode of the Measurement Procedure.

```
PROCEDURE MEASUREMENT
REPEAT;
Ttime = Tmeasure
READ Measurement;

if T_Low < Measurement < T_High then
    Measurement_Status = "Normal Glucose";
    SAVE (Date, Time, Measurement, Measurement_Status);
else if MEASUREMENT < T_Low then
    Measurement_Status = "Low Glucose";
    SAVE (Date, Time, Measurement, Measurement_Status);
    CALL PROCEDURE LOW_GLUCOSE_QUESTIONNAIRE;
else
    Measurement_Status = "High Glucose";
    SAVE (Date, Time, Measurement, Measurement_Status);
    CALL PROCEDURE HIGH_GLUCOSE_QUESTIONNAIRE;
end if
while Ttime > 0 do
    WAIT;
end while
```

If the result of the questionnaire is "Negative", the patient is considered as conscious. In this case, the patient's smart device transmits this information to the Cloud. Also, the measurement status is set to Low Glucose and the smart device stores the measurement value, along with date/time information and the measurement status. On the other hand, if the result of the questionnaire is "Positive", the patient is considered as unconscious. In this case, the patient's smart device obtains the patient's geographical position using its GPS and transmits the coordinates to the Cloud.

Algorithm 2 The pseudocode of the Low Glucose Questionnaire.

```
PROCEDURE LOW_GLUCOSE_QUESTIONNAIRE
INTEGER Ccount = 0;
BOOLEAN Answer;
PRINT ("Do you feel sweating and/or nausea?");
READ Answer;
if Answer = TRUE then
    Ccount = Ccount + 1;
else
    PRINT ("Do you feel tachycardia and/or shivering?");
    READ Answer;
    if Answer = TRUE then
        Ccount = Ccount + 1;
    else
        PRINT ("Do you feel drowsiness and/or diplopia?");
        READ Answer;
        if Answer = TRUE then
            Ccount = Ccount + 1;
        else
            PRINT ("Do you feel spasms?");
            READ Answer;
            if Answer = TRUE then
                Ccount = Ccount + 1;
            end if
        end if
    end if
end if
if Ccount = 0 then
    TRANSMIT_TO_CLOUD (Measurement && Measurement_Status);
else
    GET GPS_Coordinates;
    TRANSMIT_TO_CLOUD (Measurement && Measurement_Status &&
    GPS_Coordinates);
end if
```

Accordingly, if the measured glucose level is High, then the patient's smart device displays the questionnaire for High Glucose to the patient (Algorithm 3). Similar to the Low Glucose Procedure, the patient has to answer all questions

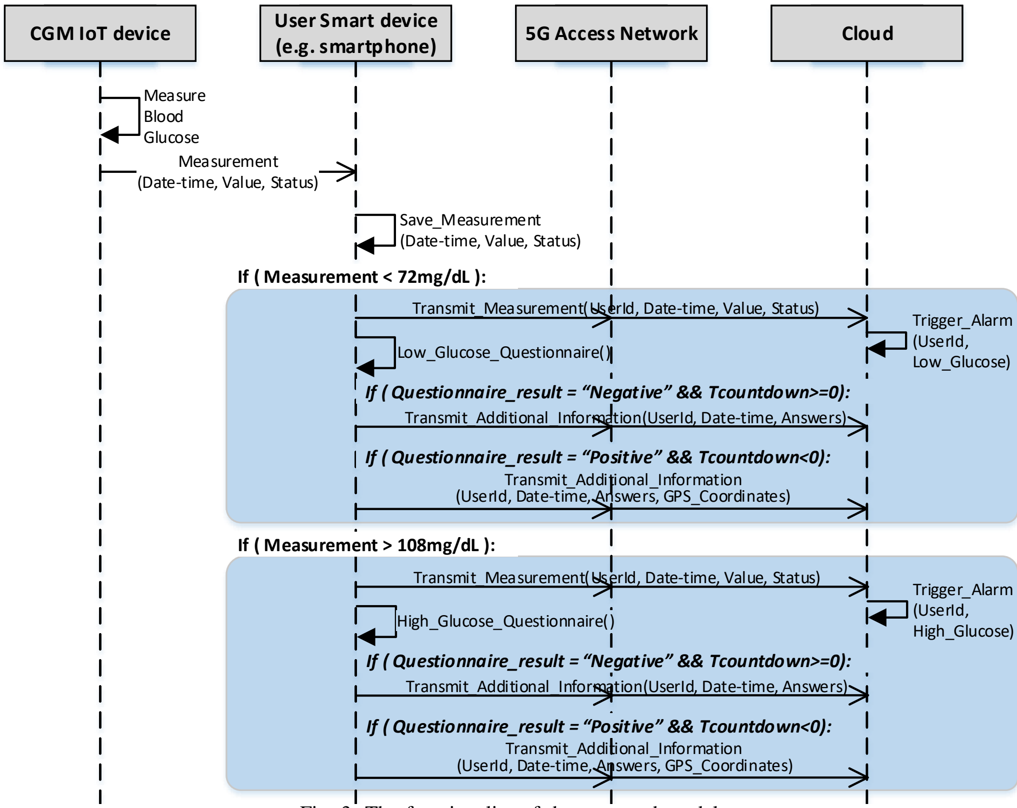

Fig. 3: The functionality of the proposed model.

in $T_{countdown}$ = 60 seconds. As in the case described in the previous paragraph, if all answers are negative and within the time frame, the result of the procedure will be "Negative". Accordingly, if at least one answer is answered positively or the time frame of one minute expires, the result of the procedure will be "Positive". If the result of the questionnaire is "Negative", the patient is considered as conscious. In this case, the patient's smart device transmits this information to the Cloud. Also, the measurement status is set to High Glucose and the smart device stores the measurement value, along with date/time information and the measurement status. On the other hand, if the result of the questionnaire is "Positive", the patient is considered as unconscious. In this case, the patient's smart device obtains the patient's geographical position using its GPS and transmits the coordinates to the Cloud.

The entire communication between the smart device and the Cloud is performed through a 5G access network infrastructure to ensure minimal communication delays, which can be considered critical since important health information must be delivered. The 5G access network consists of LTE and WiMAX Macrocells and Femtocells, as well as WAVE RSUs. Also, a Software Defined Network (SDN) controller provides centralized control of the entire system. The aforementioned process is presented in figure 3.

Algorithm 3 The pseudocode of the High Glucose Questionnaire.

```
PROCEDURE HIGH_GLUCOSE_QUESTIONNAIRE
INTEGER Ccount = 0;
BOOLEAN ANSWER;
PRINT ("Do you feel fatigue and/or nausea?");
READ Answer;
if Answer = TRUE then
    Ccount = Ccount + 1;
else
    PRINT ("Do you feel tachycardia and/or retching?");
    READ Answer;
    if Answer = TRUE then
        Ccount = Ccount + 1;
    else
        PRINT ("Do you feel drowsiness and/or hypothermia?");
        READ Answer;
        if Answer = TRUE then
            Ccount = Ccount + 1;
        end if
    end if
end if
if Ccount = 0 then
    TRANSMIT_TO_CLOUD (Measurement && Measurement_Status);
else
    GET GPS_Coordinates;
    TRANSMIT_TO_CLOUD (Measurement && Measurement_Status &&
    GPS_Coordinates);
end if
```

IV. Case Study

This section presents a case study of the proposed model. In order to fulfill the requirements of the discussed case study, the Network Simulator 3 (NS3) [35] has been used for simulating both the Dexcom G6 CGM device functionality and the underlying 5G Access Network architecture. Also, an Android Virtual Device (AVD) [36], which is interconnected with the NS3 simulation, has been implemented representing the patient's smart device.

Initially, the patient sets the time interval for the measurement of his blood glucose levels equal to 30 minutes. Furthermore, for this case study, the *T_Low* and *T_High* thresholds are considered to be equal to 72 mg/dL and 108 mg/dL, respectively. Subsequently, the CGM device starts performing periodical measurements, while each measurement is transmitted to the user's smart device, namely the AVD in this case study. Table I presents an example of obtained measurements. By receiving a new measurement, the AVD checks if it is less than the value of the *T_Low* threshold, or if it is greater than the value of the *T_High* threshold.

TABLE I: Example of measurements.

Id	Date	Time	Measurement	Status
1	12/05/2020	08:00	100 (mg/dL)	Normal Glucose
2	12/05/2020	08:30	145 (mg/dL)	High Glucose
3	12/05/2020	09:00	140 (mg/dL)	High Glucose
4	12/05/2020	09:30	120 (mg/dL)	High Glucose
5	12/05/2020	10:00	105 (mg/dL)	Normal Glucose
6	12/05/2020	10:30	125 (mg/dL)	High Glucose
7	12/05/2020	11:30	100 (mg/dL)	Normal Glucose
8	12/05/2020	12:00	80 (mg/dL)	Normal Glucosel
9	12/05/2020	12:30	65 (mg/dL)	Low Glucose
10	12/05/2020	13:00	100 (mg/dL)	Normal Glucose

Whenever the obtained glucose level is less than the value of the *T_Low* threshold, then the patient's smart device displays the questionnaire for Low Glucose as presented in figure 4. Using his smart device, the patient has answers all questions in $T_{countdown}$ = 60 seconds. If all answers are negative and within the time frame of 60 seconds, the patient is considered as conscious and the smart device transmits this information to the Cloud. Instead, the patient is considered as unconscious and the smart device obtains the patient's geographical position using its GPS and transmits the coordinates to the Cloud.

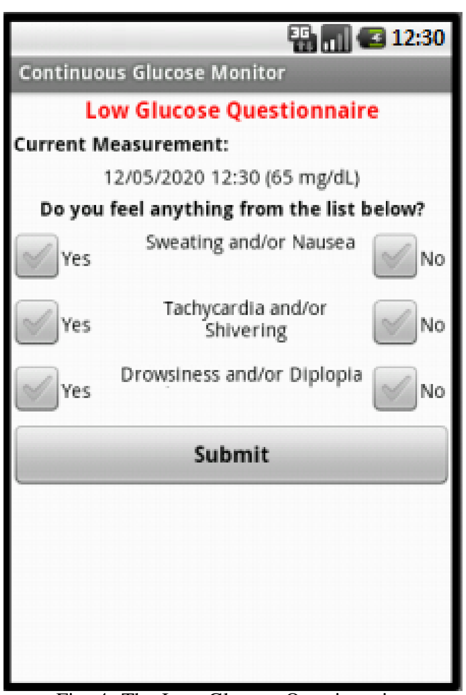

Fig. 4: The Low Glucose Questionnaire.

Accordingly, whenever the obtained glucose level is greater than the value of the *T_High* threshold, then the smart device of the patient displays the questionnaire for High Glucose to the patient as presented in figure 5. Similar to the aforementioned Low Glucose Procedure, the patient has answers all questions in $T_{countdown}$ = 60 seconds, using his smart device. If all answers are negative and within the time frame of 60 seconds, the patient is considered as conscious and the smart device transmits this information to the Cloud. Instead, as in the case described in the previous paragraph, the patient is considered as unconscious and the smart device obtains the patient's geographical position using its GPS and transmits the coordinates to the Cloud.

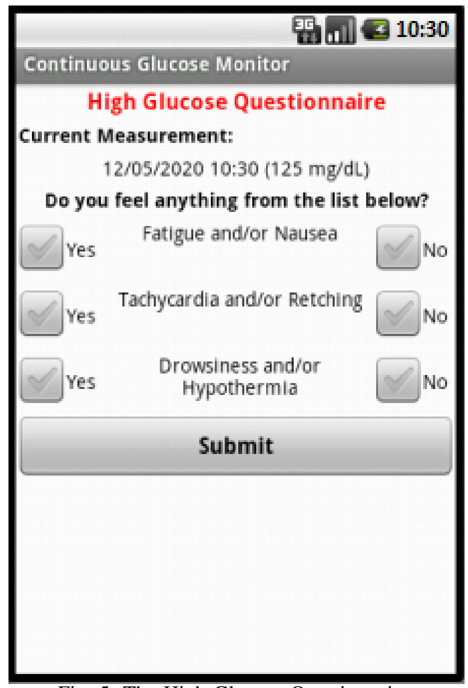

Fig. 5: The High Glucose Questionnaire.

V. Conclusion

In this paper, a model for monitoring the blood glucose levels of patients using a Dexcom G6 IoT device proposed. Specifically, the IoT device periodically measures the patient's blood glucose levels. Whenever a new measurement is performed, the IoT device transmits the measured values to a patients' smart device (e.g. a smartphone). If the patient's glucose levels are Low or High, the smart device communicates with a remote medical infrastructure and triggers an alarm. In order to assure the immediate response of the remote medical staff, the proposed model is deployed upon a 5G wireless network architecture which ensures minimal communication delays. Thus, the medical staff can immediately provide the required care or advice remotely each patient.

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