Fog Data Analytics: Diabetic Patients Monitoring Using Wearable IoT Sensors

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Abstract
Internet of things (IoT) is exceedingly permeating our daily lives and innovative solutions are being proposed to enrich our lives. In this paper we combine wearable IoT sensors and fog analytics to provide a solution for monitoring of diabetic patients. We report our system architecture and our experience in developing and testing a prototype based on this architecture. The system can be generalized into a patient-centric IoT eHealth ecosystem with a multi-layer architecture. There are several challenges related to our diabetics monitoring system such as data management, scalability, regulations, inter-operability, device-network-human interfaces, security and privacy.
Keywords:
IoT, fog computing, health care, diabetics.

1. Introduction

Technology is changing at a rising pace and IoT is one of the recent breakthroughs in the technological field. Nowadays, the idea of IoT is spreading everywhere with plans to embed communications, sensors and actuators in almost every electronic and non-electronic system of daily life. As the IoT paradigm gains momentum, it is being adopted by various industries and the healthcare industry is one of them. Various gadgets, wearables, and other healthcare devices are becoming available in the market, and they can lead to novel and innovative healthcare solutions. IoT based healthcare services are expected to diminish costs, enhance outcomes of treatment, improve disease management, lesson errors and mistakes, upgrade patient experience, and improved management of drugs.

Diabetic patients monitoring is one area that can benefit from the technological advancements in IoT. Diabetes is one of the illnesses that has serious symptoms for both high blood sugar levels (hyperglycemia) and the low blood sugar levels (hypoglycemia). Both the high blood sugar levels and low blood sugar levels can cause immediate emergency situations [1]. Some of these include blurred vision, drowsiness, dizziness, unsteadiness when standing or walking, seizure, loss of consciousness (coma), stroke, and even death [2, 3].

One way to ward off an imminent diabetic attack is to continuously monitor a diabetic patient's blood glucose level and take preventive actions in case of abnormality [4, 5]. Ideally, this monitoring should be non-invasive, non-obtrusive, real-time (rapid), reliable, and accurate [6]. The capability to process the data on-spot is desirable, along with the capability to send the acquired data to another location for further processing, information, alarm generation, and storage. The alarm generation capability should be present on the patient's side and also for service providers that can intervene in cases of emergency.

Furthermore, even though timely alarm generation is very useful for the diabetic person, but his current location must also be made available to the health care providers for any timely intervention. The monitoring of patient locations via GPS, added to glucose level sensing, potentially enables a rapid response to emergency cases. The GPS reading can be sent to a back-end platform via a transceiver situated on the IoT device. The transceiver is a GPRS communications module at minimum requirements. A GPRS module requires a proper SIM card registered with a mobile phone service. The GPRS SIM card requires enough bandwidth to be subscribed for one to send and receive data from and to the sensor part.

The data acquisition can be followed by on-device processing. However, this may be limited due to the limited capacity of the IoT devices. Data needs to be sent to some platform with larger processing and storage capacity. This platform is usually cloud based. However, there exist many challenges in cloud based systems such as latency issue, location awareness and transmission of large volumes of data [7, 8]. As large volumes of data are transmitted over a network, the chance of error is high because data transmission latency and packet dropping possibility are proportional to the volume of transmitted data. In case of emergency, single error in data transmission causes

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inaccurate diagnosis as well as delay in alerting the user which affects the human life. Healthcare applications also require immediate analysis of data and real time decision without any delay which is not possible in cloud computing. One solution is to include a fog layer between the cloud server and the IoT device. In such systems, a first layer consists of IoT based sensors to generate data for further processing on second layer. Second layer is fog layer to pre-process the data which is generated by IoT devices in first layer for real time decisions. Third layer is the cloud layer for storing and processing the data which cannot be processed by fog layer. Use of fog computing in IoT based healthcare system facilitates quality of service assurance and immediate emergency notification.

The proposed fog based system for real time monitoring and analysis of user's blood glucose levels and his physical location addresses the limitations faced by current diabetes monitoring systems. Its primary objectives are:

- Providing remote monitoring of diabetic patients based on their blood glucose levels using the fog computing paradigm.
- Generate immediate diagnostic and emergency alerts to patients.
- Generate emergency alerts and provide patient's current location to health care providers enabling them to take appropriate action on time.

The acquired data is sent to a fog layer rather than being sent to the cloud layer for processing in order to obtain fast and high rate service. In fog layer, the data is processed through a rule based system to classify the patient's situation as normal or abnormal. Once the user is diagnosed, the fog layer will provide diagnostic and emergency alert messages to user so as to take necessary action on time. It will also send the same messages and the user's current location to a designated person (or team) so that help can be provided. The data is also sent to the cloud layer for storage and possible aggregation from the user's past data and data from other users. Thus, the primary novelties in this research are:

- integration of IoT and GPS for patient status and location monitoring, and,
- the use of fog computing for a faster and reliable system.

The next section presents the background of the topic and discusses some previous work. In Section 3, we describe our diabetes monitoring system using wearable IoT sensors and fog based data analytics. Section 4 presents the implementation details of a prototype system, and experimental setup for its validation and performance evaluation. It includes the obtained results and their discussion. Section 5 is devoted to the conclusions drawn from this work and listing of future work.

2. Background and Literature Survey

Diabetes is a group of metabolic diseases in which there are high blood glucose (sugar) levels over a prolonged period. Blood glucose monitoring reveals individual patterns of blood glucose changes and helps in the planning of meals, activities, and medication times. Knowing their glucose levels can help patients in scheduling their meals, activities, and medication.

2.1 Non-IoT based Glucose Level Sensing

Most research applications in glucose monitoring are not based on IoT-based architectures. Correspondingly, doctors or caregivers cannot monitor glucose levels of a patient remotely in real-time. Murakami et al. present a CGM system in critical cardiac patients in the intensive care unit. The system is built by a disposable subcutaneous glucose sensor, a glucose client, and a server. The system collects glucose data four times per day and stores in a hospital information system. Doctors can use the bedside monitor to monitor the glucose data. Ali et al. propose a Bluetooth low energy (BLE) implantable glucose monitoring system. Glucose data collected from the system is transmitted via BLE to a PDA (smart-phone, or Ipad) which represents the received data in text forms for visualization. The system shows some achievements in reducing power consumption of an external power unit and an implantable unit. Lucisano et al. present a glucose monitoring in individuals with diabetes using long-term implanted sensor system and model. Glucose data is sent every two minutes to external receivers. The system shows its capability of continuous long term glucose monitoring. In addition, the system proves that implanted sensors can be placed inside a human body for a long period time (i.e. 180 days) for managing diabetes and other diseases. Menon et al. propose a non-invasive blood glucose monitoring system using near-infrared (NIR). Glucose in blood is predicted based on the analysis of the variation in the received signal intensity obtained from a NIR sensor. The predicted glucose data is sent wirelessly to a remote computer for visualization.

2.2 IoT based Glucose Level Sensing

An m-IoT configuration method for noninvasive glucose sensing on a real-time basis is proposed in [9]. In this method, sensors from patients are linked through IPv6 connectivity to relevant healthcare providers. The utility model in [10] unveils a transmission device for the transmission of collected somatic data on blood glucose based on IoT networks. This device includes a blood glucose collector, a mobile phone or a computer, and a background processor. A similar innovation is found in [11]. In addition, a generic IoT-based medical acquisition detector that can be used to monitor the glucose level is proposed in [12].

The authors of [13] propose a blood glucose level monitoring system based on wireless body area network for detecting diabetes. The system is built by using a glucometer sensor, Arduino Uno, and a Zigbee module. Doctor and caregiver can access to a web-page to monitor glucose levels of a patient remotely. However, the system is not energy efficient due to high power consumption of the Arduino Uno board and the Zigbee module. In [14], the authors introduce a monitoring system for types 2 diabetes mellitus. The system is able to make decision on the statues of diabetes control and predict future glucose of an individual. Obtained glucose data can be monitored remotely by medical staffs via wide area networks.

IoT based remote patient monitoring: Perhaps this is the most dominant and basic idea of IoT for healthcare applications in the market [15]. The basic idea of this category of applications is to monitor a patient against certain symptoms by integrating or plugging in relevant sensors which can read signs suitable for monitoring/diagnosis [16]. Remote patient monitoring has been defined as the applications and devices which help the healthcare providers track and check on the patients remotely. Thus, remote patient monitoring means keeping a check on the patients without being physically present, gather the data and analyze it to propose better ways of treatment to the patients. This approach helps the healthcare provider to keep an eye on their patients round the clock that is checking on them, responding to their requests, and doing a follow up on their health. Thus, IoT enables the healthcare industry to be proactive and suggest the best ways to improve their patients' health by analyzing the information collected by the IoT sensors placed in the environment surrounding them. Remote patient monitoring makes use of technology which is already being used by the patient such as internet, phone, or laptop [17]. Wearable's are also used to collect information from patient. Patients who are using IoT to perform monitoring of their diseases have informed health advice and outcomes in comparison to others [18, 19].

2.3 Novelties of our Proposed System

Although the present systems show their advantages in continuous glucose monitoring, there are still many limitations. For example, some systems do not consider real-time and remote monitoring. while other systems are not able to inform the response team in real-time in cases of emergency. Furthermore, none of them is able to provide the current location of the patient. The main motivation of our research is to provide an advanced IoT-based system for unobtrusive, non-invasive, real-time and remote continuous glucose monitoring enhanced with GPS based location determination. The aim is not only to have real time alarm generation for both patient and health care providers, but also to provide a rapid and efficient response in emergency situations where the patient may be unable to help himself. The use of fog computing paradigm increases the chances of timely and accurate response, even though it assumes the proximity of patient to the response team (e.g. in the same building or same entertainment park). The design is flexible enough and other medical and non-medical modules can easily be integrated.

GPS based location monitoring: IoT applications for emergency response in general have benefited from the streamlined communications and the distribution of information [20]. Rescue teams build on these benefits in operations such as search and rescue, finding unaccounted individuals and pets, checks for wellness for the elderly, and help in food and water delivery to remote locations [21]. As mentioned in [22], authors have shown how to exploit IoT and big data to build a real-time healthcare emergency response system. Moreover, authors in [23] proposed an ubiquitous data accessing method in an IoT-based system for emergency medical scenarios. A semantic data model to store data was developed and a resource-based data access method needed to control the data ubiquitously. Decision-making in emergencies might be improved by this method.

Fog computing based systems: Internet of Things (IoT) devices are flooding the world. In fact, studies show that we can expect over 75 billion IoT devices to be active by 2025 [24]. From smart voice assistants to in-store beacons, brands are experimenting with touch points in a bid to improve the customer experience and collect data in new and inventive ways. The only problem is the massive influx of data being collected from each device. How (and where) can such vast amounts of data be processed? Fog computing is a potential solution. Fog computing is a horizontal, physical or virtual resource paradigm that resides between smart end devices and traditional cloud or data centers. This paradigm supports vertically-isolated, latency-sensitive applications by providing ubiquitous, scalable, layered, federated, and distributed computing, storage, and network connectivity. Fog computing has the basic functionality of pushing both data and intelligence to analytic platforms that are situated either on, or close to where the data originated from, whether that's screens, speakers, motors, pumps or sensors. This is as opposed to carry out the computations in the cloud. The fog technology can help organizations reduce their reliance on cloud-based platforms to analyze data, which often leads to latency issues, and instead be able to make data-driven decisions faster. With fog computing, the data is processed within a fog node or IoT gateway which is situated within the LAN. With data storage and processing taking place in LAN in a fog computing architecture, it enables organizations to aggregate data from multi-devices into regional stores. That's in contrast to collecting data from a single touch point or device, or a single set of devices that are connected to the cloud.

3. Proposed Fog based IoT System

The proposed system for monitoring abnormal blood glucose levels is shown in Fig. 1. It is comprised of three layers, namely, wearable IoT sensor layer, fog layer and cloud layer. Wearable IoT sensor layer collects data in real time from the wearable blood glucose sensor and location sensor. The acquired data is transmitted to the fog layer for real time processing. If an abnormality is detected, the fog layer immediately generates alert to the patient mobile phone and sends alarm signals to the on-place health care team. Analysis results and compiled medical information of each user are also stored on cloud layer for permanence and any long-term analysis. The detailed description of each layer of the proposed system is as follows.

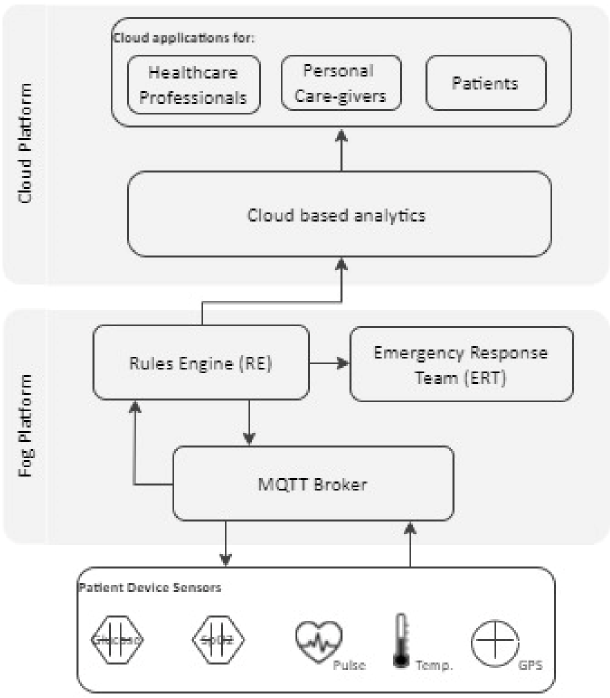

Fig. 1 Proposed system architecture.

Our proposed system has the following features. Patients with diabetes willing to be monitored will have to register in the system to avail the service. Registered patients will put on a wearable device that includes the required sensors. The device is connected to the WiFi network of the premise. The device sends MQTT messages with vital signs and the glucose level of the patient to the fog server via MQTT broker. The rule-engine at the fog server monitors every message and generates alerts to the Emergency Response Team (ERT) and sends alert messages to the patient device if a patient's condition is very critical. The fog server also forwards the MQTT messages to the cloud for further, long term, storage and analytics. The cloud server can host various applications for health care professionals, care givers, and the patient for overall and comprehensive patient management. The following sections explain each component of the system in more details.

3.1 Wearable IoT Sensor Layer

IoT sensor layer is responsible for collecting blood glucose level data and the GPS location of the monitored person. Data are collected from the wireless hardware devices worn by the monitored person. These devices have the capability of sensing and transmitting data in real time.

Health data set in our prototype comprises of only the blood glucose level of user. However, it can be easily scaled to include more measurements by adding appropriate sensors to the strap-on band worn on the user's body.

Location data is the current location of the user. This location is sensed by Global Positioning System (GPS) sensor to get movement history of the user. The system is scalable and the collected data can include environmental data. Furthermore, it can be combined with the health record of the patient and meteorological data of the city. For example, medicinal data that includes medication procedure of the patient can be acquired through RFID tags. The data may comprise of medicine name, medicine form, quality and ingestion time of the medicine. Such data are usually found in the prescription and can be added to an RFID card.

Patient Wearable Devices (PWD): A patient wearable device consists of several components. These are discussed below.

Location Sensor: location sensor uses GPS signal and available WiFi signals to identify patient's location within the premises. It sends MQTT messages with the geographical coordinates (and indoor location) of the patient or the last known location when location signals are not available.

Continuous Glucose Monitoring Sensor (CGM): CGM sensors are typically inserted under the belly or arm skin of the patient and are attached to a transmitter to send signals. The glucose readings are taken continuously throughout the day and transmitted to the PWD.

Vital Signs Sensors: this sensors are body temperature, heart rate, and oxygen saturation (SpO_2) level. The sensor probe is attached to the patient's body and the data is transmitted to the PWD.

MQTT Client (Publisher): The sender module combines all the sensor readings into a single MQTT message payload and sends to the MQTT broker along with the patient ID and a time stamp.

MQTT Client (Subscriber): The MQTT receiver module subscribes to the patient ID and listens for any alarm messages sent by the Rules Engine (present in the fog layer). Upon receiving an alarm message the PWD sets off a beeping sound to alert the patient about a possible hypoglycemia attack which needs an emergency care.

MQTT Broker: MQTT broker is responsible for passing messages between the PWD and the Rules Engine of the fog layer. It subscribes and publishes messages for individual patients.

3.2 Fog Computing Layer

Fog computing layer acts as a bridge between IoT sensors and cloud computing layer. Usually the server(s) forming the backbone of this layer are in proximity of the persons being monitored. An office building and the office employees, a school and the students, a theme park and the visitors, and a hotel and the guests, can be examples of the relationship between the physical entity and the users. The layer is used for real time processing and analysis of accumulated data from IoT based sensors. It sends immediately real time notification or alert to user about current category of user as possibly in-trouble or out-of-trouble. This system is further connected to cloud layer for storing, analyzing results and compiled medical record of each user. Fog computing layer consists of two components: user health status classification, and alert generation. The detailed descriptions of the components are as follows.

User health status classification: Classification is an important tool for taking decision in various medical diagnoses. This component provides a diagnosis by classifying the monitored persons using a rule based expert system classifier as possibly "in-trouble" or "out-of-trouble".

Alert generation component: Alert generation component is responsible for immediately sending alert messages on user's mobile and also to health care response team. The monitored person's alert comprises of a loud warning with a few simple instructions that he should follow. Whereas, response team's alerts not only have all the relevant data (personal identification and medical data) about the monitored person and his current location. The response team will have information about nearby hospitals depending upon the location of user. The same information can be transmitted to the user's mobile, also. These alerts are also stored on cloud storage for any immediate or future use.

The descriptions of the modules in the fog layer are as follows:

Rules Engine: The rules engine subscribes to the individual patient's "Readings" topic. When it receives an MQTT message (in JSON format) it parses the message and applies a list of rules to generate Alarms and Warnings based on preset thresholds. The outputs are in three categories:

a) Emergency: For conditions which require immediate actions such as hypoglycemia, an MQTT message is immediately published to the patient's "Alarm" topic and a visual alert is generated for the emergency response team.
b) Warning: Conditions which do not command for immediate action such as fever, high heart rate, etc. Only visual alert is generated.
c) Healthy: In case all the readings fall within the specified threshold limits, the patient is considered healthy and no warning or alarm is generated.

Dashboard: Dashboards are designed for the emergency response team to monitor the patients' health conditions in real time. The dashboard displays the sensor readings and locations for all the patients with appropriate color codes corresponding to the alert level. Every dashboard component can be zoomed in to a single patient level to view the details of that particular patient's condition. In addition to visual alerts, notifications can be sent to mobile devices of emergency response team personnel in case of emergency alarms.

3.3 Cloud Layer

Cloud layer is responsible for storing and processing the data which need not be processed by the fog layer. It consists of three components namely; cloud storage, information analytics, and health communication. The following paragraphs discuss these components.

Cloud Storage: The objective of cloud storage is to store information related to the continuous monitoring of glucose levels of all patients including any alerts generated and details of subsequent intervention by a response team. It consists of huge amounts of storage to store analysis results and compiled medical information of each user and securely share among authorized medical staff, users, pharmacies, hospitals and healthcare professionals. Diagnostic and emergency alert messages generated from fog layer are also stored on cloud storage for further analysis by experts to take immediate action and provide precautions in case of emergency. Cloud storage component stores personal and health details of the user. It has three levels.

Level 1 (highly sensitive – one time): personal data such as age, name, gender, mobile number and residential address.

Level 2 (highly sensitive - continuous): consists of blood glucose levels including the patient's circumstances. They can be aggregated and summarized for compactness.

Level 3 (highly sensitive - discrete): information about emergency situations and interventions needed.

Information Analytics: The cloud layer acts as a central backbone to a wide array of possible apps that will serve individual patients, their care-givers and health care professionals. All the data generated by the PWD is stored at the cloud in a TSDB. The data can be used for real time monitoring and historical analysis and predictions. For example, a patient's care-giver or family doctor can view the historical records for the past one month and recommend treatments if required.

Health Communication: This component is used to send informative and motivational messages regarding diabetics control and management to all users. System will generate these health education messages to user via instant message or e-mails.

The health information, reminders and suggestions can be sent repetitively to user's mobile phone to improve knowledge of preventive measures which may lead to reduction in diabetic emergency risk.

3.4 Network Architecture

The network architecture consists of the following layers:

Layer 1 or Patient's Body: The architecture includes personal sensor network of wearable sensors connected to a transmitter device. Ideally, it can be the smartphone or any other similar devices. The sensors will be connected over blue-tooth or short range 2.4G wireless connection.

Layer 2 or Patient's Device Network: The PWDs will be connected via infrastructure's WiFi network to the MQTT Brokers. When the number of PWD is large, they can be clustered under multiple MQTT brokers for efficiency.

Layer 3 or Server Layer: The MQTT broker and the fog server are on the same LAN which will be in turn connected with the cloud infrastructure over public network.

4. Implementation and Experiments

This section illustrates the system implementation and performance evaluation.

4.1 Device Implementation and Data Acquisition

A two fold approach was adopted. First, we implemented a prototype of the device (with actual sensors and related software) for sensing of blood glucose levels (Fig. 2 and Fig. 3). The prototype provides data of two types. First, the data depicting glucose levels and second, GPS data. These data are sent to the fog layer from the prototype. However, the prototype alone does not satisfy our experimental needs due to two reasons. First, the quantity of device prototypes is limited and we wanted to observe the behavior of our system when it comprised of several dozen devices (scalability). Second, the data for testing the accuracy of the Expert System has to be of sufficient variety to cover the different possibilities. This led us to develop a simulation part.

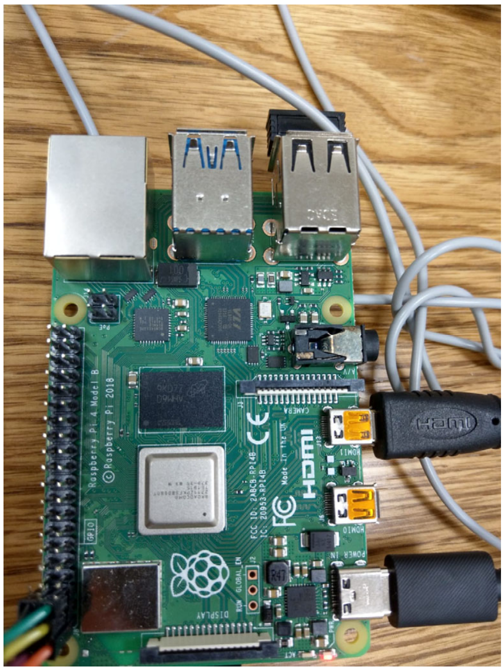

Fig. 2 A few parts of implemented system prototype.

Data simulation: We have utilized the online simulation website AIDA for blood glucose data generation. The website provides readily available choices for simulating glucose levels of diabetes patients. The simulated data can be further modified to fit different diagnosed cases and their relative doses and meals in a 24-hour time span. The glucose level is sampled every 15 minutes for a total duration of 24-hours. Glucose levels data simulated for this application has been downloaded from the website for 30 different cases. At least some cases of high and low severity glucose levels are included in the simulation data. AIDA's glucose level samples are uploaded to a relational database that we have developed for this purpose. The first field carries typical IDs of glucose level entries. The second field carries the timestamp of the glucose levels data acquisition. The fourth field is the actual glucose level of the patient.

Each patient's data is stored in a separate table for him/her. We interpolate uploaded data in the MySQL database into intervals of 1-minute. Thus, the 15-minutes samples are increased to 1-minute samples. Two points of glucose level samples separated by a 15-minutes interval at a time are used to generate 1-minute samples of linearly interpolated data between the two sampled points. That is 13 samples between every two points of the MySQL table. The entire 24-hour set of glucose level data is interpolated in this way.

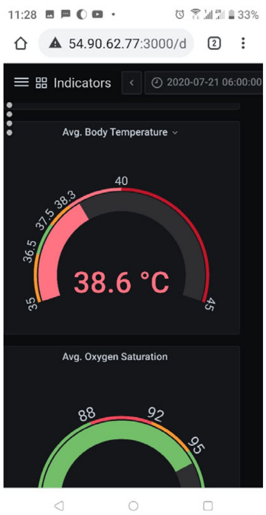

Fig. 3 Visual part of the prototype.

GPS data were generated using Geo MidPoint which gives simulated GPS data based on some seed input. Our goal here is to generate random paths or set of points which simulate data from outputs of GPS devices carried by the users being monitored. In our experiments, the movement is restricted to a 1 km circle (due to the emphasis of fog's proximity to user). Initial latitude and longitude values have to be given to generate simulated GPS data. The GPS data is uploaded into the MySQL database and combined with the glucose levels data.

After developing the Node-RED modules, the data which was saved in MySQL is to be sent to it, sample by sample, looping after every 60 seconds. This forwarding of the simulated data from the MySQL database to the Dashboard via different MQTT channels simulates data acquisition from several IoT devices.

4.2 Data Processing in the Fog Layer

We developed an Android app through which patients can use this service at various participating offices, malls, parks, etc. A once-only registration for the service is required. The patient can then use the service wherever it is offered. The app connects the user with the on-place fog layer and the associated emergency response team. Data received from the devices is given as input to a rule based expert system. The data for each user, for each time interval, is categorized as normal or abnormal.

We also developed a rule based Expert System. The Expert System, is implemented on an Intel i7 CPU at 2.50 GHz with 4 GB memory using Matlab running on Windows 11.

The proposed system is examined for determining the validity of alert generated on user's diabetic condition. The main aim for statistically analyzing the efficiency of alert generation component is to verify the false positive alerts. Various other statistical parameters are also considered for this purpose, such as sensitivity, specificity, precision, coverage, mean absolute error, root average square error, root relative squared error and relative absolute error. Statistical parameters indicate that proposed system is highly accurate and effective as the low value of false positive alerts. Moreover, less error rates also enhance the utility of alert generation method.

We compared our rule based Expert System (rules induced by Decision Tree algorithm) with a back propagation based NN (Neural Network) using the same data. The rules based classifier has higher accuracy and has the advantage of rules being validated and verified with the help of available medical expertise.

4.3 Data Transfer to the Cloud Layer

Since the storage capacity of fog layer is limited, we transfer the data to the cloud layer for long term storage. Joint analytics with data obtained from other fogs is done on the fog layer.

6. Experiments and Results

Fog computing provides computation and communication services in the close proximity of end users. Only higher level, processed data is sent to the cloud layer. It reduces the volume of data transmitted over network which leads to less traffic resulting in low latency rate and ultimately less power consumption. But in case of cloud computing, large amount of data is transmitted to cloud server for processing which leads to higher traffic congestion over network. This has an adverse effect on response time and power consumption rate.

We set-up an empirical study using the simulated environment to investigate the benefits of our fog centric topology over a cloud centric topology. Our experimental set-up is described in the following paragraphs.

Patient's device receives sensor readings from various sensors and publish them in JSON payload as MQTT messages. The devices are simulated by containerized devices running a minimal implementation of Linux operating system. Each device hosts node.js to run javascript for publishing and receiving the MQTT messages. The java scripts are CSV data sources.

We designed 13 hypothetical test cases with different health conditions to simulate different health conditions in real life patients (Fig. 4).

MQTT messages are formed by concatenating the sensor reading from the PWD into a single JSON payload as it is expected to be done in the actual system. The messages are published in 5 second interval to the MQTT broker.

Mosquito MQTT is used as the MQTT broker. It is configured to subscribe to messages on Topics. The broker also publishes all the incoming messages on their respective topics. On the fog server a NodeRed instance receive all the incoming MQTT messages and parses the included JSON payload. The data extracted from the JSON payload is then fed to rules engine and visualization dashboard. The rules engine determines the severity level of each measurement according to predetermined threshold levels.

We have setup three cloud-centric systems with the same functionalities. All the three systems has the same architecture but have been setup on three different cloud service providers: Microsoft Azure, Amazon AWS, and Google Cloud. Our purpose is to compare the performance differences with our fog based system.

The classification execution time (testing time) is important and when combined with the transmission time to cloud, highlights the advantage of using the fog for processing and analysis. The graphical trend shows that proposed system through fog computing layer identifies category of user as possibly normal or abnormal with less time than through cloud computing. It is because fog computing provides various resources such as compute, storage and communication in the close proximity of patients as compared to cloud computing. It also avoids unnecessary flow of raw information from patient user to cloud server while processing and sharing the information. Efficiency of alert generation mainly relates to the effectiveness of diabetic emergency diagnosis in the generation of timely and true alerts through fog computing.

These alerts are based on total number of alerts and evaluate alert generation in terms of delay to deliver information to the patient and response team. Delay time is calculated between time to deliver alert about the occurrence of event to patient (and response team) and time at which event occurred. As a comparative model, cloud based alert generation to patients (as well as response team) are compared with fog based alert generation in terms of response time. The results show that real time notification from fog system is far efficient as compared to the notification from cloud with low value of delay during the occurrence of any abnormal or emergency situation.

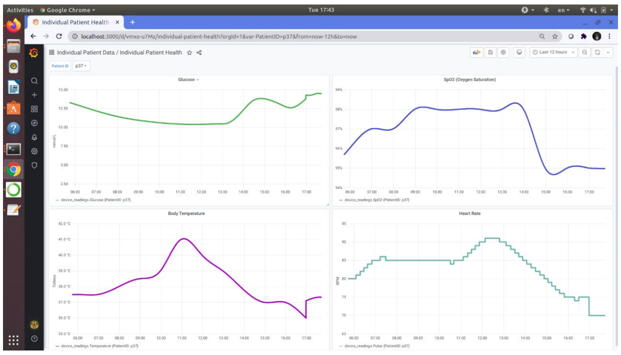

Fig. 4 System dashboard for a single patient.

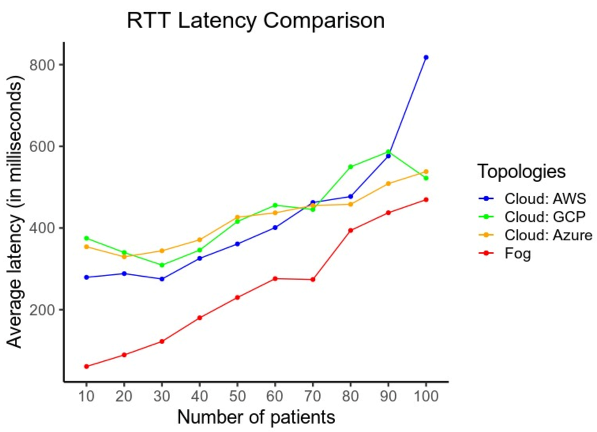

Fig. 5 Two way message latency comparison.

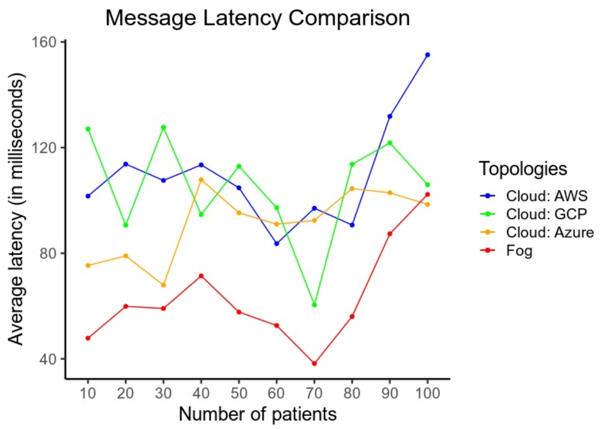

Fig. 6 Message latency comparison for different topologies.

The fog and cloud based systems were compared in terms of message latency. Message latency is measured as round trip latency and one way latency. Fig. 5 compares the average RTL of all the four environments. Our fog based system demonstrated the lowest latency in comparison to all cloud based setups. The fog based system demonstrated its superiority in terms of one-way latency as well. Fig. 6 shows the one way latency measured for all the system.

5. Conclusion

In this research we have demonstrated the methodology, design and implementation of a fog based glucose level monitoring system for patients with diabetics. The system consists of two main parts, a simulation of IoT device and a dashboard. The simulation of IoT devices include a glucose levels chart, GPS locations data and a glucose level severity card via MQTT channels to the dashboard. The dashboard displays the glucose levels chart, glucose severity levels and patient positions. Alerts for severe glucose levels are sent to the real-time dashboard and on email as part of the dashboard environment, which are used to supply the emergency team with an extra channel of alert.

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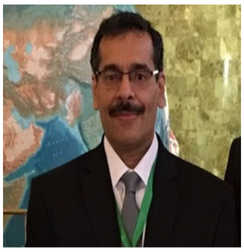

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