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A Review on IoT based m-Health Systems for Diabetes

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***Abstract*—This paper presents a review of the latest mobile health applications based on Internet of Things that are used for diabetes management. Diabetes is a group of metabolic diseases in which there are high blood sugar levels over a prolonged period. Long-term diabetes care requires involvement from patients as well as doctors and family caregivers. With rapid advancements in wireless and web technologies, a number of applications based on Internet of Things have been proposed for management of diabetes. Most of these applications focus on patient monitoring and technology-based decision making. We analyze the working and underlying architecture of these latest applications and discuss the major issues and challenges faced by them. The main objective of this paper is to help researchers in designing advanced applications for diabetes management.**

***Index Terms*—Diabetes, Health Applications, Internet of Things, Issues, Challenges and Survey**

I. INTRODUCTION

DIABETES is a metabolic disorder that is characterized by high blood glucose and either insufficient or ineffective insulin. Diabetes leads to blindness, renal failure, amputation, heart attacks and stroke. It is the third leading cause of death in many developed countries. It is estimated that in 2010 there were globally 285 million people (approximately 6.4% of the adult population) suffering from this disease. This number is estimated to increase to 430 million in the absence of better control or cure. An ageing population and obesity are two main reasons for the increase. Furthermore, it has been shown that almost 50% of the putative diabetics are not diagnosed until 10 years after onset of the disease; hence the real prevalence of global diabetes must be astronomically high. Diabetes is broadly classified into two: insulin – dependent diabetes mellitus (IDDM) or Type I and non-insulin dependent diabetes (NIDDM) or Type II. Type I diabetes mainly occurs in childhood particularly between 12-15 years age. Type II diabetes is the most common accounting to 80 to 90% of the diabetic population. NIDDM occurs in adults (usually above 35 years) and is less severe than IDDM.

Diabetes is curable when it is diagnosed before reaching the danger zone; otherwise it becomes a serious issue. There is a need to continuously monitor the blood glucose level to keep this disease at bay. Daily meditation and regular diet will keep the disease under control. Recent research indicates that using diabetes self-management systems help to control glycaemia and associated blood glucose levels. For this reason, software solutions have been defined for monitoring and modelling of blood glucose. Since these solutions have the restriction of dependence on a PC, different kinds of solutions closer to the user are being defined such as glucometers integrated in digital photography and in cellular phones, i.e., mobile Health solutions (m-Health). In recent years, extensive research work and system addressing the design and development of m-Health-based diabetes management systems have been witnessed.

Internet of things (IoT) [1]-[4] is one of the major communication advances in recent years that links the internet with everyday sensors and working devices for an all-IP-based architecture, linking physical and virtual objects through the exploitation of data capture and communication capabilities. It is a network of ubiquitous devices or things that are capable of computation and communication over the Internet. Internet of things architecture will offer specific object identification, sensor and connection capability as the basis for the development of independent cooperative services and applications. Utilizing the power of wireless ad hoc [5]-[8] and sensor networks [9] and latest technologies like fog computing [10] smart devices IoT is redesigning modern health care with promising technological, economic, and social prospects.

Over these years a number of healthcare applications [11]-[16] based on IoT have been proposed for diabetes management. This paper surveys the latest IoT based healthcare applications for diabetes management and reviews the working and underlying architectures. The paper discusses the major issues and challenges faced by them that include technological issues, safety, and security, privacy, and trust, leading to new insights and research directions in IoT. The main objective of this article is to help researchers in developing much more advanced and efficient IoT based healthcare applications for diabetes management. The paper is

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organized as follows. Section II discusses the working and architecture of the latest diabetes management applications based on IoT. Section III presents the major issues and challenges existing in these latest applications. In the next section we conclude the paper with possible solutions to the problems and new research directions.

II. M-Health Systems For Diabetes Based On Internet Of Things

A. Web Based Services and Sensors [17]

One method proposed to manage diabetes remotely is by using a web service that provides low cost global connectivity between the patient's personal device and the patient's web portal and updates the personal details, drugs remainder and the blood sugar level. When there is an increase, an automatic update is sent by a phone call or an SMS to the personal doctor.

One of the popular technologies used is a Sensor Support system for Diabetes Patient Monitoring. This service facilitates registration of new members, people with diabetes, their family members, or anyone else with an interest in the disease. The user has to fill the registration form with their private information and choose the account's username and password. Once the information is conformed and the registration is successful, the user can login and use the opportunities that other services offer. Management of the user profile entered during the registration is mandatory. It is important to enrol their sensor reading automatically. The sensors have to be attached with the diabetes patient and the RFID tag that has to be connected with the patient's hand. The patient must be in their home or in a hospital that has to be monitored wirelessly with the IoT. Different sensors used in this technology; Arduino-it is a microcontroller which is open source electronics to make things more flexible and more accessible to develop the multi-disciplinary projects*;* E-health Sensor Platform-it allows arduino to perform biometric and medical applications where the body monitoring is needed by using different sensors based in their needed*;* Body Temperature Sensor-Used to measure the current temperature of the body*;* Pulse and Oxygen in Blood Sensor (SPO2) – used to measure the pulse level and amount of oxygen content available in blood*;* Glucometer sensor- It is a medical device for determining the approximate concentration of glucose in the blood. A small drop of blood, obtained by pricking the skin with a lancet, is placed on a disposable test strip that the meter reads and uses to calculate the blood glucose level.

The Blood Pressure sensor, Glucometer Sensor, Pulse and Oxygen Sensor, Body temperature sensor must be connected with the body of the patient and the corresponding readings have to be monitored using the arduino and E-Health Sensor shield. Every time the user logs into the web page, it has to verify the login id and password using RFID tag. Then the measurements are automatically updated. The readings are measured by the sensors that are fixed on the body which communicates using IoT technology. The sensors are deployed in the diabetes patient by using the arduino and

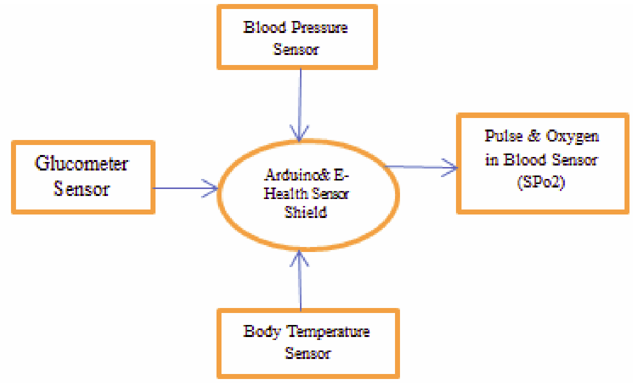

Figure 1. Sensors deployed for diabetes management [17]

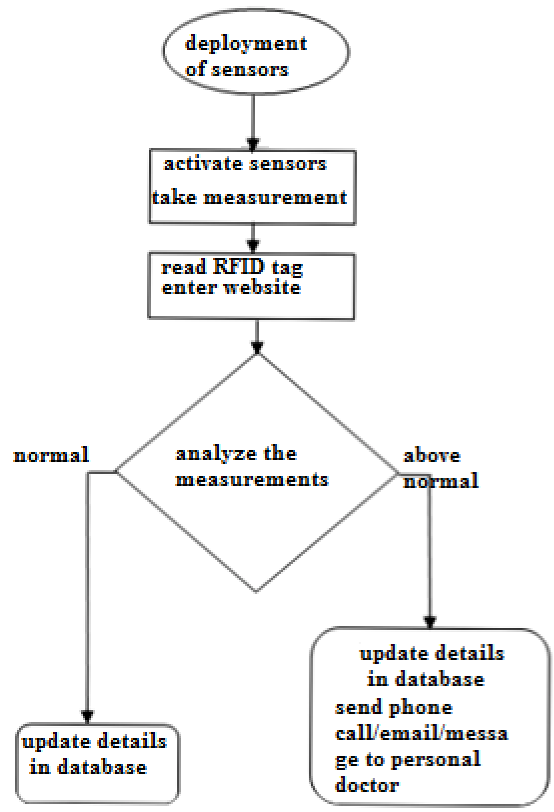

Figure 2. Architecture of Sensor support for diabetes management [17]

E-health sensor shield, the measurements taken from the diabetes patient and then compared with the database and finally the observed reading is analyzed; normal, then update; above the normal level, it will automatically send a message and the phone call to the personal doctor to the patient. Then the collected information is updated into the website for Diabetes patient management.

B. Robot Assistant in Management of Diabetes Based on the Internet of Things [18]

This system presents a new e-Health platform incorporating humanoid robots to support an emerging multidimensional care approach for the treatment of diabetes. The architecture of this technology extends the Internet of Things (IoT) to a web-centric paradigm by utilizing existing web standards to access and control objects of the physical layer. This technology platform is based on policy-aware IoT objects with the following design dimensions; Awareness – understands to what extent the patients' activities comply with their individual treatment plans; Representation – applies a set of rules on patients' data streams and extracts useful summaries and health indicators such as blood glucose (BG) patterns, insulin bolus calculation, and patients' categorization depending on attributes of their health conditions; Interaction – uses accumulated data stored in the patient's electronic medical record to create reminders, warnings messages, and appropriate health advices when self- management outcome deviates from pre-specified targets.

This e-Health platform has two main components; capillary networks and a web-centric disease management hub (DMH) for patients monitoring and disease management. The long-range connectivity between these components is performed through a wireless local area network (Wi-Fi) linked to an existing network infrastructure (the Internet). Each capillary network comprises a set of medical sensors (blood glucose monitor, blood pressure & pulse rate monitor, and weight scale), and an existing humanoid robot. The medical sensors are linked to the robot through a personal area network in which the robot acts as a master Bluetooth device. The robot at each capillary network also acts as a conduit between the patient and his/her medical sensors from one side and the DMH and caregivers from the other side.

The architecture of the software used has three main components; system, database, and applications. System – refers to the core classes, configurations and service libraries that provide a skeleton. Database – represents both local and centralized storage for the robots of the capillary networks and the DMH, respectively. Applications – refer to the modules that handle various functionalities including human objects.

Application modules of the robot are devoted to handle all day-to-day interactions with the patient and his/her medical sensors from one side and the DMH from the other. It's module include Data collection, Dialogue handler, Event handler, Network handler, Security handler and Database. The platform is driven by the technology support needs of an emerging multidimensional care approach for diabetes. This platform offers the tools necessary to fulfill this need over a distance and thus avoiding the place and time restrictions of the face-to-face clinic visits. For patient monitoring a DMH dashboard is used, that provides a single-page summary for patient's health profile. It also provides access links to all key platform applications such as treatment plan, dialogue wizard, diabetes diary, BG patterns, and other applications. Patient-robot dialogues support patients' empowerment and motivation towards healthy lifestyle and improved BG control. These dialogues are created by specialist clinicians and saved into a dialogue library at the DMH that is made accessible to all caregivers. The dialogues in this library can be assigned to patients as required, depending on their individual needs to support the disease management process. During the dialogue execution, the robot may also communicate with the DMH server to exchange data/messages between the local and remote database.

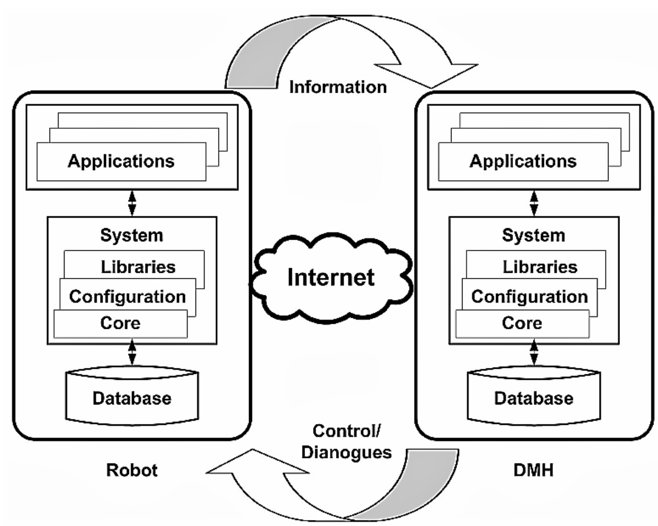

Figure 3. Architecture of the humanoid based e-Health System [18]

C. Smartphone Based m-Health System [19]

This system presents a new Internet of Thing (IoT)-based platform to support self-management of diabetes. This mobile health (m-Health) approach allows for multiple care dimensions of diabetes by means of remote collection and monitoring of patient data and provision of personalized and customized feedback on a smart phone platform. Such support to self-management of diabetes enables real-time clinical interaction and feedback tailored to the personal needs of the patient, utilizing current and historical patient data. The platform understands to what extent the patient's activities comply with their individual treatment plans, deriving rule based health indicators, and generating appropriate warnings and support in terms of feedback advices. The physical layer of the platform incorporates wireless nodes; each of which encompasses a set of medical sensors linked wirelessly to a mobile device. The physical layer nodes are linked to a Web based application layer through an existing telecommunication infrastructure.

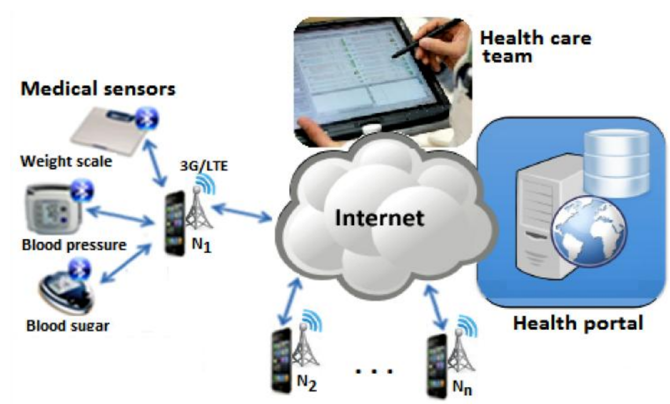

Figure 4. Architecture of the smart phone based e-Health System [19]

Technical architecture of the proposed platform comprises a physical objects layer, a web health portal, and a network layer as shown in Figure 4. The development methodology of the platform was based on the evolutionary rapid-prototyping approach in which, the users (i.e. patients and clinicians) were engaged throughout the development lifecycle. Architecture of the platform comprises three layers; physical objects, network, and a remote web-based layer, called health portal.

The Physical Objects Layer layer performs the communications between people and device objects as well as between objects and other objects. It involves several medical sensors (blood glucose monitor, blood pressure, pulse rate monitor, and weight scale) and a mobile device (e.g., smart phone). All these devices communicate via Bluetooth connectivity. The smart phone, which acts as a master Bluetooth node for one piconet of medical sensors, plays a key interface role between this layer and the health portal applications. It also acts as an access terminal for patient's interactivity with the platform. The Network Layer is represented by the long-range connectivity between the physical layer and the Web health portal. It is based on existing GSM network (3G/LTE) and/orWi-Fi network linked to the Internet. The Health Portal layer represents the application layer of the platform that is built on top of the Internet. It interfaces the various objects of the physical layer to other objects (e.g. health care professionals, hospitals, and other systems). It is also responsible for remote data collection and storage, data processing and monitoring, and making decisions based on constraints specified by individual patient treatment plans.

D. An IoT-Based Personal Device for Diabetes Therapy Management in Ambient Assisted Living [20]

Diabetes therapy management in AAL environments, such as old people and diabetes patient's homes, is a very difficult task since many factors affect a patient's blood sugar levels. Factors such as illness, treatments, physical and psychological stress, physical activity, drugs, intravenous fluids and change in the meal plan cause unpredictable and potentially dangerous fluctuations in blood sugar levels. Therefore, right insulin infusion calculation needs to be supported by the next generation of personal-care devices. For this reason, a personal device has been developed to assist and consider more factors in the insulin therapy dosage calculation. The system is based on Internet of things in order to, on the one hand, support a patient's profile management architecture based on personal RFID cards and, on the other hand, provide global connectivity between the developed patient's personal device based on 6LoWPAN, nurses/physicians desktop application to manage personal health cards, glycemic index information system, and patient's web portal.

This system presents a personal diabetes management device based on Internet of things, in order to provide a new generation of mobile assistance services and consider more of the mentioned factors for insulin therapy, in order to reduce the number of the patient hyperglycemia and hypoglycemia episodes and consequently their risks. This personal device supports 6LoWPAN connectivity in order to link the personal device with the developed home gateway [19], RFID identification in order to load patient's profile from the personal health card, serial communication based on RS232 and IrDA to connect the glucometers from different vendors, and a color touch screen to interact with the patient. In addition, this personal device is complimented with a glycaemic index information system (with more than 2,600 indexed products and growing) to provide information about the impact in the glucose of the diet, a desktop application for nurses/physicians to configure and review the patient's personal health card based on RFID, a web portal for online patients and specialist management, and finally, this personal device is complemented with an application layer based on artificial intelligence to define an adaptive insulin therapy for the patients.

E. Context Aware m-Health system [22]

Diabetes is currently an incurable disease which requires long term treatment and care from patient and his caretakers. This new system provides a two-way communication between patient and the health professionals using Internet of Things technology. This system lets patient upload their blood-glucose readings to the system database and the abnormalities in these readings are monitored by both health professionals and caretakers. System consists of a glucometer General Packet Radio Service (GPRS), Blood-Glucose Monitor (BGM) which is used to get the readings from patient, a telecare android and iOS application for caretakers for communication between patient, health professional and caretaker and a cloud server through which all these readings are monitored. The cloud server is the core of the system as it stores patient's data and permissions from authorized caretakers. It also includes Abnormal Blood-glucose Level Detection (ABLD) and a Proactive Notification Engine (PNE). GPRS BGM is an android based two-way communication device. Blood-glucose readings are collected via GPRS BGM in different timings (before/after meals, at morning and so on) and these readings are uploaded to the cloud server using GPRS protocol and XML format. Telecare application offers remote assistance to patients by providing

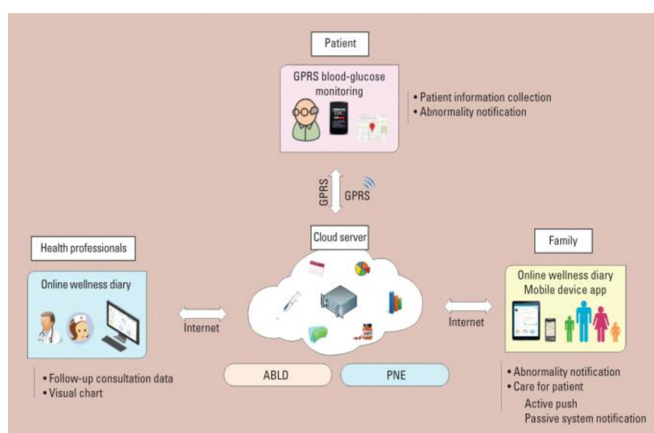

Figure 5. Interactive mobile health service (ImHS) architecture [22]

the data of patient's blood-glucose readings to caretakers. This helps caretakers to keep track of patient's condition and if any abnormality is found then caretaker can take necessary actions as per the advice of the health professionals.

Cloud server is the core of ImHS and integrates all the components and end users. All the data uploaded by patient are stored and then the health professionals can access the patient profile through the cloud server which provides a user friendly interface (UI) with all data regarding a patient (current reading trends, historical reading trends, etc). The cloud server is also responsible in detecting abnormal readings using ABLD, it is divided into two categories blood-glucose abnormalities and scenarios in which measurement data is not received on schedule. Blood-glucose abnormalities are divided into five levels:-Level 0: Normal state; Level 1: Minor abnormality, only requires observation; Level 2: Moderate abnormality, requires hospitalization.; Level 3: Indicate danger, risk of coma or unconsciousness.; Level 4: Indicate most dangerous scenario, patient could become unconscious. Blood-glucose readings taken are classified into seven:- Low 3- Less than 20 mg/dl; Low 2- Between 20 and 69 mg/dl; Low 1- Between 70 and 99 mg/dl; Normal- Between 100 and 162 mg/dl; High 1- Between 163 and 299 mg/dl; High 2- Between 300 and 600 mg/dl; High 3- More than 600 mg/dl. Blood-glucose abnormality rule engine is used to identify and handle abnormalities. Proactive Notification Engine (PNE) is used to send message to both patients GPRS BGM and caretaker regarding readings and uses ABLD to check abnormalities and take necessary actions. PNE also sends remainders for patients to take readings and alerts caretaker if patient does not take reading as per schedule.

TABLE 1. COMPARISON OF DIFFERENT DIABETES MANAGEMENT SYSTEMS

System / Parameter	Web Based Service	Robot Assisted	Smartphone assisted	Personal Device In AAL	Interactive M-Health Service
Cost	Low	High	Medium	Medium	Medium
Security	Insecure	Secure	Secure	Secure	Secure
Complexiy	Low	High	Medium	High	Medium
Protocols Used	GPRS	GPRS, WiFi	GPRS, Bluetooth	6LoWPAN, GPRS	GPRS, XML, MQTT
User Control Over System	No	No	Yes	No	Yes
Flexible	No	Yes	Yes	Yes	Yes
User Interaction With System	No	Yes	Yes	Yes	Yes

III. ISSUES AND CHALLENGES

The Internet of Things has the potential to provide physicians with valuable data that can improve patient outcomes, but there are several barriers to IoT adoption in healthcare.

- *Security Concerns* - With so many interconnected devices out there in market and plenty more to come in the near future, a security policy cannot be an afterthought. If the IOT devices are poorly secured, cyber attackers will use them as entry points to cause harm to other devices in the network. This will lead to loss of personal data out into the public and the entire trust factor between internet connected devices and people using them will deteriorate. In order to evade such scenarios, it's extremely critical to ensure the security, resilience and reliability of internet applications to promote use of internet enabled devices among users across the world.

- *Privacy issues* - The possibility of tracking and surveillance of people by government and private agencies increases as the devices are constantly connected to the internet. These devices collect user data without their permission, analyze them for purposes only known to the parent company. The social embrace of the IoT devices leads people to trust these devices with collection of their personal data without understanding the future implications.

- *Inter-operatability standard issues* - In an ideal environment, information exchange should take place between all the interconnected IoT devices. But the actual scenario is inherently more complex and depends on various levels of communication protocols stacks between such devices.

- *Legal Regulatory and Rights issues* - There are no concrete laws present which encompasses the various layers of IoT across the world. The gamut of devices connected to each other raises many security issues and no existing legal laws address such exposures.The issues lie in whether current liability laws will extend their arm for devices which are connected to the internet all the time because such devices have complex accountability issues.

- *Emerging Economy and development issues-* IoT provides a great platform for enablement of social development in varied societies across the world and with the proliferation of Internet across the various sections of the society in developing countries coupled with lowering costs of microprocessors and sensors will make IoT devices accessible to low income households. But there are lot of shortcomings related to enablement of high speed internet and basic technology services architecture for commercial and business usage in developing countries. Until and unless, a basic infrastructure is in place, devices would be of no value to the users.While IoT brings about new opportunities; at the same time, it adds multiple layers of complexity. Such a new environment of devices will add a new dimension for policy makers in emerging economies who will need to chalk out a new blueprint for IoT related regulatory concerns. The future lies in interconnected devices but how we manage them will decide how our Digital future is shaped.

IV. CONCLUSIONS

It is well know that diabetes is a major chronic disease problem worldwide with major economic and social impact. Benefiting from technology advancements and cost reduction in wireless networks and web technologies,numerous electronic/mobile health (e/mHealth) applications have been proposed over these years..In recent years, more sophisticated eHealth applications have been suggested and successfully implemented, benefiting from recent advancements and cost reduction in wireless networks and web technologies. We presented the working and underlying architecture of the latest healthcare applications based on Internet of Things used in diabetes management. We reviewed the issues and challenges faced by these latest applications. Finally we suggested possible solutions and future research directions in Internet of Things.

REFERENCES

[1] G. Kortuem, F. Kawsar, V. Sundramoorthy and D. Fitton, "Smart objects as building blocks for the Internet of things," in *IEEE Internet Computing*, vol. 14, no. 1, pp. 44-51, Jan.-Feb. 2010.

[2] A. Zanella, N. Bui, A. Castellani, L. Vangelista and M. Zorzi, "Internet of Things for Smart Cities," in *IEEE Internet of Things Journal*, vol. 1, no. 1, pp. 22-32, Feb. 2014.

[3] A. Kamilaris and A. Pitsillides, "Mobile Phone Computing and the Internet of Things: A Survey," in *IEEE Internet of Things Journal*, vol. 3, no. 6, pp. 885-898, Dec. 2016.

[4] P. A. Laplante and N. Laplante, "The Internet of Things in Healthcare: Potential Applications and Challenges," in *IT Professional*, vol. 18, no. 3, pp. 2-4, May-June 2016.

[5] Varun G Menon and Joe Prathap P.M, "Analysing the Behaviour and Performance of Opportunistic Routing Protocols in Highly Mobile Wireless Ad Hoc Networks", *International Journal of Engineering and Technology*, vol. 8, no. 5, pp. 1916-1924, 2016.

[6] Varun G Menon, Joe Prathap P M and Vijay A, "Eliminating Redundant Relaying of Data Packets for Efficient Opportunistic Routing in Dynamic Wireless Ad Hoc Networks",*Asian Journal of Information Technology*,vol. 12, no.18, 2016.

[7] Varun G. Menon and Joe Prathap P. M., "Performance of various Routing Protocols in Mobile A Hoc Networks-A Survey", *Research Journal of Applied Sciences, Engineering and Technology*, 6(22), pp. 4181-4185, December 2013.

[8] Varun G Menon and Joe Prathap P M, "Routing in Highly Dynamic Ad Hoc Networks: Issues and Challenges", *International Journal of Computer Science and Engineering*", vol.8, no. 4, pp.112-116, 2016.

[9] Varun G Menon and Joe Prathap P M, "Survey on Latest Energy Based Routing Protocols for Underwater Wireless Sensor Networks", *International Journal of Computer Networks and Wireless Communications*, vol.6, no.6, pp.52-55.

[10] Varun G Menon and Joe Prathap P M, "Moving From Vehicular Cloud Computing to Vehicular Fog Computing: Issues and Challenges", *International Journal of Computer Science and Engineering*, vol. 9, no. 2, 2017.

[11] L. Catarinucci *et al*., "An IoT-Aware Architecture for Smart Healthcare Systems," in *IEEE Internet of Things Journal*, vol. 2, no. 6, pp. 515-526, Dec. 2015.

[12] A. Dohr, R. Modre-Opsrian, M. Drobics, D. Hayn and G. Schreier, "The Internet of Things for Ambient Assisted Living," *2010 Seventh International Conference on Information Technology: New Generations*, Las Vegas, NV, 2010, pp. 804-809.

[13] F. Corno, L. De Russis and A. M. Roffarello, "A Healthcare Support System for Assisted Living Facilities: An IoT Solution," in Proceedings of the 2016 IEEE 40th Annual Computer Software and Applications Conference (COMPSAC), Atlanta, GA, 2016, pp. 344-352.

[14] N. A. Ali and M. Abu-Elkheir, "Internet of nano-things healthcare applications: Requirements, opportunities, and challenges," *2015 IEEE 11th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, Abu Dhabi, 2015, pp. 9-14.

[15] Y. Ma; Y. Wang; J. Yang; Y. Miao; W. Li, "Big Health Application System based on Health Internet of Things and Big Data," in *IEEE Access* , vol.PP, no.99, pp.1-1

[16] Vinu Philip, Vishnu K Suman, Varun G Menon and Dhanya K A, "A Review on latest Internet of Things based Healthcare Applications", *International Journal of Computer Science and Information Security*, vol.15, no.1, 2017.

[17] M. Usha Rani, J. Goutham, S. Monicka, P. Anupa Elizabeth, "Web Based Service for Diabetes Patient Monitoring Sensors" , *International Journal of Computer Science and Informatics*, Vol. 3, No. 2, 2013.

[18] M. A. Al-Taee; W. Al-Nuaimy; Z. J. Muhsin; A. Al-Ataby, "Robot Assistant in Management of Diabetes in Children Based on the Internet of Things," in *IEEE Internet of Things Journal* , vol.PP, no.99, pp.1-1.

[19] M. A. Al-Taee, W. Al-Nuaimy, A. Al-Ataby, Z. J. Muhsin and S. N. Abood, "Mobile health platform for diabetes management based on the Internet-of-Things," *2015 IEEE Jordan Conference on Applied Electrical Engineering and Computing Technologies (AEECT)*, Amman, 2015, pp. 1-5

[20] A. Jara, M. Zamora and A. Skarmeta, "An internet of things–based personal device for diabetes therapy management in ambient assisted living (AAL)", *Personal and Ubiquitous Computing*, vol. 15, no. 4, pp. 431-440, 2011.

[21] M. A. Zamora-Izquierdo, J. Santa and A. F. Gomez-Skarmeta, "An Integral and Networked Home Automation Solution for Indoor Ambient Intelligence," in *IEEE Pervasive Computing*, vol. 9, no. 4, pp. 66-77, October-December 2010.

[22] S. H. Chang, R. D. Chiang, S. J. Wu and W. T. Chang, "A Context-Aware, Interactive M-Health System for Diabetics," in *IT Professional*, vol. 18, no. 3, pp. 14-22, May-June 2016.