Internet of Things in Healthcare

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1 Introduction to Internet of Things

IoT has been gaining popularity rapidly since its inception into the IT community and is being used in healthcare, education, gaming, finance, transportation, and several more. The healthcare industry is among the fastest to adopt the Internet of things. The primary goal of IoT in healthcare is to connect doctors with patients through a smart device. Healthcare providers are expecting the IoT to revolutionize the gathering of healthcare data and care delivery.

Internet of Things (IoT) is a worldwide network that connects devices to the Internet and to each other using wireless technology. IoT is expanding rapidly and it has been estimated that 50 billion devices will be connected to the Internet by 2020. These include smartphones, tablets, desktop computers, autonomous vehicles, refrigerators, toasters, thermostats, cameras, pet monitors, alarm systems, home appliances, insulin pumps, industrial machines, intelligent wheelchairs, wireless sensors, mobile robots, etc.

There are four main technologies that enable IoT [1]:

1. Radio-frequency identification (RFID) and near-field communication.
2. Optical tags and quick response codes: This is used for low-cost tagging.
3. Bluetooth low energy (BLE).
4. Wireless sensor network: They are usually connected as wireless sensor networks to monitor physical properties in specific environments.

Other related technologies are cloud computing, machine learning, and big data.

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The Internet of things (IoT) technology enables people and objects to interact with each other. It is employed in many areas such as smart transportation, smart cities, smart energy, emergency services, healthcare, data security, industrial control, logistics, retails, government, health, traffic congestion, manufacturing, industry, security, agriculture, environment, and waste management. Figure 1 shows the Internet of things and its application areas [2].

IoT supports many input-output devices such as camera, microphone, keyboard, speaker, displays, microcontrollers, and transceivers. It is the most promising trend in the healthcare industry. This rapidly proliferating collection of Internet-connected devices, including wearables, implants, skin sensors, smart scales, smart bandages, and home monitoring tools, has the potential to connect patients and their providers in a unique way.

Today, smartphone acts as the main driver of IoT. The smartphone is provided with healthcare applications.

IoT helps people and communities by making their systems smarter and their lives easier, more secure, and safer. IoT transforms ordinary products such as cars, buildings, and machines into smart, connected objects that can communicate with people and each other. These applications have given birth to smart everything, smart cars, smart homes, smart refrigerators, smart cities, smart parking, smart

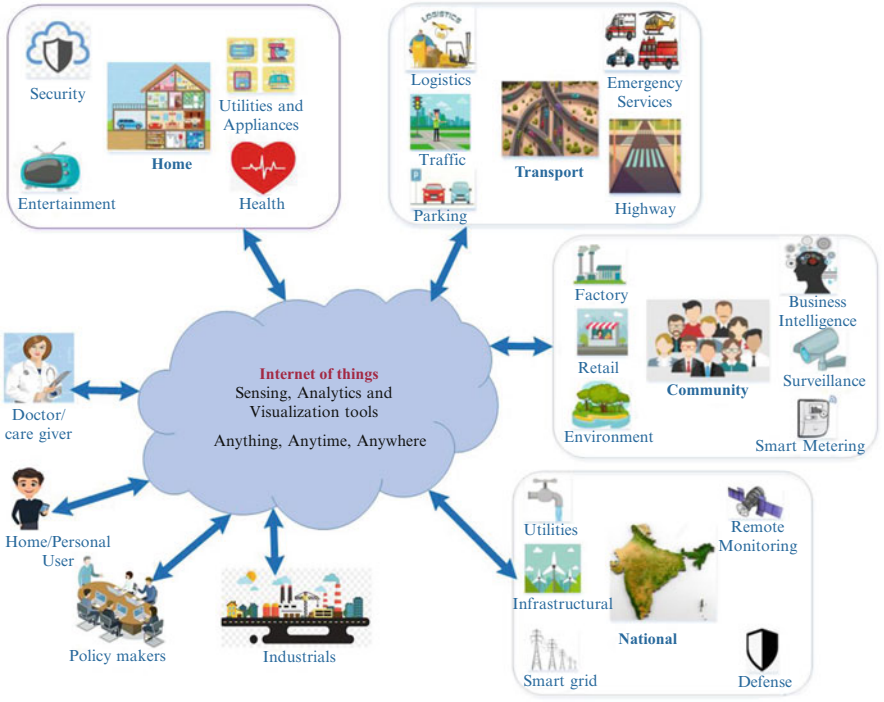

Fig. 1 The Internet of things and its application areas [2]

health, smart environment, smart transportation, smart shopping, smart agriculture, smart lighting, smart grid, smart bandages, and smart energy.

The narrowband version of IoT is known as narrowband IoT (NBIoT). This is an attractive technology for many sectors including healthcare because it has been standardized [3]. The main feature of NBIoT is that it can be easily deployed within the current cellular infrastructure with a software upgrade.

2 Healthcare

Healthcare is an essential part of the modern life. As they say, "Health is wealth." Healthcare is an essential service sector which has ubiquitous demand worldwide. It meets the basic need of every individual in the modern society. The healthcare system consists of patients, medical institutions, and healthcare resources to deliver healthcare services to meet human health needs. Unfortunately, the system is overwhelmed with problems such as expensive services, overworked doctors and nurses, illegitimate patient diagnoses, the growing rate of the aging population, increasing global demand for medical services, rise in the number of chronic diseases, and living environments with poor health [4]. Some of these problems are illustrated in Fig. 2 [5]. In addition, present approaches used for monitoring a patient in hospitals are time-consuming. The Internet of things (IoT) (also known as Future Internet) can resolve these issues quite well.

In healthcare system, the motivation of using modern technologies such as IoT is to offer promising solutions for efficiently delivering all kinds of medical healthcare services to patients at affordable cost. IoT could be a game changer for the healthcare services [6]. It makes it now possible to process data and remotely monitor a patient in real time.

The healthcare industry happens to be one of the fastest industry to adopt IoT. This is due to the fact that integrating IoT technologies into medical devices substantially improves the quality and effectiveness of service. The IoT enables

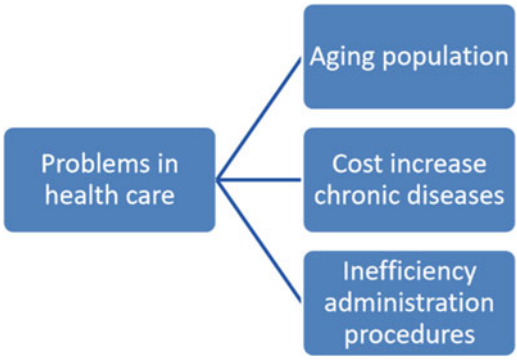

Fig. 2 Some problems in healthcare [5]

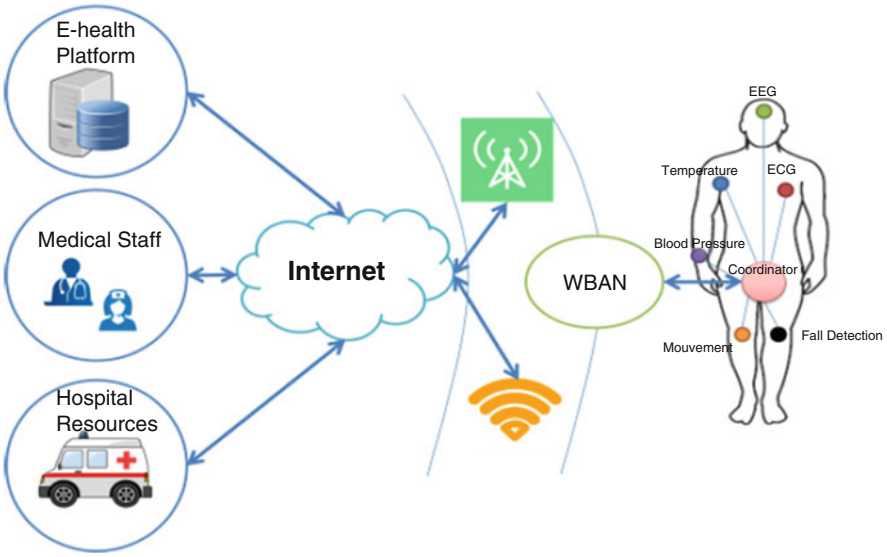

Fig. 3 A typical IoT in healthcare system [7]

practices in the area of healthcare for children, elderly, chronic care, real time monitoring of patients, operation theaters, and medicine dispenser. The application of IoT in healthcare can provide immediate treatment to the patient as well as monitor and keep track of health record for healthy person.

IoT has been identified as a technological solution to some medical challenges and a game changer for the healthcare services. Through the IoT, anything in the healthcare system can be identified and monitored anytime and anywhere. Monitoring the health parameters (such as blood pressure, heart rate, temperature, and humidity) of a patient remotely is achieved by IoT healthcare. A typical IoT in healthcare system is shown in Fig. 3 [7].

IoT in healthcare helps in [8]:

- Reducing emergency room wait time
- Tracking patients, staff, and inventory
- Keeping patients safe and healthy
- Enhancing drug management
- Ensuring availability of critical hardware
- Saving doctor's time and work
- Enabling nurses, doctors, and other team members to connect and communicate in real time
- Receiving critical information at the point of care without unnecessary alerts

3 Internet of Medical Things

The Internet of things in healthcare is variably referred to as IoT-MD, IoMT, Medical IoT, mIoT, and IoHT. Internet of medical things (IoMT), a healthcare application of the IoT technology, has emerged as a combination of advanced medical sensing system and computer communication technologies. The sensing systems include RFID, GPS, and wireless sensor networks. IoMT enables machine-to-machine interaction and real-time intervention solutions which are helping the healthcare industry increase its delivery, affordability, reliability, and productivity. When connected to the Internet, ordinary medical devices become smart and can collect more data, give insight into trends, enable remote care, and give patients more control. For example, IoT devices can be used for reminding patients about appointments, changes in blood pressure, calories burnt, and much more [9]. An illustration of IoMT is shown in Fig. 4 [10].

IoMT devices can sense real-time data for patient monitoring. Such devices are used to monitor parameters such as blood pressure, random blood sugar levels, and weight. IoMT will promote personalized care and high standard of living. Technologies used in IoMT can be divided into the three technical classes:

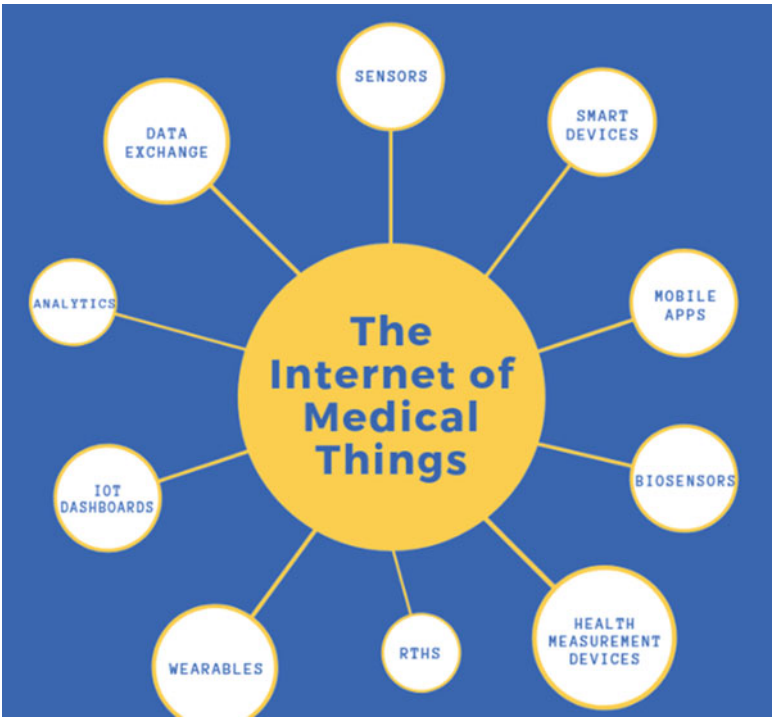

Fig. 4 The Internet of medical things [10]

local patient systems and controls, device connectivity and data management, and analytics solutions [11]. IoMT technology includes remote patient monitoring and medical system management. Smartphones are increasingly used as integral parts of IoMT. Various medical Internet of things platforms have been built for patient information management, telemedicine monitoring, and mobile medical [12].

4 Applications of IoT in Healthcare

Besides Internet of medical things, applications of IoT in healthcare are numerous, ranging from remote monitoring to smart sensors and medical device integration. The applications benefit patients, families, nurses, and physicians. IoT in healthcare is applicable in many medical instruments such as in ECG monitoring, glucose level sensing, and oxygen concentration detection. These various applications provide solutions for the patient and healthcare professionals. Some of the common applications are discussed below [11, 13]:

1. *Digital hospital*: Internet of Things has broad application prospects in the field of medical information management. Currently, the demand for medical information management in hospitals is in the form of identification, sample recognition, and medical record identification. Healthcare in hospitals is one way the medical segment is involved in IoT. With IoMT, hospital medical work is becoming increasingly intelligent, meticulous, and efficient.
2. *Cancer treatment*: Smart technology helps simplify care for both cancer patients and their care providers. By using smart monitoring system, patients experience less severe symptoms related to both the cancer and its treatment [11].
3. *Glucose monitoring:* Diabetes has been a fertile ground for developing smart devices. Such devices can help diabetics to continuously monitor their blood glucose levels for several days. Another smart device for diabetes patients is the smart insulin pen, which can automatically record the time, amount, and type of insulin [11].
4. *Drug anti-counterfeiting:* The amount of counterfeit medicines in the world has increased greatly, and a lot of people die each year as a result of wrong medication. The label attached to a product will have a unique identity that is very difficult to forge, and this will serve as an effective countermeasure against medical fraud [14].
5. *Elderly independent living*: RFID sensor systems are being developed to support older people so that they can safely stay independent. This application is important in view of an aging population. IoT applications can provide support for the elderly by detecting the activities of daily living using wearable devices.
6. *Remote monitoring*: Many patients continuously wear medical sensor-based devices to monitor their health statistics. Fitness, health electronics, and even smart watches have a role to play in monitoring and providing feedback and in some cases as a link to medical professionals. Remote monitoring translates into

a greater number of patients worldwide having access to adequate healthcare. Continuous patient monitoring provides the real-time tracking, collects patient data, and wirelessly transmits for ongoing display. This increases operational efficiency.

7. *Wearable devices*: Innovative devices, such as wearable devices, implantable chips, and embedded systems in biomedical devices, have been developed to continuously track continuous data on patient activity. Smart wearable devices allow the transfer of patient personal information between different devices. They support fitness, health education, symptom tracking, and disease management. They can be used to store health records especially for patients with diabetes, cancer, coronary heart disease, stroke, seizure disorders, and Alzheimer's disease [15].
8. *Body sensor network* (BSN): This technology is another IoT development in healthcare system, where a patient can be monitored using a collection of tiny-powered and lightweight wireless sensor nodes. It is essentially a collection of intelligent, miniaturized wireless sensor nodes used in monitoring the human body functions and surrounding environment. It opens the possibility for monitoring systems to operate wirelessly using low-cost wearable sensors [16, 17].

Other applications include people with disabilities, tracking and monitoring of objects and persons, identification and authentication, transport and data collection, clinical care, and continuous cardiac monitoring.

5 Benefits

Internet of things is a way of connecting devices to the Internet and to each other using wireless networks. It is injected into everything in healthcare, from X-ray machines to patient monitors. It creates new jobs and employment opportunities and bridges traditional engineering, computer sciences, and healthcare. It is transforming healthcare industry by increasing efficiency, lowering costs, and improving patient quality of care and safety. It ensures the personalization of healthcare services by providing digital identity for every patient. The doctors can break the limit of the geographical scope and provide medical education for medical personnel in remote areas. Figure 5 shows the most popular benefits of IoT in healthcare [18]. Besides these, other benefits include [19]:

- *Quality:* Integrating IoT features into healthcare devices greatly improves the quality and effectiveness of service. It enables a radical improvement of healthcare and quality of life. IoT healthcare principles are already being applied to improve access to care, increase the quality of care, reduce the cost of care, reduce medical errors, improve patient safety, and optimize the healthcare processes.
- *Connectivity and affordability*: Connectivity lies at the heart of Internet of things. It is the primary purpose of using IoT technology in healthcare, i.e., connect

Fig. 5 The most popular benefits of IoT in healthcare [19]

doctors with patients through smart devices, without restrictions. The IoT links the medical devices with the virtual worlds, thereby enabling anytime and anyplace connectivity for anything and not only for anyone. IoT opens doors of opportunity for greater connectivity in healthcare. It enables interoperability, machine-to-machine communication, information exchange, and data movement that makes healthcare service delivery effective. It allows nurses, doctors, and other medical practitioners to connect and communicate instantly and receive information proactively in real time inside and outside the hospital. IoT in healthcare should provide better healthcare services to people at any time, from anywhere in a friendly manner. The IoT promises to make healthcare cheaper and better.

- *Monitoring:* Applications deliver care to people in remote locations and real-time monitoring systems that provide a stream of accurate data for better care decision-making [20]. IoT enables real-time monitoring of connected smart medical devices. Real-time monitoring can save lives in an event of a medical emergency like heart failure, diabetes, asthma attacks, etc. The IoT-connected devices can collect health data (such as blood pressure, oxygen and blood sugar levels, weight, and ECGs) and use smartphone to transfer the data to a doctor who may be several kilometers away. This makes healthcare service effective. The healthcare remote monitoring systems have contributed to the improvement of the elderly people's quality of life [21].
- *Tracking:* A healthcare facility needs to be able track all the devices and applications on the network continuously. IoT is used in tracking patients, staff, and inventory. It is difficult to maintain maximum security without the ability to track assets (patients, medical staff, and hardware) throughout the hospital. The

tracking may also include pharmaceutical inventory, helping elderly patients stay safe in their homes, and reminding patients when to take their medications. IoT and real-time location systems facilitate asset tracking. This is an inexpensive and effective method of monitoring and tracking day-to-day activities in a hospital setting. The ability to enable location tracking of assets using sensor-based technology has created a service which is known as location-as-a-service.

6 Challenges

Medical devices present some unique IoT challenges. These include the broad range of medical technologies, the diversity of network protocols, critical security and vulnerability considerations, regulatory compliance imperatives resulting from the handling of patient data, and stakeholders with varied interests. There is also an ambiguity about data ownership and a lack of EHR integration. This allows attackers/hackers to wreak havoc on the network. It is the responsibility of IT staff to bring more awareness to the health professionals about the challenges in supporting IoT devices. Besides these, other challenges include [8]:

- *Data security and privacy*: A significant challenge that IoT poses is of data security and privacy. The data that is being shared across the IoT devices are sensitive. Security and privacy of patients' medical data are crucial for wide acceptance and use of IoT in healthcare. Wearable sensors, for example, are prone to expose patient information and patient privacy. Medical security and privacy issues directly influence patient life and the healthcare system all over the world. Privacy issues may include misuse of medical information, leakage of prescriptions, and eavesdropping on medical data. An enemy may obtain your health status while you are busy exercising in a fitness center since medical sensors may be placed on your body [22]. Security solutions must be resource-efficient since medical sensors have limited processing power, memory, and communication bandwidth. Many countries prohibit privacy violations.
- *Integrating multiple devices*: Integrating complex medical devices is problematic due to lack of standards. Device manufacturers have not reached a consensus regarding communication protocols and standard.
- *Data overload*: The medical IoT generate massive data which can be utilized to gain insights and make smart decisions. The big data accumulated by IoT devices is a challenge for the IoT data processing. Handling the data is becoming very difficult for doctors, and this consequently affects the quality of their decision-making.
- *Workforce:* It is challenging to change the mentality of the current workforce. It can be difficult to convince those in the upper levels about the opportunities of IoT projects. Sometimes, there is not enough technical skill to gain valuable insights from the huge amount of data collected from IoT. Healthcare industry should hire experts with relevant IoT training.

- *High investment cost:* The high initial costs in IoT investments can scare some companies off. But IoT costs are declining rapidly. IoT project implementations with reasonable costs are recommended. Breakthroughs in the cost of sensors and processing power are enabling ubiquitous connections right now. The sensing devices such as RFID tags, sensors, actuator, etc. can be designed to minimize cost.

Other issues that negatively impact the adoption of IoT into healthcare include laws and policies, insurance coverage, standardization (lack of standards), data integrity, interoperability, compatibility, and cost [23]. These challenges may prevent healthcare from fully adopting the IoT technology.

7 Conclusion

The era of the Internet of things has already started and it will drastically transform our way of life. The central concept of the Internet of things is to connect anyone, anything, anytime, anyplace, any service, and any network. Healthcare is one of the major sectors where IoT can have the most relevant economic and social impact. IoT has enabled healthcare system to provide better healthcare services to people at any time and from anywhere in a friendly manner. It has opened up a world of possibilities in healthcare. From adherence to diagnosis, the applications are manifold. Due to these applications, the healthcare industry is changing at fast pace and is adopting the IoT rapidly. It has been long predicted that IoT in healthcare will revolutionize the healthcare sector in terms of social benefits, penetration, accessible care, and cost-efficiency. The IoT revolution is redesigning modern healthcare with extended benefits.

However, the rapid growth of IoT has presented some significant challenges. IoT's development has been restricted by the challenges. Security happens to be the most prominent challenge for physicians interested in IoT applications in medicine. More information about IoT in healthcare can be found in the book [24].

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