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REVIEW ARTICLE

A Review on Human Healthcare Internet of Things: A Technical Perspective

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Abstract
The Internet of Things (IoT) is a promising technology which interconnects the available resources to offer reliable and effective smart objects. The smart objects act as a definitive building block in the development of interdisciplinary cyber-physical systems and smart ubiquitous frameworks. The IoT revolution is improving the potential of healthcare infrastructures for providing quality care to patients and assisted living. IoT is renovating the traditional healthcare system with promising technical, economic and social forecasts. The current researches in the IoT have opened more possibilities in the field of medicine that aims to improve the quality of healthcare with minimum cost. This survey paper explores the advances in Human Healthcare Internet of Things (H^2IoT) and analyses the present-day networks, architectures, topologies, platforms, services and applications in healthcare. This paper also surveys the challenges in H^2IoT design, privacy, security, threats and attack classification.

Keywords Human healthcare internet of things · Remote monitoring · WiMAX · ZigBee · Wearable's · Medical sensors

Introduction

The vision of IoT aims at the interconnection of physical objects in an efficient, practical and standardized way via internet [1]. A global vision of such objects is accompanied with one single concept IoT with the use of sensors, and the whole physical infrastructure is tightly coupled through communication technologies, where network enabled embedded devices provide a smart monitoring and management system [2]. The remunerations characteristically embrace the intelligent connectivity between the devices, systems and services that goes beyond machine-to-machine (M2M) circumstances [3]. As a result, task automation is convincing all the fields. It provides solutions for widespread of applications such as smart home, smart city, smart grid, industrial internet, connected vehicles, connected health, wearable's, smart retail, smart supply chain and smart farming.

One of the most noticeable application areas of IoT is health care and medical care, which will transform the traditional healthcare from hospital-centric to patient-centric [4]. The ubiquitous and personalized services of H^2IoT renovated the healthcare from career-centric to patient-centric [5–7]. The key benefits of IoT sensors and technologies influenced plenty of application areas. In particular, implanted sensors on patients collect the data remotely which aided to provide anticipatory healthcare by predicting the health problems earlier via the monitoring of vital signs. Implantable sensors have a cumulative history of success and deep impact on the persistent quality of patient's life.

Such transforming healthcare scenario with IoT is shown in Fig. 1. The IoT is likely to result in boom for many applications including chronic disease management, fitness maintenance, remote health monitoring systems and ambulatory caregiving to elder-parents. Amenability with treatment and prescription at home by medical practitioners are also one of the important potential applications. The healthcare smart objects such as medical devices, sensors, imaging and diagnostic devices constitutes a primary section of the IoT. IoT-enabled healthcare services reduced the medical expenses,

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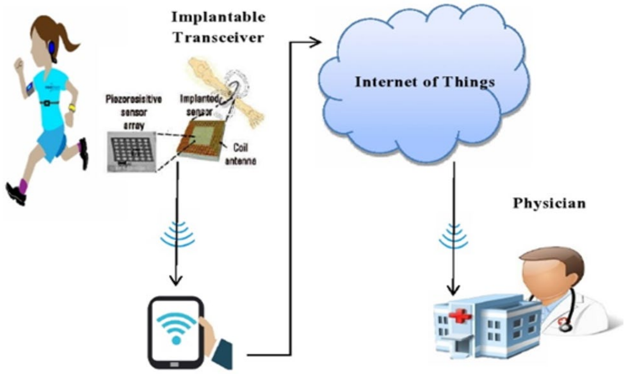

Fig. 1 Transforming healthcare scenario with IoT

improved the quality of life and also reduced the device idle time through remote sensing. By 2020, IoT will be present in 85 percent of healthcare organizations and 75 percent of healthcare industries are expected to be transformed for providing quality services.

A wide range of researches has been identified in order to monitor patient's conditions which includes diabetes and parkinson's disease [8, 9]. Some of the research looks to provide a continuous monitoring of patients for aiding rehabilitation [10]. Yin et al. [11] used various wireless physiological sensors which read and transmits the physiological factors of a person via a wireless communication medium. Plenty of determinations have been made in health monitoring and control [12], patient-centric drug identification [13], and ubiquitous healthcare [14, 15]. Many of the researchers and organizations have been dedicated to the development of IoT-enabled medical applications with the aim at increasing the abilities of healthcare systems [16, 17]. Remote monitoring system increases the efficiency of solving the patient accessibility problems. In USA, only 9% of physicians working in rural areas for 20% of total population and the past works revealed the healthcare inequalities faced by the rural residents [18]. Urban residents used to travel twice or thrice to consult a physician, specialist and through which they experiences the problematic effects for some common health conditions like diabetes and heart attack [19, 20]. Wearable sensors and remote health monitoring systems enhanced the reachability of physicians in urban areas to rural areas and reduced the disparities. This survey paper deals with:

- Categorizing and summarizing the H^{2}IoT frameworks into three different arenas.
- Identifying and comparing the wireless communication technologies available for H^{2}IoT.
- Providing an inclusive study on H^{2}IoT sensing devices and technologies.
- Discussing on the security and privacy issues from H^{2}IoT perspective.

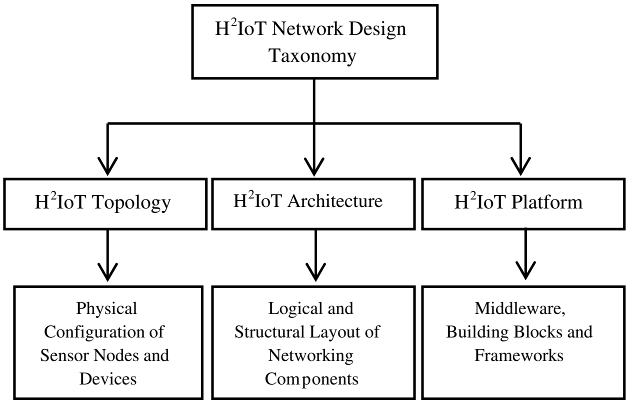

Fig. 2 H^{2}IoT network design taxonomy

- Emphasizing the various applications arenas of H^{2}IoT.
- Highlighting the major technologies that modernized the healthcare domain using IoT.

H^{2}IoT Network Design Taxonomy

The main intension of IoT is to provide access and control to a wide variety of pervasive and uniquely identifiable objects and devices. The network design taxonomy is a major constituent of the H^{2}IoT and it acts as a channel for the sending and receiving of healthcare data among connected medical devices. As shown in Fig. 2, this section presents the idea of H^{2}IoT network design taxonomy into three categories such as H^{2}IoT network topology, architecture and platform. However, taxonomy will support in defining the structural requirements for H^{2}IoT from high level insight [21].

1. H^{2}IoT Network Topology The H^{2}IoT network topology depicts physical organization of the healthcare elements such as physiological sensors, actuators and gateways from communication perspective. The factors to be taken into account while choosing the appropriate network topology and IoT protocols for medical systems are cost, energy consumption, communication and reliability. These factors must be analyzed with respect to the characteristics, capabilities and performance of the network topologies.

Latency: Latency is a time taken by a network to transmit the data from medical sensor node to the gateway node and vice versa. In general, latency decides the speed of the H^{2}IoT network, when the latency of a network decreases then the network speed will increase.

Throughput: Throughput is the total amount of data transmitted over an H^{2}IoT network within a given period of time. Thus, the systems providing high throughput are well suited for transmitting real-time data transmission.

Fault Tolerance: In case of failure in the wireless communication between the medical sensor nodes and gateway, the system must reconfigure its path transmission and ensure the delivery of packet to its destination.

Scalability: The framework of H^2IoT system must adapt to the situation of adding any number of medical sensor nodes into the network.

Range and Number of Hops: The range denotes the maximum available distance between one to any other node of the network. For transmitting of data packet from medical sensor node to gateway, it has to travel through ‘n’ number of medical sensor nodes, where ‘n’ is the number of hops.

Figure 3 demonstrates a remote health monitoring system based on wearable sensors, in which healthcare data is collected using body-worn wireless sensors and transferred to the medical practitioner through the gateway for further interventions [22]. Wearable sensors (e.g., heart/pulse rate and respiratory rate) are deployed as per clinical requirements to monitor vital signs and movement sensors would be incorporated for increasing the efficiency of home-based rehabilitation when patients are suffering from severe heart disease, respiratory syndrome or any lung disorders.

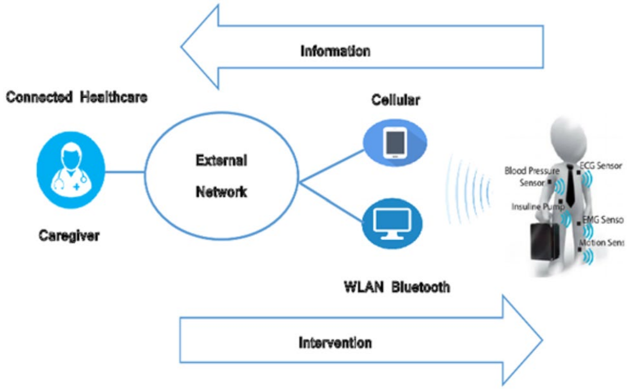

Fig. 3 Wearable sensors-based remote health monitoring system

This topology uses the wireless communication technologies such as Bluetooth, ZigBee or Wireless Local Area Network (WLAN) to transfer patient’s data to a mobile or access point gateway and then it is forwarded to remote data storage center via internet. Finally, family members and caregivers are notified during emergency situations for instant medical assistance.

Figure 4 describes the general IoT-based health monitoring system that has three important components such as area sensor network, gateways and cloud data center [23]. The sensed physiological data of patient’s made availed to the caregivers or authorized end-users, enables them to monitor the health status from remote location at any time. In this topological view, gateways act as a middleware between sensor network and cloud data center. The nature of gateway is to narrow down the mobility and location of users and it uses self-controlled resources such as processing power, energy consumption and network bandwidth.

Figure 5 visualizes the e-Health tele-monitoring system which comprises of various components like smart home, gateway, application server and healthcare data center [24]. Smart home integrates a Body Area Network (BAN), a Wireless Personal Area Network (WPAN) and a WLAN within itself. The BAN contains a Body Gateway (BG) which collects the vital clinical parameters from patient’s body and then transmits the data to the Base Station (BS) through WPAN.

The BS transfers the data to the Residential Gateway (RG) via WLAN, which incorporates the various networking technologies used in smart home and Public Packet Network (PPN). The PPN is essential for transmitting the data from RG to the healthcare center and it supports the carrying of remedies to the patient’s from healthcare providers. The extended gateway comprises of ETSI/Parlay SCSs and Sensor Networks SCSs allows e-health tele-monitoring

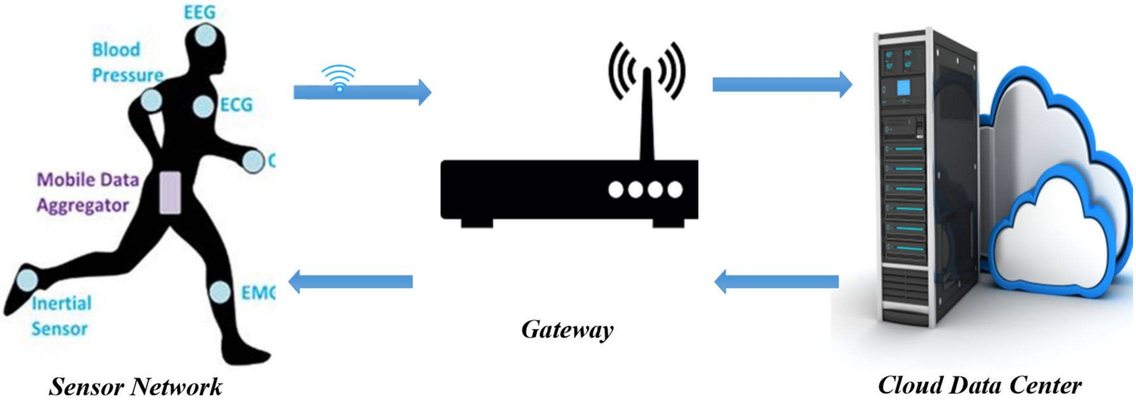

Fig. 4 General IoT-based health monitoring system

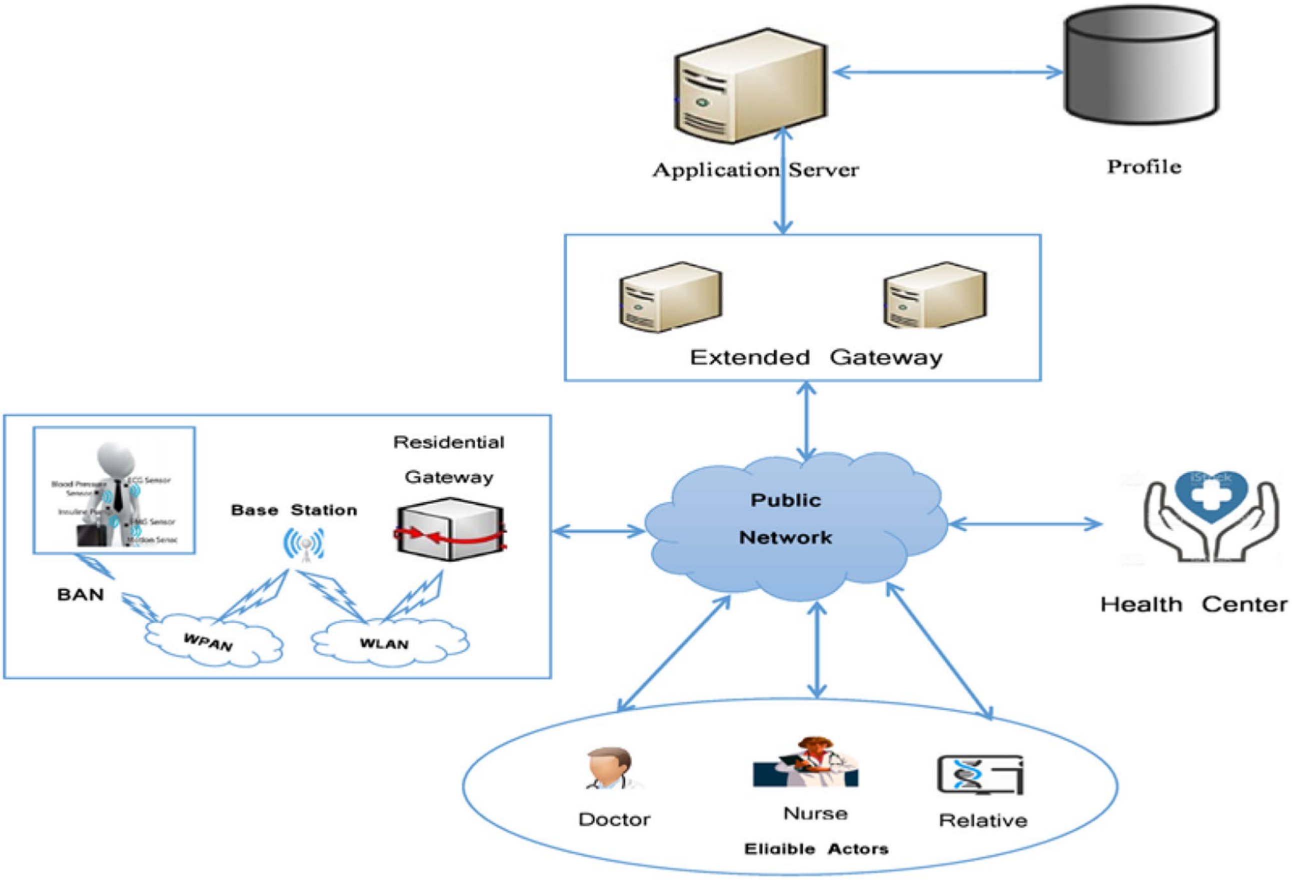

Fig. 5 e-Health tele-monitoring system [24]

system to provide services under standardized and secured framework mechanisms. Such servicers are deployed on the application server, which is connected with a profile database for storing the patient and subject profiles.

The design considerations of H^2IoT network topology would attained the concentration on certain things such as network terminal, complexity of topological structure, resetting of network resources and changes. In addition, designing of H^2IoT topology will create a significant impact on IoT network performance. It is necessary to identify the relationship between the topological structure change and network performance prior to the resetting of network resources which may improve the network performance [25]. This research study discovers the comparison results of the H^2IoT topologies based on various attributes is shown in Table 1.

2. H^2IoT Network Architecture The IoT architecture can be referred as an outline of a physical, virtual or a hybrid system, which includes physical devices, sensors, actuators, user-specific protocols, cloud platforms, communication layers, functional organization and its working principles. Figure 6 presents the architecture of Home Health Hub Internet

Table 1 Comparison of topologies

Topologies	Technologies-used		Services offered			IoT interoperability		Data center	
	Sensor networks	Mobile	Remote monitoring	Patient tracking	Medical intervention	WPAN	WLAN	Analytics	Decision making
Figure 3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Figure 4	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes
Figure 5	Yes	No	Yes	No	No	Yes	Yes	No	No

of Things (H^3IoT), established for monitoring the elderly people resides at home [26]. H^3IoT incorporates the medical sensors, communication technologies, microcontrollers, gateways, internet and applications with respect to economical and mobility perspectives. It is a five layered framework architecture which includes User Application Layer (UAL), Internet Application Layer (IAL), Information Processing Layer (IPL), Local Communication Layer (LCL), and Physiological Sensor Layer (PSL).The core job of the PSL is to sense the physiological factors like Electrocardiogram (ECG), Electroencephalogram (EEG), and Electromyogram (EMG). The sensed raw data is forwarded to the next upper layer LCL for further processing. The LCL consists of communication technologies used for transmitting the data from PSL to upper layers and the communication technologies range from 10 to 900 m.

The third layer IPL acts as a soul of H^3IoT architecture and it a hardware platform that receives the raw data from LCL and process the data for performing further actions in higher layers. This also includes a gateway (network point) that provides a communication link for transferring information from IPL to IAL. The next layer is IAL which is considered as the backbone of the system, receives the medical data from IPL and is transferred to android or cloud platform for future analysis and visualizations. The top-most layer is UAL of H^3IoT architecture through which end-users (i.e., physician, relative, hospital and caregiver) can monitor the real-time information about the patients.

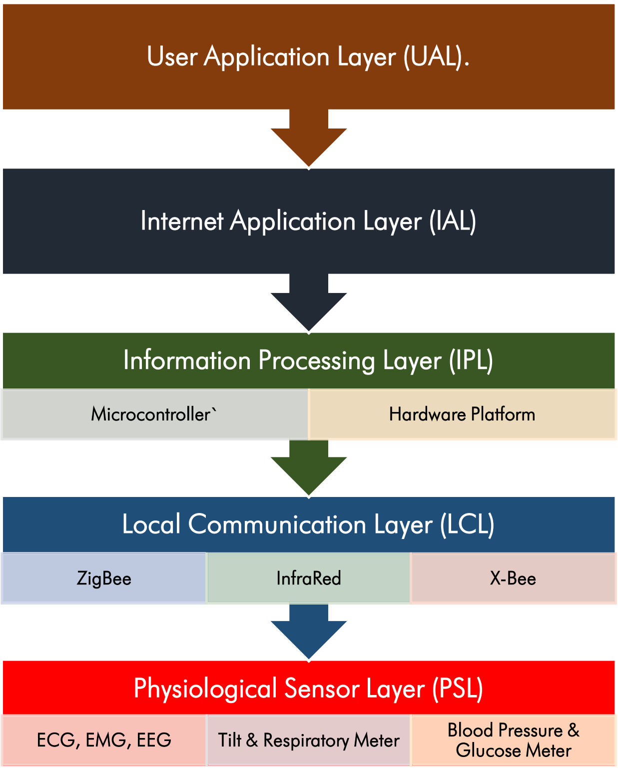

Fig. 6 Architecture of home health hub Internet of Things (H^3IoT)

Figure 7 demonstrates the architecture of smart e-health gateway which consists of five major components such as Medical Sensors and Actuators Network, communication protocols, smart e-health gateway, internet and remote data center [23]. Initially, medical sensors and actuator network sense the condition of patient and environmental factors and the data are forwarded to the smart e-health gateway through the protocols such as ZigBee, Bluetooth, Wi-Fi or 6LoWPAN. The gateway is designed to support as many communication protocol standards required to increase the interoperability and flexibility of the system. Based on the studies [27–37] have identified that the Bluetooth, Wi-Fi, ZigBee or 6LoWPAN are the basic communication protocols that act between the sensor networks and the gateway. Each gateway performs the necessary protocol conversions on data received from various sub-networks and also it provides other services like data aggregation, filtering, fusion, compression, analysis, local storage, and actuation. Finally, gateway itself performs investigation operation on data and displays it on remote data center via internet [38]. Smart e-Health Gateway Architecture has used a fog computing paradigm which offers a hierarchical system architecture and a more reactive design [39]. It acts as an intermediary component between the cloud and end-users that accomplish the merits by providing priority-based services. The identified advantages of this architecture on comparing it with the architecture of Home Health Hub Internet of Things (H^3IoT) are shown in Table 2.

3. H^2IoT Network Platform H^2IoT network platform is an application that offers both network and computing platform that connects the IoT devices with cloud. The conventional components of an IoT platform can manage, control, monitor and also deploy a secure connectivity between connected devices [40–46]. Designed a semantic platform architecture which provides interoperability among the diversified devices with the help of four kinds of ontologies. In terms of separating the IoT into hardware and software platforms, it is identified that many of the vendors focused on the hardware platforms. Only very few vendors offering IoT software platforms, and 13 top ranked IoT software platforms were identified [47].

Figure 8 shows, H^2IoT Big Data Platform for managing the real-time healthcare data sets have been presented. It enables the integration and storing of huge volume and wide variety of healthcare data. This can eventually provide highly configurable data ingestion, alerts for real-time patient engagement, data customization using parsers, active managing and monitoring are mandatory to make

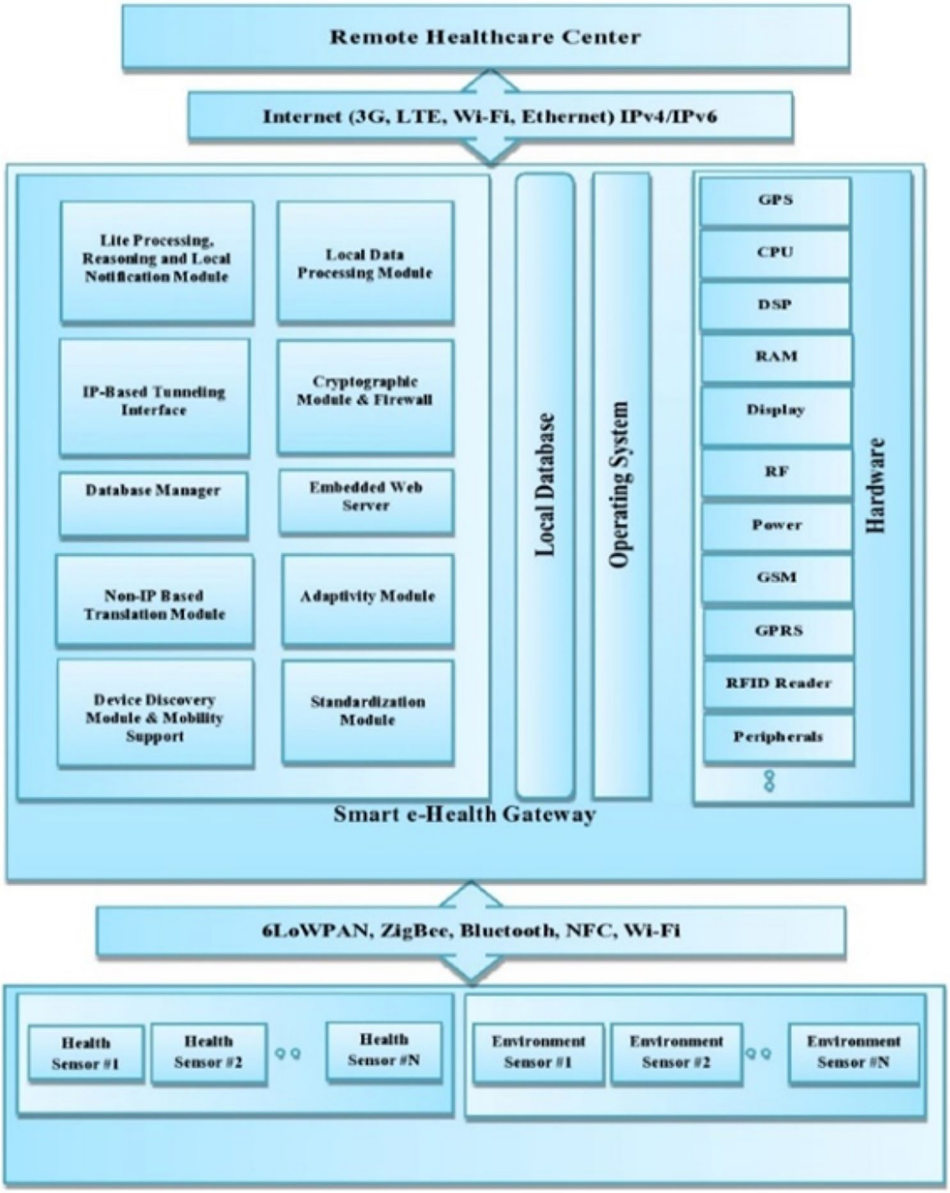

Fig. 7 Smart e-Health gateway architecture

Table 2 Comparison of Architectures

Parameters	Figure 6	Figure 7
Adaptivity	Low	High
Data transmission Latency	High	Low
Energy efficiency level	Low	High
interoperability	High	High
Level of security	Low	High
Local data storage	Yes	Yes
Mobility support	Low	High
Priority-based data transmission	No	Yes
Quality of service (QoS)	Low	High
Re-configurability	Yes	Yes

sure the quality of data to be used in medical intervention. Additionally it provides automated analytics and sends messages to patients, healthcare providers to enable decision making.

Figure 9 depicts the components of Microsoft Azure IoT Architecture in which IoT devices transmits the collected data to the cloud gateway for processing by back-end services [48–50]. After processing, back-end services distribute the data to business applications or dashboards.

Figure 10 shows the 4-Tier H^{2}IoT model, which allows to integrate different hardware with the help of respective protocols, topology and software. The base layer of 4-Tier H^{2}IoT platform model is medical things comprises of medical sensors, medical devices, wearables and mobile apps for observing the vital signs of the patients.

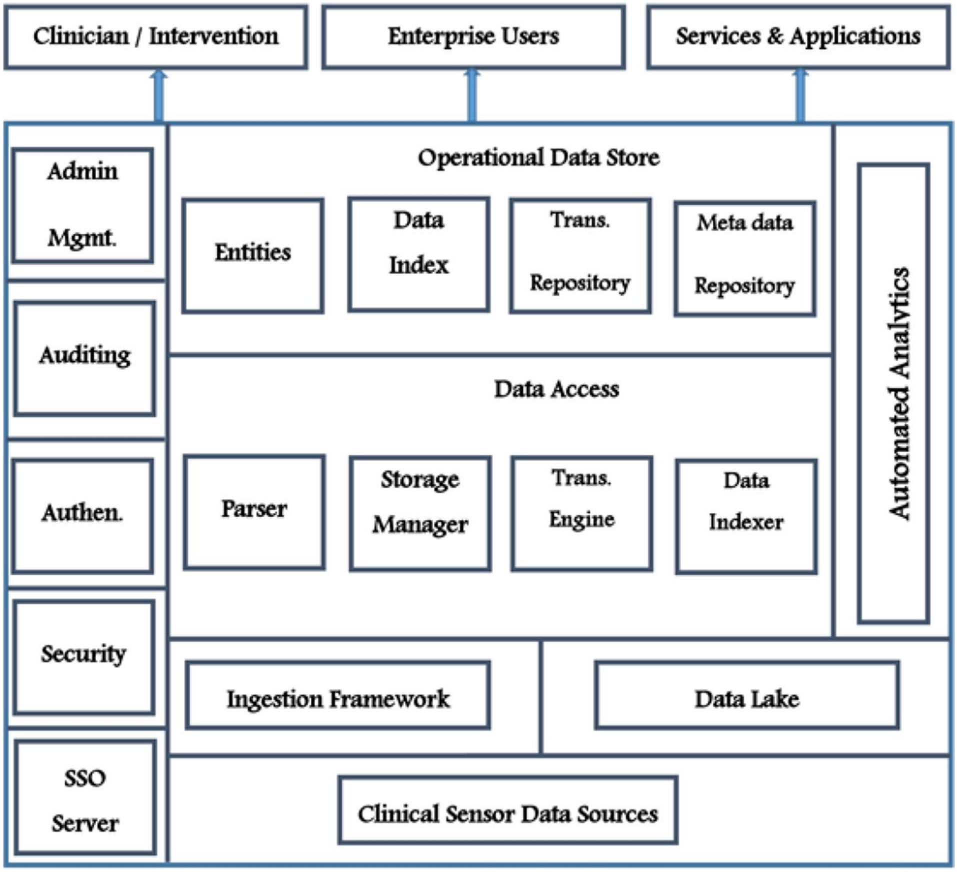

Fig. 8 H^2IoT big data platform

The connectivity layer of 4-Tier H^2IoT model is responsible for carrying the data generated by the base layer to the next layer. The third layer is the management service act as a central-tier for the 4-Tier H^2IoT platform model which facilitates various functionalities to take place in cloud infrastructure. The top most layer comprised of vertical specific data analytics components provides the intelligence for healthcare applications.

H^2IoT Wireless Technologies

This section explores and compares the enabling wireless technologies for the H^2IoT. Wireless Sensor Networks (WSN) can be referred as a network which is capable to function with limited resources such as battery and processing power. Since the sensor nodes are battery powered in IoT applications and so these nodes must function for a longer period of time. Many studies [5, 27–37] have justified the commonly used wireless technologies includes World Wide Interoperability for Microwave Access (WiMAX), Bluetooth, Wi-Fi, LoRa, Ultra Wide Band (UWB) and ZigBee. These are the low power and short range communication technologies which belongs to the IEEE 802.11 a/b/g/n and IEEE 802.15 standards.

Bluetooth is a communication technology belonging to IEEE 802.15.1 standard, can function with low power consumption and replaces the wired connectivity between the interactive devices [51, 52]. UWB is a high data rate offering technology which belongs to IEEE 802.15.3 standard and it consumes low power when compared to other short range technologies [53, 54]. The ZigBee was the modified version of 802.15.4 LoWPAN, developed by ZigBee alliance. This was designed to work with low power consumption and to achieve long transmission power [55, 56]. IEEE 802.11 a/b/g/ac/ah forms a part of IEEE 802.11 WLAN standard, which is suited only for high rate indoor communication (100 meters) whose frequency band range from 2 to 5 GHz. To overcome this range issue, a non-standard version Wi-Fi WLAN was developed with enhanced range which operates in 900 MHz [57]. The WiMAX is an advance communication technology that belongs to IEEE 802.16 standard. It provides point to multipoint communication. Its transfer rate is 75 Mbps and range is up to 3 miles [58]. The Low-Power Wide Area Networks (LPWAN) presents a new wireless communication technology Low Range (LoRa) to support wide range of IoT applications [59]. Table 3 compares the different H2IoT enabling wireless technologies in terms of discrete parameters.

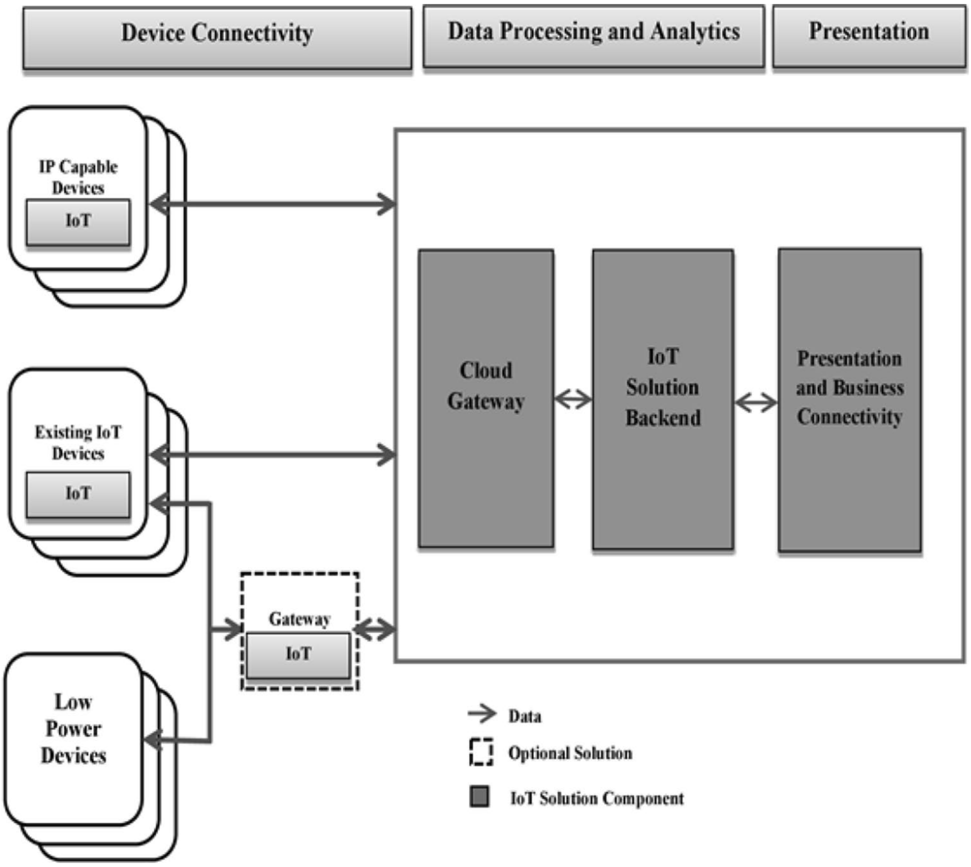

Fig. 9 Microsoft azure IoT architecture

H^{2}IoT Sensing Devices and Monitoring Systems

Technical improvements in mobile and electronic healthcare arenas are transforming the traditional healthcare devices into modernized healthcare devices with the capability of remote monitoring the biological parameters [70, 71]. Thus, innovations provide a new pathway for every individual to dynamically take part in remote monitoring of clinical parameters in a non-clinical environment [72, 73]. Many of the studies [74–76] proved that the routine care of acute and chronic diseases increased the patient's life quality. Sensors enable the healthcare providers to monitor, track and evaluate physiological factors via the interfaces and dashboards [76]. These medical sensors are becoming precise and reliable for forecasting the disease [74, 77, 78]. Mostly the wearable sensor offers flexibility and comfort for patients. The wearable sensors can be worn in any part of the body including wrist, ankle, waist, chest, arm, legs, and fingers depending on the clinical applications. The system designed in [79, 80] monitors the daily activities like standing, walking and the postures. The models developed in [81–83] monitor the blood oxygen saturation, heart rate, body temperature, galvanic skin responses and hand postures during movements. In addition, some Micro-Electro-Mechanical System (MEMS)-based inertial sensors like accelerometers, gyroscopes and magnetic field sensors are commonly used for evaluating the activity related events. In G. Ciuti et al. and M. Salerno et al. applied the MEMS accelerometers for localization purposes in capsule endoscope procedures [97, 98]. To present a patient's motion tracking system in healthcare domain, the studies [100–102] identified that the accelerometer alone cannot provide an accurate data regarding motion and hence the gyroscopes have been adopted to perform gait analysis. S.Lapi et al. designed an appropriate accelerometer-based system for monitoring the breathing and heart rates along with postural changes [99]. List of noninvasive sensors with their use cases in detecting health conditions are shown in Table 4.

H^{2}IoT Security and Privacy Issues

In near future, the widespread adoption of IoT to the medical sector rapidly increases the growth of healthcare technologies. Thus, it enables the healthcare devices to deal with vast amount of private data such as patient's records, which acquires the importance of security. A secured device must rely on three essential factors [106, 107] such as

1. Data availability, consistency and accessibility.

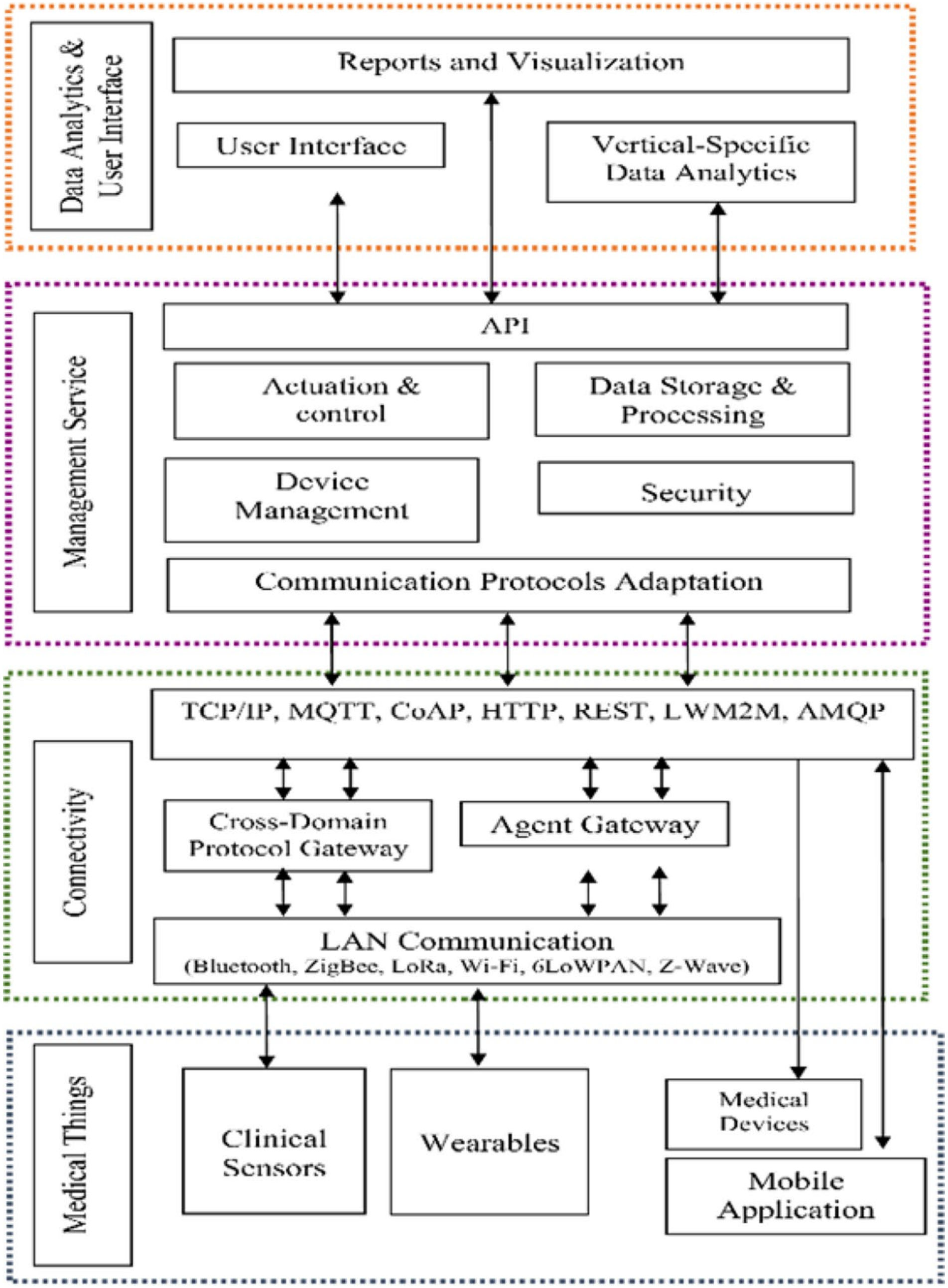

Fig. 10 4-Tier H^2IoT model

2. Providing authentication and authorization to ensure privacy of data on transmission.
3. Ensuring System Integrity

In this section, crucial H^2IoT security issues are identified and analyzed to address all the factors as shown in Fig. 11.

1. H^2IoT Security Essentials The H^2IoT security essentials form the basis for providing secured IoT-enabled healthcare services and so it is necessary to focus on the security needs specified in Table 5. As shown in Fig. 12 Deltahedron Security Rigidity Model explains the H^2IoT security rigorousness with four nodes: human, process, object and technological solutions. An object in the H^2IoT systems has higher complexity in controlling the clinical sensors, network components, protocols, system and application software. The communication between the human and object is difficult because H^2IoT network involves in processing of more objects. As the H^2IoT is diversified and scalable in nature, security issues related to human resources are high and that have been represented in the human node. Process node explains the way of performing the operations within the designed H^2IoT security framework. Since objects are being intelligent, H^2IoT systems must comply with various

Table 3 Comparison of wireless communication technologies for IoT

Technologies parameters	Bluetooth [60–62, 64, 65, 69]	LoRa	UWB [53, 54]	Wi-Fi [66]	WiMAX [58]	ZigBee [63, 67, 68]
Authentication	Shared key authentication	CCM	CBC-MAC/CCM	WPA2	CBC-MAC	CBC-MAC/Extension of CCM
Battery life	Weeks	Years	Days	Hours	Years	Months to years
Cost	Low	High	Low	High	High	Low
Data protection	16 Bit CRC	128 Bit CRC	32 Bit CRC	32 Bit CRC	128 Bit CRC	16 Bit CRC
Data rate	1–24 Mbps	0.3–50 Kbps	110 Mbits per second–1.6 GBits per second	1 Mbps –6.75 Gbps	1 Mbps –1 Gbps	250 Kbits/s
Encryption	E0 stream cipher	AES block cipher	AES block cipher	RC4 stream cipher (WEP), AES block cipher	3DES, AES block cipher	Stream cipher, AES block cipher
Power consumption	Medium	Very low	Low	High	Medium	Very low
Frequency band	2.4 GHz	868/900 MHz	3.1–10.6 GHz	5–60 GHz	2–66 GHz	868/915 MHz, 2.4 GHz
Nodes	8	120	128	32	100	65,000
Spreading	FHSS	Chirp Spread Spectrum (CSS)	DS-UWB, MB-OFDM	DSSS, CCK, OFDM	OFDM	DSSS
Standard	IEEE 802.15.1	IEEE 802.15.4 g	IEEE 802.15.3 (Ratified)	IEEE 802.11 a/c/b/d/g/n	IEEE 802.16	IEEE 802.15.4
Topology	Mesh, star, tree	Star of stars	Star, P2P	Star, P2P	Radio access network, mesh	Tree, P2P, star and mesh
Transmission range	8–10 m	< 30 km	4–20 m	20–100 m	< 50 km	10–300 m

Table 4 List of noninvasive sensors used in H^2IoT

Noninvasive sensors	Use case/susceptibility
Blood pressure/sphygmomanometer	This sensor measures the two kinds of blood pressure in arteries such as systolic and diastolic pressure at the time of heart dilation. Blood Pressure is one of the factor for predicting hypertension (cardiovascular disease) and also heart attack [84, 85]
Body position sensor	Body positions like standing, sitting, supine, prone, left and right to be monitored for diagnosing many diseases
Body temperature sensors	It is a prompting vital sign for detecting hypothermia, heat stroke and fever. It must be incorporated in a wearable system because it is a supporting factor for diagnosing many clinical conditions [86, 87]
Electrocardiogram (ECG) sensor	ECG evaluates the functioning of the heart to diagnose the abnormal cardiac patterns [88]
Electroencephalogram (EEG) sensor	EEG evaluates the brain activity, tumors, seizures, dizziness and sleeping problems [89, 90] developed an EEG system for identifying the driver drowsiness/stress management
Electromyogram (EMG) sensor	EMG measures the electrical activities of muscles at rest and during contraction for predicting neuromuscular diseases, assessing back pain and kinesiology
Glucometer	Glucometer is a type of glucose sensor that assesses the concentration of blood glucose
Galvanic skin response (GSR) sensor	GSR measures the electrical conductance and resistance of skin, which is a good indicator of psychological arousal. It is widely used in prediction of human stress levels [96]
Pulse oximetry sensors/SpO_2 sensor	Pulse oximetry or SpO_2 measures the oxygen level in the blood and it is one of an indicator of respiratory function and hypoxia [91, 92]
Pulse sensors	Pulse sensor monitors the heart/pulse rate and detects the cardiac arrest, pulmonary embolisms and vasovagal syncope [93]
Respiratory rate sensors/airflow sensor	The number of breaths or respiratory rate per minute is a vital sign for the identification of asthma attacks, panic attacks, lung cancer, airway blocks and tuberculosis [94, 95]
Accelerometer, magnetometer and gyroscope	Accelerometer, magnetometer and gyroscope are MEMS-based inertial sensors regularly measures the physical activities of the patients who have undergone surgery, stroke patients and the patients with chronic pulmonary diseases [103–105]

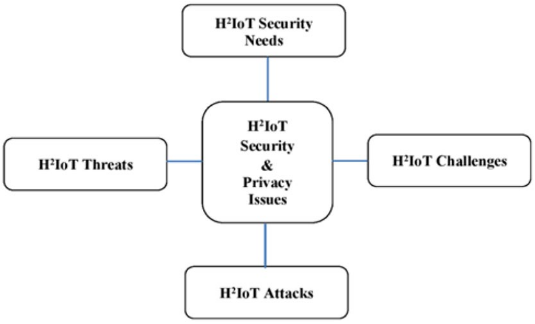

Fig. 11 H^2IoT security and privacy issues

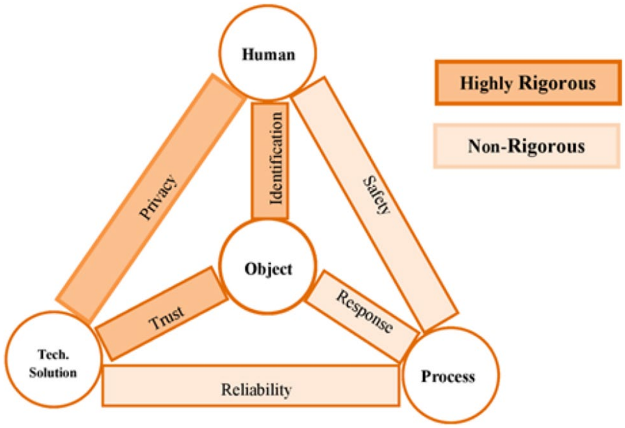

Fig. 12 Deltahedron security rigidity model

security levels. Finally, technological solutions node represents the security level to ensure efficient functioning of H^2IoT system.

2. H^2IoT Security Challenges H^2IoT security needs to satisfy only the traditional security factors and so the novel countermeasures are considered as regulatory phenomenon to address the new challenges presented by H^2IoT. Some of the H^2IoT security challenges are explained below:

Mobility or Dynamic Connectivity In general, H^2IoT is not a new paradigm but the way of using the existing architectures creates a new security challenges. H^2IoT devices are connected to internet which is not static in nature. Consider an example of wearable body motion monitoring system which includes various sensors like accelerometer, gyroscope and magnetometer and is connected to the internet to transmit the physical activity information to the doctor. The network used by the wearable device may change as per the mobility of the patient, i.e., it may use home network when the patient at home and office network when the patient is at office. Such scenarios require many security configurations and developing a security algorithm for dynamic connectivity devices is a major challenge.

Device Variability and Interoperability H^2IoT devices are diversified in terms of computational power, memory, power consumption, hardware configuration and software. Therefore, building a secured H^2IoT system with the compliance of functionality, protocols, terminologies and standards is a challenging factor.

Scalability and Vulnerability With respective improvements in medical sector using IoT, the H^2IoT devices are increasing rapidly and those are connected to the network. Hence, developing a non-compromising security mechanism for scalable H^2IoT infrastructure is a challenging task.

Communication Media H^2IoT devices are connected to the local and a global network via any wireless communication medium which includes Wi-Fi, Bluetooth, LoRa, ZigBee, WiMAX and UWB. The existing traditional security

Table 5 H^2IoT security needs

H^2IoT security essentials	Purpose
Authentication	It allows an H^2IoT device to ensure the identity of the other end device on establishing the communication and grants permission to perform pre-defined operations [112]
Authorization	It permits only the authorized nodes to access the resources and services [112]
Availability	It allows the authorized users to access the H^2IoT services anytime and anywhere even under vulnerable attacks [108]
Confidentiality	It permits only the authorized users to access the patient's information [109]
Data reliability	The term reliability specifies the freshness of the medical data, it ensures the data received by data sink are recent and none of them are old
Fault tolerance	It ensures the system must adopt to the changing environments and to provide a trustworthy service even under the presence of faults [113]
Integrity	It ensures that the data received from the sensor nodes are reliable and are not altered by any opponent in transmission [110]
Non-repudiation	Non-repudiation ensures that the sender or receiver cannot deny the messages once it has been sent or received [111]

protocols does not satisfy H^{2}IoT scenario and it is difficult to find a security protocol for H^{2}IoT scenario.

Multiple Authentications The process of multiple authentications adhere the user to provide more information like fingerprint or retinal scan other than usual username and password procedure. While adopting this on H^{2}IoT networks and devices, it would be a time consuming and tedious task. Since IoT network contains enormous cluster of sensor nodes, maintaining multiple authentication will be tedious.

Intrusion Identification and Blocking Mostly attacks target the vulnerability of IoT devices and deliver the attacks via internet. It is more crucial to detect and block attacks trying to gain the access to network. Applying countermeasures to distributed sensor networks will require more efforts.

3. H^{2}IoT Security Threats H^{2}IoT devices are designed for sending and receiving the medical data over global network are exposed to wide range of threats. Figure 13 is an H^{2}IoT threat classification model which depicts the H^{2}IoT threats with respect to impact on security requirements. The vital threats of H^{2}IoT devices are: data leakage or disclosure, exploitation of access privilege, Spoofing, Repudiation, Denial of Service (DoS) and Tampering.

4. H^{2}IoT Security Attacks Attacks are the irregular action which disturbs the normal functioning of an H^{2}IoT system by exploiting the vulnerabilities using certain methods [114]. There are two common attacks: active attacks and passive attacks. The active attacks affect the physical performance of the system and the passive attacks is a trespasser node snips the information without affecting physical performance of the system [114, 115]. Table 6 presents the various types of attacks and their behavior

H^{2}IoT Applications

The fast emerging technologies cannot completely eliminate the chronic diseases but it can provide accessible healthcare services in a pocket. The regular healthcare services are expensive and so the technologies transformed

Fig. 13 H^{2}IoT threat classification model

Table 6 Types of H^{2}IoT attacks

Attacks	Behavior/nature
Access attacks	It allows unauthorized persons to access the H^{2}IoT devices or networks. It can be of two forms: 1. Gaining access via an intruder 2. Gaining access remotely via IP connected devices
Attacks on privacy	Privacy preservation becomes a major task in H^{2}IoT because huge volumes of data can accessed globally. For example, eavesdropping silently monitors the medical data on transmission [116]
Cyber-crimes	It uses network and smart devices as a weakness to exploit the user's data [117–119]
DoS attack	DoS attacks are intended to degrade the system performance by increasing the network traffic by sending the replicated messages again and again. Thus consumes the more memory capacity and computation resources in majority of H^{2}IoT devices
Physical attacks	This kind of attack cause damages to the physical equipment's of H^{2}IoT because those are supposed to operate in various environments [121, 122]
Investigation attacks	This attack includes packet sniffers and scanning of network ports enables unauthorized discovery of devices [120]

the routine health checks from hospital-centric to patient-centric (home-centric) thus, reducing the need of hospitalization. With extensive applicability of IoT in healthcare paradigm enables the doctors to function more competently and provide better treatment for patients. In this section, applications are broadly discussed in two categories such as dispersed applications and congregate applications as shown in Fig. 14. In addition to applications, this section also presents a comparative analysis on wearable applications.

1. Blood Pressure Monitoring J. Puustjarvi and L. Puustjarvi presented a communication structure between health post and center through which blood pressure is remotely monitored and controlled [123]. A device developed in [124] collects the blood pressure data and transmits over an IoT network to remote data center. An intelligent blood pressure monitoring system has been proposed with location tracking facility [125].

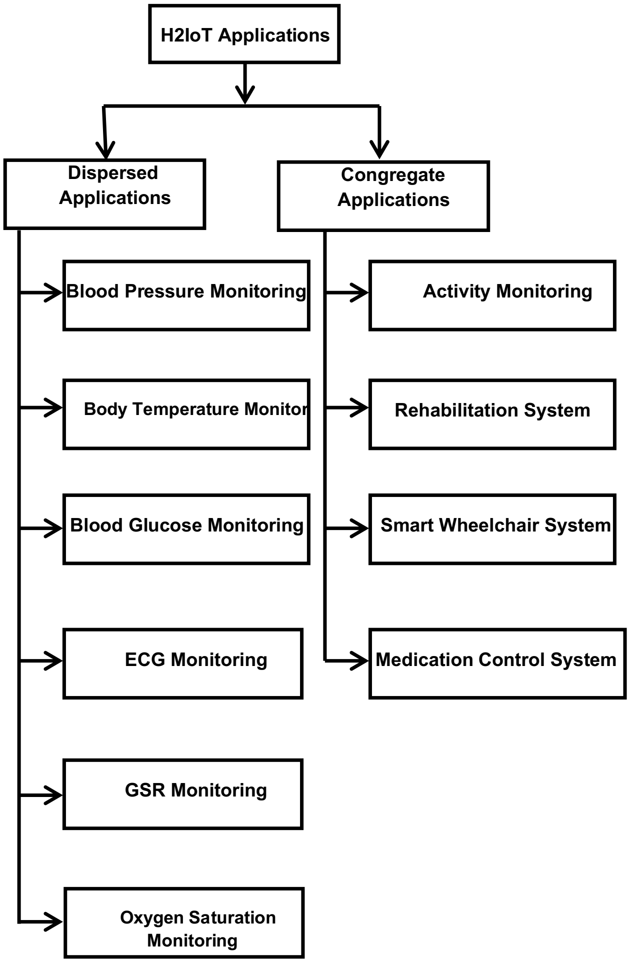

Fig. 14 H^2IoT applications

2. Body Temperature Monitoring Body temperature provides vital signs to indicate any abnormalities in the health [126]. An IoT-based temperature monitoring system is developed which uses the home gateway to transmit the sensed temperature data [127]. An m-IoT-based embedded TelosB mote device is presented which uses body temperature sensor for showing the variation in body temperature [128]. This method uses IPv6 connectivity mechanism between the patients and healthcare providers. An IoT-based temperature monitoring system has been developed for acquiring the temperature data and an integrated RFID module has been used for transmitting the recorded to the data center [129].

3. Blood Glucose Monitoring Prolonged high blood glucose level leads to diabetes, which is one of metabolic disease in humans. It is considered as an important factor to be monitored for planning the diets, activities and medications. In [128], along with temperature sensing module it uses a non-invasive blood glucose sensing module for enabling real-time monitoring of blood glucose level. A generic IoT-based medical system is proposed for monitoring the glucose level [130]. The utility model based on IoT discloses the blood glucose level and this model incorporates the components such blood glucose collector, a processor and mobile phone or computer [131].

4. ECG Monitoring The ECG can measure the heart rate and rhythm of the heartbeat and it is an indirect sign of blood flow to the heart muscle. In addition, it helps in diagnosing prolonged QT intervals (electrical depolarization and repolarization of the ventricles), myocardial ischemia and arrhythmias [132]. Many studies [30, 32, 42, 133–135] clearly states and discusses about IoT-based ECG monitoring. In [136], a portable IoT-based ECG monitoring system has a transmitter and receiver. This system makes use of the real-time abnormal ECG data for detecting the cardiac problems.

5. GSR Monitoring The sympathetic and parasympathetic nervous systems control and regulate the body to internal or external stimuli [137]. The parasympathetic system is responsible for conserving and restoring the body energy and the sympathetic system drives the blood pressure, heart rate and sweat secretion. In order to assess the stress and emotions of a human, GSR can be used for reflecting the activity of the nervous system [138, 139]. A low powered and wearable system for GSR monitoring is developed and it can be worn for a longer period of time to disclose psychophysiological conditions [140, 141].

6. Oxygen Saturation Monitoring Oxygen saturation (SpO_2) indicates the amount of oxygenated hemoglobin in the blood and abnormal oxygen level in blood acts as a vital sign for health issues like cardiovascular diseases, pulmonary diseases and anemia. In [142], IoT-based pulse oximeter is proposed for remote patient monitoring which consumes less energy and also cost effective. Larson et al. [143] developed a WSN-based wearable device for monitoring the oxygen saturation in blood.

7. Activity Monitoring The regular monitoring of physical activities and movements is widely done in rehabilitation, prediction of musculoskeletal diseases and fall assessment. A research study identified that the walking patterns of an individual person strongly reveals their health conditions [144]. Therefore, walking style of a person needs good balancing and synchronization of various body parts and any abnormality in walking patterns indicates the central nervous system, musculoskeletal or nervous system diseases. In [146] designed a gait detection system composed of inertial motion and magnetic sensors, which measures the angular velocity and flexion–extension angle for each leg. In addition, an adaptive algorithm is proposed for detecting the gait-event.

8. Rehabilitation System The main intention of rehabilitation is to improve or restore the quality of life of the persons with physical disability. The potentiality of IoT enhanced the rehabilitation systems which modified the life of aged persons. An IoT-based smart rehabilitation system with an active platform provides an effective remote rehabilitation and intervention [147]. Many studies [148–151] have justified that IoT plays a prominent role in rehabilitation systems applied on smart city medical systems, hemiplegic patients and childhood autism patients.

9. Smart Wheelchair System With a focus toward wheelchair users, identified that there is the necessity of monitoring their health condition and safety. Many studies explored the fully automated smart wheelchairs for physically disabled people. IoT accelerated this work and proposed a wheelchair-based healthcare system in [152]. This system uses Wireless Body Area Network (WBAN) composed of many sensors as per physiological requirements. Intel developed IoT-based connected wheelchair that can monitor various vital signs of the person sitting in the chair and also it aggregates the user's environment to provide location accessibility [153].

10. Medication Control System The denying of medication is a serious hazard to human health and it upholds huge financial supports. IoT overcomes this issue by providing many cost-effective solutions. In [154], an IoT-based medication management system is proposed with intelligent and interactive packing (I2Pack) method and intelligent medicine box (iMedBox). This system collects various medical data by wearable sensors for the diagnosing of diseases. Thus, it enhances the life quality of elderly, physically disabled and sick patients. An IoT-enabled medication control system uses RFID tags that allow physicians to remotely prescribe medicines and drug delivery [155]. Finally, Table 7 presents the strengths and weaknesses of applications.

Conclusion

Organizations and researchers have initiated globally to explore IoT solutions to improve healthcare facility. This has renovated the existing medical services using potential of the IoT. This paper focuses on diversified aspects, recent trends and system development using IoT from healthcare perspective. A number of IoT-enabled health monitoring systems have been analyzed and compared the various H2IoT network design taxonomy in terms of H2IoT network topology, architecture and platform. In addition, this paper explored the different wireless communication technologies used in H2IoT systems, which facilitates the transmission and receiving of health data. This paper consolidated the various security issues, requirements, challenges, threats and attacks in H2IoT area. Then, the applications of IoT in healthcare domain has been discussed in two different variations and revealed how the technologies enhancing the intelligence of H2IoT. The results found in this survey paper are assessed to be useful and highly effective for healthcare providers, researchers, scientists and medical organizations to endorse the ubiquitous deployment of IoT in healthcare industry.

Table 7 Evaluation of H^{2}IoT applications

H^{2}IoT application type	Applications analyzed and references	Strengths	Weakness
Dispersed applications	Blood pressure monitoring [123–125]	Allows monitoring of patient blood pressure level continuously and remotely Allows accessing of patient data in real-time via internet An intelligent blood pressure monitoring system tracks the location of the patients [125]	In [123] the authors presented only the communication structure for BP monitoring and the structure requires modification for real-time deployment The system presented in [124] requires manual intervention for sensing the BP levels
	Body Temperature Monitoring [127–129]	Provides accurate detection of patient temperature levels No exclusive communication required and it make use of home networks for transmitting the sensed data	The system monitors without clinical follow-up Inefficient analysis of data
	Blood glucose monitoring [128–131]	Allows detecting of blood glucose level via noninvasive methods.	The system intelligence is low
	ECG monitoring [132–136]	Provides monitoring of various parameters in heartbeat Provides excellent service at the time of medical emergency	Clinical support was not implemented efficiently
	GSR monitoring [137–141]	System continuously monitors the GSR with low power consumption for accurate diagnosis of psychological conditions	The gathered data are not mined effectively with the help of clinical support algorithms
	Oxygen saturation monitoring [142, 143]	Systems are cost effective and consume less energy	Absence of medical intervention or assistance upon an emergency situation.
Congregate applications	Activity monitoring [145, 146]	Provides high degree of accuracy in evaluating the activities Provides accurate gait-event detection based on adaptive algorithms	Clinical validation is not provided sufficiently
	Rehabilitation system [147]	The system provides remote monitoring along with medical intervention	Medical support algorithms are underutilized
	Smart wheelchair system [152, 153]	Allows early detection of medical exacerbation for wheelchair users	Patient involvement in caring process is narrow
	Medication control system [154, 155]	Intelligent based approach for resolving the denying of medication problem Allows issuing of remote medicine prescription	Clinical validation of the data is not provided

Compliance with Ethical Standards

Conflict of interest Authors declare that they have no conflict of interest.

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