Noname manuscript No.
(will be inserted by the editor)

Internet of things in healthcare: A survey

Ahmed Izzat Alsalibi, Mohd Khaled Yousef Shambour, Muhannad A. Abu-Hashem, Mohammad Shehab, and Qusai Shambour

Received: date / Accepted: date

Abstract The Internet of Things (IoT) is a novel technological that makes smart devices the essential building blocks in the growth of smart pervasive frameworks. Health-related problems considered as one of the major issues that directly affect the quality of the life. Among other applications enabled by the IoT, healthcare technologies might be the most important one. Although there are several pieces of research are developed for the IoT health-care field, there are still considerably demanding research and projects of exploiting the benefits of IoT in the healthcare domain. This paper surveys current advances in IoT-based health care focused in the aspects of privacy and security techniques, e-health and m-health, system design and architecture, cloud, fog, and evolutionary computing, and network and communication techniques. This paper will directly support researchers and health care professionals in their understanding of developments in the domain of IoT-based health care technologies, thus enabling them to spark further research in this area.

Keywords Internet of Things, Wearable sensors, E-health, Cloud computing, Authentication, Encryption

1 Introduction

The Internet of things (IoT) is group of smart objects that are wirelessly connected via smart sensors. IoT will consist of billions of smart communicating

A. I. Alsalibi (corresponding author), Information System College, Israa University, Gaza-Palestine; M. K. Y. Shampour, Department of Scientific Information and Services, The Custodian of the Two Holy Mosques Institute for Hajj and Umrah Research, Mecca, Saudi Arabia; M. A. Abu-Hashem, Department of Geomatics, Facilty of Environmental Design, King Abdulaziz University KAU, Jeddah, Saudi Arabia; M. Shehab, Faculty of Science and Information Technology, Al Zaytoonah University of Jordan, Amman, Jordan; Q. Shambour, Department of Software Engineering, Faculty of information Technology, Al Ahliyya Amman University, Amman Jordan. Emails: asalibi@israa.edu.ps, Myshambour@uqu.edu.sa, abuhashem4@yahoo.com, moh.shehab12@gmail.com, q.shambour@ammanu.edu.jo.

'things' and is considered as an integrated part of the future Internet. Recently, the IoT has drawn significant research attention in which it provides proper solutions for many modern applications such as waste management, smart cities, transportation, emergency services, security, retails, automotive industries, agriculture, and healthcare [137], [50].

Healthcare represent one of the most attractive applications that are enabled by the IoT. The IoT has the prospective to enhance many healthcare applications such as fitness programs, remote health monitoring, elderly care, and chronic diseases. Enriching the user's experience, decreasing costs and enhancing the quality of life are expected benefits by IoT-based healthcare services. IoT-based healthcare providers are expected to be benefited by the reduction of device downtime through remote provision, the identification of optimal times for reloading supplies for diverse devices for their continuous operation, and fairly distributed the restricted resources over the patients. In addition, IoT based healthcare provide many benefits compared to conventional healthcare solutions, such as reliability, accessibility, stability, etc. [92], [50].

In recent years, the IoT in the healthcare domain has high broad attention from researchers across the world to discover the potentials of utilizing the IoT in the healthcare and address its challenges. Accordingly, there are currently various applications, prototypes, and services in the field. Nevertheless, the use of IoT in the healthcare field stills in its infancy. Thus, a comprehensive details of existing research on the IoT based the healthcare is very helpful for a variety of researchers who are greatly concerned in conducting more research in this field. This paper reviews current advances in IoT-based healthcare research and expose different aspects such as: security and privacy, network and communications, cloud computing and big data, e-health and m-health, system design and architecture, evolutionary and fog computing.

The rest of the paper is organized as follows: Section 2 mainly provides a classification of the existing research works of IoT-based healthcare technologies based on their contributions into five categories: (1) privacy and security techniques,(2) e-health and m-health, (3) system design and architecture, (4) cloud, fog, and evolutionary computing, and (5) network and communication techniques. Section 3 provide classification based on optimization objective and solution schemes. Section 4 provide extensive detailed about state of the art techniques as follow: In Section 4.1, the IoT-based healthcare techniques in terms of their privacy and security approaches is discussed. In Section 4.2, the IoT-based healthcare techniques in terms of compression and encryption is presented. In Section 4.3, the methods that focus on improving e-healthcare and m-healthcare including ageing, framework, system, model, platform, gateway, heart and medicine are investigated. In Section 4.4, the methods that focus on utilizing the huge amount of healthcare data in order to improve healthcare services are reviewed. In Section 4.5, the methods that using evolutionary algorithms to improve the efficiency of heathcare are discussed. In Section 4.6, the methods that using Fog and cloud computing are discussed. In Section 4.7, the methods that discussed the network and communication of heathcare are presented. Section 4.8 provides a comparative evaluation of data handling technique, energy consumption, combined technique, electrocardiogram, monitoring, mobile applications, sensor technology, wearable devices, and smart systems. Finally, summary and future research hints are given in Section 5.

2 Classification and overview

This section classifies the existing research works of IoT-based healthcare technologies based on their contributions into five categories: (1) privacy and security techniques, (2) e-health and m-health, (3) cloud, Fog, and evolutionary computing, (4) network and communication techniques, and (5) system design and architecture.

2.0.1 Based on privacy and security techniques

Privacy and security is the main concern issue in IoT healthcare systems. Many techniques was proposed to overcome this issue by encrypting the user data using different methods such as symmetric and a symmetric encryption, cryptography, hashing, and granted privileges to an authorized users to access these data. Table 1 presents the techniques that focus on privacy and security techniques including encryption, hashing, access control and authentication.

Table 1 Classification based on privacy and security techniques

Category	References
Encryption	[61, 76, 24, 81, 13, 64, 85, 105, 71, 82, 48, 49, 4, 27, 36, 112, 17, 84]
Hashing	[43, 65]
Access control and authentication	[21, 37, 42, 47, 57, 66, 130, 138]

2.0.2 Based on E-health and M-health

Electronic health (E-health) and Mobile health (M-health) are recent healthcare techniques gained significant attention nowadays because of the wide availability of IoT healthcare devices.

The massive quantity of data that gathered by IoT platforms gained the attention of researchers to analysis and utilize these data, in order to enhance the efficiency of heathcare services.

Table 2 presents the techniques that focus on improving E-healthcare and M-healthcare including ageing, framework, system, model, platform, gateway, heart, medicine and age.

Table 2 Classification based on E-health and M-health

Category	References
Framework	[41][32][93] [70][94][107][125] [127][114]
Gateway	[90] [99] [100]
Heart	[79][11][110][123] [72]
Medicine	[30][52][53]
Age	[63]
Medical emergency decision support systems	[102] [103] [124] [133]

2.0.3 Based on cloud, Fog, and evolutionary computing

Fog and cloud systems are essentially incorporated in IoT-health care domain. The data gathered from IoT platforms and devices are stored in Fog and cloud systems, for analysis and prediction purpose. Then, the data and information will be accessed by an authorized users only. Table 3 presents the techniques that focus on cloud, Fog, and evolutionary computing.

Table 3 Classification based on cloud, Fog, and evolutionary computing

Category	References
Cloud computing	[23] [31] [40] [44] [45] [87] [96] [111] [117] [121] [128]
Fog computing	[28][34][116] [16][77]
Evolutionary computing	[15] [78] [139]

2.0.4 Based on network and communication techniques

In this part we presents three different IoT aspects in terms of networks and communications, which are: (i) **data handling techniques** which focused on the communication protocols that are used and employed to transfer health data, scalability and fault tolerance, and scheduling. (ii) **energy consumption** which focused on the possibilities of improving the power consumption, decreasing overall delay, and enhancing the overall reliability of IoT systems. (iii) **combined techniques** which applied various approaches to manipulate health data measurements such as gathered data, sending, storing, and analyzing stages. Table 4 presents the techniques that focus on network and communication techniques.

Table 4 Classification based on network and communication techniques

Category	References
Data handling techniques	
Data synchronization techniques	[3] [97]
Network communication protocols	[60] [91] [122]
Scalability and fault tolerance	[35] [129]
Scheduling	[22] [46]
Energy consumption	
[98] [20] [62] [62] [131] [118] [132]	
Combined technologies	
[8] [18][19] [26] [56] [113] [120]	

2.0.5 Based on system design and architecture

This part considers evolutionary algorithms and techniques that proposed to improve the efficiency of using IoT in healthcare industry by performing different data analysis such as prediction and optimization on the gathered data. Table 5 presents the techniques that focus on system design and architecture including Electrocardiogram (ECG), monitoring, mobile applications, sensor technology, wearable device, and smart systems.

Table 5 Classification based on system design and architecture

Category	References
ECG	[39] [108] [126]
Monitoring	[10] [51] [12] [95] [104] [140]
Mobile applications	[5] [67] [33] [54] [109] [69] [68] [119]
Sensor technology	[89] [74] [83] [101] [2] [55] [58] [115] [80]
Wearable device	[14] [75] [73] [7] [86] [106]
Smart systems	[88][38] [29] [25]

3 Classification based on optimization goal and evaluation platform

Table 6 classifies the works based on optimization metric and it is clear that the techniques proposed are guided by multiple optimization goals which need to be carefully balanced.

The select of the tools for evaluating IoT based healthcare techniques is very important. while the simulation has flexibility to examine the designs which may be currently not has any real implementation, its may be very slow to permit high exploration of the design-space. In contrast, real-systems insemination permits more accuracy testing and because of their high speed, its permit to executing huge number of procedures and instructions. based on

Table 6 Classification based on optimization metric and evaluation platform

Category	References
Optimization metric	
Performance	[32][93] [100][99][110] [102][103][133] [40] [77][116] [91][60] [122][129] [46][22][8] [18][20] [62] [118] [131] [95][54][58][88] [25] [21][37][138][66] [130][43][76] [64][85][4] [27][112][17]
Energy consumption	[90][100][99] [77] [35] [119][74][38][73] [42] [105] [49] [59]
Accuracy	[63][32][41] [70][125][127] [90] [99][11] [100] [79] [110] [123] [52] [53] [102] [103] [133] [128] [135] [28] [116] [19] [97] [7][75] [65] [81] [82][48][36]
Security	[21][37][138][66][130][43][76][64][85] [4][27][112][17] [42][105][49][59] [65][81][82][48][36] [65][81][82][48][36]
Hardware cost	[3] [39][140][83]
Evaluation platform	
Real-system/prototype	[63] [70] [93] [94] [107] [40][135][23][16] [127] [90] [100] [99] [11] [100] [79] [110] [52] [53] [102] [103] [133] [91] [60] [35] [129] [22] [18] [19] [56] [108][95][109] [68][69][5][101][29][134][57] [24] [85] [36] [59]
Simulator	[124] [44] [28] [77] [116] [122] [46] [8] [3] [97] [62] [118] [131] [126] [12][51][80][115] [43] [65] [82] [64] [105] [48] [17]
Both simulator and real system	[51][67][10]
Framework	[32] [41] [70] [94] [107] [114] [125] [90] [100] [123] [30] [32] [41] [70] [94] [107] [114] [125] [90] [100] [123] [30] [104][2][86][9][6] [21][42][37][47] [66][130][138] [61] [76] [81] [13] [71] [27] [112] [84]

the above reasons, Table 6 also classifies the works based on their evaluation tools and platform.

4 IoT Techniques

4.1 Access and Authentication

This section discusses the IoT-based healthcare techniques in terms of their privacy and security approaches.

Chibelushi et al. [21] argue that the IoT Identification Management (IDM) issues have been raised as an important concern when building an IoT system. Each Thing (device and user) should have a unique identity, and the IDM should has the ability to differentiate between a user and a device, therefore, ensuring information and identity context safety. The paper studies the expected issue behind the IDM and introduces a new framework to examine the identity of things. The proposed framework is embedded inside mobile Ad Hoc network and designed to serve the wireless devices only in mobile. The proposed technique considers the limitation of network bandwidth by exchange little information at the same time. For security purposes, a sandboxing technique is used to protect the user's data when device is sharing with others.

Gope and Hwang [37] propose a new technology that uses a Body Sensor Network (BSN) to protect the privacy of the user. As users may be vulnerable for privacy violation in case they are not considering the security requirements, the paper highlights the major security requirements that should be considered in the BSN. Subsequently, a new BSN security system is proposed to fulfill such requirements. The proposed system consists of wearable sensors (i.e. Electromyography (EMG), Electrocardiogram (ECG), Electroencephalography (EEG), and Blood Pressure (BP)). The main function of the previous sensors is to gather the data and send it to a Local Processing Unit (LPU), which works as a coordinator. The LPU can be a smart phone, a PDA, or any other portal device. The main function of the LPU is to work as a router between the server and the BSN by using wireless communication medium (i.e mobile networks GBRS/CDMA/3G). In case the LPU observe any abnormal behavior, thereafter it will send an alert to the patient who is wearing the sensors.

Habib et al. [42] claim that the traditional authentication method that requires the user to show their credentials only has an issue, as it cannot examine the claimed ID of the user after the login process. The new proposed authentication system is based on wireless device radio fingerprinting and biometric modalities. The proposed system has the ability to ensure that the monitored data is belong to the proper user through the overall session. The proposed framework consists of three phases to increase the accuracy by correctly validate the patient's device, patient's physiological characteristics, and patient's behavior on continuous basis. The patient's smartphone is paired with the medical sensors during an issuing procedure. Thus, the patient used only the sensor that paired with smartphone. This pairing operation can ensure only that the smartphone can only connect with pre-authenticated sensors. The three authentication phases are: (1) Patient to smartphone authentication, (2) Smartphone to network authentication, (3) Patient to remote medical server authentication.

Hou and Yeh [47] introduce a sensor based communication architecture. The proposed technique is based on Single Sign On (SSO). In order to ensure system security and efficiency, one way hash function is used to ensure the security and the robustness of the proposed system. Furthermore, a coexistence mechanism is proposed to insure the correctness of the coexisting medical items. A coexistence mechanism has the ability to identify many tagged objects existing at the same time at the same location. This proof can be conducted at the application field of the medication management and inpatient safely.

Kai et al. [57] argue that to protect the privacy of any patient in IoT based healthcare system, a systematic mechanism is required. For trust purposes, an interactive vector is proposed to communicate the user devices with system brokers. The main idea is to maintain a trustful IoT Application Market (IAM). In addition, features and behavior of applications in the marketplace and user devices respectively can be exchanged in mathematical value to setup the connection among users and market. The proposed system works as follows: to establish any healthy IoT application to the IAM, the application owners as service providers should have been authenticated first from the PA. Then, the PA should provide cryptography credentials for each actor. Through the monitoring period, the users generates feedback vector and send it to the IAM and PA. After that, the IAM gathered the feedback vectors to calculate and measure the next evaluation vector.

Kumar et al. [66] propos a system ontology based IoT. The ontology decision model makes the critical medical operations easier for all the doctors in emergency time. This will provide information for the doctors about diseases and help to provide treatment, thus the rate of deaths could be decreased. The position of doctor and hospital will get increased due the shared information through the database of ontology. As a result, the details of disease such as treatment, symptoms, causes, effects are all structured in ontology manner and saved in different databases. Data is shared among different organization by using PROTEGE tools [137].

Wortman et al. [130] propos a new system based on Architecture Analysis and Design Language (AADL), in order to make an efficient fit for the design of embedded systems. The core function of AADL is to link system architecture and design requirements to perform analysis at early stage in order to discover and solve error. The proposed language is flexible; it could be extended to work as user-defined mechanism for integrating customized constraints or existing AADL Annexes. This flexibility also provides an ability to add the random networks of wireless sensor definition to the description of customizable properties, devices, processes and systems.

Yeh [138] proposes a secure healthcare system based on BSN architecture. To simultaneously grantee the efficiency of the system with confident to transmit the data through public IoT devices. They using solid crypto-primitives to establish two communication methods to grantee confident transmission and provide extra authentication between smart objects and devices. When the two channels, i.e. "sensors to Local Processing Unit (LPU)" and "LPU to BSN server", are opened, no grantee that the transmission of data is secured. An attacker may initiate malicious behaviors, (i.e. bio-data espionage on a person). The result can be much worse if the connection is not secure. Furthermore, the proposed system is implemented with Raspberry PI platform in order to express the efficiency and feasibility.

4.2 Compression and Encryption

[136] try to enhance the security of the wearable devices based IoT. The proposed system handles the key exchange using Elliptic Curve Cryptography (ECC). The ECC composed of three stages: setup, regeneration, verification, and key exchange. The proposed system identifies the patient using patient's SIM card number along with the private key. In order to avoid the replay attack, the private key is created by legal use without using third party.

Kumar and Gandhi [65] propose an authentication method by using hash functions, agents, session keys and random numbers to validate devices using public key algorithms and a combination of hash and encryption. Furthermore, they proposed an authentication scheme to validate the IoT healthcare system's device groups. They have authenticated devices using 5 key steps of mutual authentication session.

Another hashing method proposed in this paper, called Transport Layer Security (TLS) protocol, to move the records from source to destination in more secure and reliable pattern. The proposed protocol helps the user to avoid no- lose messages. Datagram Transport Layer Security (DTLS) is also proposed to tolerate unreliability. The DTLS composed of a base protocol, handshake protocol, record layer, cipher layer and alert protocol. The ability of an attacker to send multi messages, which causes a Denial-Of-Service (DOS) attack toward the server, is the main challenge for this protocol. To overcome this concern, a smart authentication gateway to protect the sensitive data from both the attacker and malicious is proposed.

Over and above, there are plenty of security methods proposed in literature to address the security issue of IoT such as: [61], private key [76], public key [24], private and public [81, 13], symmetric [64, 85, 105] symmetric and asymmetric [71, 82], cipher text [48], cryptographic [49, 4, 27, 36, 112, 17], and handshake [84].

Table 7 summarizes the advantages/disadvantages of different security techniques.

Table 7 A comparative evaluation of different IoT security techniques

Data encryption	(+) IoT can guard exposing healthy and steady improvement in practical applications. The IoT gateway can solve sensor communication interoperability problems as well as secure the process of authenticating the services and patient's data transmission. (+) It provides a secure services in which confidentiality, integrity, and availability are guaranteed for all users. (+) Robust in terms of preventing security breach attacks on the databases. afford scalable and robust end-to-end security. (-) Managing private key and controlling the access requires further investigation. (-) User security choices are limited since it does not define specific cryptography algorithm or key generation function
Hashing	(+) Confidentiality is protected by using hash functions and channel protection during data exchanged in the communication sessions. Anonymity is assured by using fixed keys with random numbers and hash functions. (-)An effective and highly secure authentication methods is required.
Access control and authentication	(+) Suitable to be utilized as the core protection method for an IoT based healthcare systems. Guaranteeing data exchange confidentiality and affording entity verification among smart objects, the local processing unit and the back-end server. (-) More development is required if robust IoT applications are to execute on diverse Mobile Ad Hoc Network (MANET) in support of healthcare applications.

4.3 E-health and M-health

Electronic health (E-health) and Mobile health (M-health) are recent healthcare practices that growing rapidly due to the spread of IoT healthcare devices. The massive amount of health data that collected through IoT healthcare devices drags the attention of researchers to utilize these data in order to improve healthcare services. This section discusses the methods that focus on improving E-healthcare and M-healthcare including ageing, framework, system, model, platform, gateway, heart and medicine.

4.3.1 Ageing

New technologies contribute directly in improving population ageing in the last decades. As IoT devices become widely used, IoT drags researchers interest to utilize the huge amount of information that is captured and collected using these devices.

Konstantinidis et al. [63] present a new idea that aims to utilize the huge amount of data collected by IoT devices in order to assist active ageing as well as ageing well. The proposed method employs IoT healthcare devices with the aid of IoT-oriented infrastructures such as Extensible Messaging and Presence Protocol(XMPP). The proposed platform provides a disease management tool.

4.3.2 Framework system model and platform

speeding up the growth of healthcare data leading to a massive amount of data that require high quality framework in order to manage and analyze such amount of data to provide high quality healthcare services. This section discusses the proposed frameworks, models, systems, and platforms that aim to utilize IoT devices to increase healthcare services quality.

Gelogo et al. [32] present a mobile gateway architecture for u-healthcare as well as provide a general idea of IoT in terms of u-healthcare applications. The proposed framework utilizes the heterogeneous data collected from various IoT devices in order to improve u-healthcare services. The presented work opens new path for researchers to utilize IoT sources to solve u-healthcare challenges.

A smart healthcare kit is proposed by Gupta et al. [41] to monitor emergency medical services. The proposed model utilizes patient's data that were collected from various IoT devices in order to aid emergency medical services with useful information. The proposed design considered as a health manager in which the system could replace the doctor by checking patient's status and giving alarms if the patient health is at risk.

Another healthcare model is proposed by Lee and Ouyang [70] in order to utilize the data collected from personal health devices of IoT. The proposed model presents collaboration protocols, which detect risky information and share them among other devices. The proposed model aims to improve the quality of personal health feedback by increasing and utilizing the collaboration between IoT devices.

Patra et al. [93] target another aspect of healthcare by proposing low power acquisition and digitization system. The proposed system filters and amplifies the signals that have linearity above 12bits. The proposed work comes as a response to the increasing demands for low power signal acquisition and digitization system.

As could-based web services spread widely due to its popularity for expanding the market. Pescosolido et al. [94] propos a cloud-based web server architecture for healthcare services. The proposed model can improve the market in e-health and m-health by aggregating huge amount of data collected from different IoT resources. Furthermore, Santos et al. [107] propos an architecture and a classification for m-health IoT systems. The proposed architecture uses a wide variety of gateways and health managers to distribute them on different locations to enable multiple IoT health devices to access single service.

Building smart healthcare center coins the main goal that inspired Singh [114] to propose a mobile e-healthcare system. The proposed model allows doctors to address the patients through healthcare IoT devices without being in the healthcare center physically. The main function of the system is to utilize the capabilities of IoT in order to overcome the shortage of healthcare centers in Indias villages.

Ullah et al. [125] present a semantic model called k-Healthcare for recording and accessing patients' health information. The proposed model consists of 4 layers; starting with sensor layer, going through network layer, then Internet layer and ending with services layer. The main purpose of the model is to create a platform that simplifies accessing patients health information.

A disease diagnosis framework using cloud-centric IoT is proposed by Verma and Sood [127] to build m-healthcare monitoring framework. The proposed framework utilizes IoT services especially in m-healthcare applications in order to trace potential disease and ranks its severity level.

4.3.3 Gateway

Healthcare data are massively increasing as IoT personal healthcares devices are growing rapidly and continuously. The growth of IoT healthcare devices increases the heterogeneity of collected and transmitted data across the network, which demands effective and robust healthcare methods to utilize gateways in order to control and manage this massive amount of transmitted data. This section discusses healthcare methods that utilize gateways in order to control data transmission among IoT devices.

Niranjana and Balamurugan [90] propose an igateway platform to improve heterogeneous data communication. The proposed platform presents iMedBox (intelligent Medicine Box) and iMedPack (intelligent pharmaceutical Packaging). The proposed platform affords uncomplicated IoT devices' connectivity as well as in-home healthcare service. Furthermore, to afford high quality healthcare services, Rahmani et al. [100] propose a utilization of smart E-health gateways positions. The purpose of the proposed method is to utilize the huge number of health monitoring systems. In addition, Rahmani et al.

[99] propose another means of utilizing smart E-health gateways by adapting Fog computing architecture. The proposed method employs the strategic locations of smart gateways to enhance the quality of E -health.

4.3.4 Heart

Heart diseases are life-threatening diseases. Early detection of heart diseases leads to avoid health complications that may result in patient's death. In this context, many researches are conducted to utilize new technology in order to detect any heart related anomalies. This section discusses the methods that utilize IoT healthcare devices in order to improve heart diseases detection. Ukil et al. [123] discuss and analyz the importance of utilizing IoT healthcare devices for diseases detection and prevention. They highlighted the importance of anomaly detection accuracy especially under high noise conditions. The authors aim to raise the awareness of the significance of IoT healthcare devices and to encourage researchers to utilize IoT in healthcare research field. A real time monitoring system for heart diseases is proposed by Li et al. [72] to utilize the large number of available healthcare services. The proposed method consists of two stages: data collection stage that is used to build a monitoring scheme, and data transmission stage. The aim of the proposed method is to build a monitoring system that transmits patients health information in real time. Azariadi et al. [11] develop an Electrocardiography (ECG) system for heartbeat diagnosis. The proposed method presents an analysis and classification for ECG signals gained through wearable ECG devices. The analysis is done by using Discrete Wavelet Transform (DWT) while Support Vector Machine (SVM) is applied to categorize the signals. Furthermore, heart attack detector is proposed by Manisha et al. [79] to eliminate or at least reduce heart attack hazardous effects. The proposed system employs heart rate monitoring as well as IoT blood pressure systems in order to improve the heart attack detection. The proposed system is aiming to help people get rid of heart attack or at least reduce its danger by early detection of the disease.

Senthilkumar et al. [110] propose monitoring and emergency healthcare management system for monitoring the level of heart beat and finger moisture. The proposed system allows data transmission between patients and physician through healthcare IoT devices remotely using GPRS/GSM. Furthermore, the transmitted data are sent to cloud for further analysis and monitoring. The proposed system aims to reduce the healthcare management and operational costs as well as providing high quality services.

4.3.5 Medicine

Medicines have gained an important position in healthcare system as its direct role in fighting diseases. Even though medicines are important but prescribing the right medicine considering patient's health condition and without side effects still a challenge. This section discusses the methods that utilize IoT healthcare devices to collect, analyze, monitor, and manage patients' health information in order to prescribe medicines without jeopardizing patients' health. Farahani et al. [30] proposed a patient centric Ehealth ecosystem architecture in order to connect doctors with patients remotely and improve the provided healthcare services. The proposed system contains 3 layers; device, fog computing and cloud. The proposed system comes as a response to several challenges in healthcare such as data management, scalability, regulations, and others. Furthermore, drug interaction checker is proposed by Jara et al. [52] to utilize IoT in pharmaceutical system by testing any harmful side effects of drugs. The proposed system employs Near Field Communication (NFC) and barcode identification in order to match drugs ID with patient health records and check its suitability. In addition, another drug interaction checker is proposed by Jara et al. [53] in order to reduce adverse drug reaction and increase drug compliance. The proposed system utilizes IoT devices in order to monitor medicine for any side effects of pharmaceutical excipients.

4.4 Big Data and Cloud Computing

The spread of IoT healthcare devices contribute directly in increasing the amount of collected healthcare data. This increment in healthcare data drags the attention of researchers to utilize computational capabilities in order to support doctor decisions by inferring useful information about patients' health, which reduce the burden on doctors' side. This section targets the methods that focus on utilizing the large amount of healthcare data in order to improve healthcare services.

4.4.1 Medical Emergency Decision Support Systems

Supporting doctors' decision for emergency cases using computers become necessity as the medical data massively growing because of the spread of medical sensors that tied to patients. This section discusses the decision support methods that utilize the collected data from IoT devices in order to make proper actions accordingly.

Rathore et al. [102] proposed management system for medical emergency using Hadoop in order to utilize and manage the massive amount of heterogeneous data that collected through IoT devices. The proposed management system employs enhanced network architecture to collect the data then an intelligent system is used to analyze the data and make the proper actions. The proposed system is supposed to manage collecting data from a huge amount of sensors that attached to humans body in order to improve the quality of healthcare services. In addition, Rathore et al. [103] presented a real time emergency system to utilize IoT healthcare devices for public health using the medical sensors that attached to human bodies. The proposed system consists of multiple layers starting with data collection and ending with intelligent building layer, which handles data analysis decision making. The purpose of such systems is to utilize and manage the huge amount of heterogeneous data collected from diverse healthcare sensors.

A semantic interoperability model is proposed by Ullah et al. [124] in order to manage healthcare data exchange among IoT devices. The proposed model works as decision support system as its ability to recommend medicine based on information that collected from various and heterogeneous IoT healthcare devices. Xu et al. [133] proposed emergency medical services method to utilize the heterogeneous data that collected using IoT devices. The proposed method consists of three stages, starting with semantic data model to save and infer IoT data. Then building UDA-IoT (resource- based data accessing) method to maintain collected data. Ending with the construction of emergency medical services system to manage data collection, integration, and interoperation.

Table 8 summarizes the advantages/disadvantages of various E-health and M-health techniques.

Table 8 A comparative evaluation of various E-health and M-health techniques

Framework	(+) Utilizing IoT devices to increase healthcare services quality. (-) Due to the size of targeted data, building efficient systems still a challenge.
Gateway	(+) Utilize gateways capabilities in order to control the massive amount of data transmission among and between IoT devices. (-) Highly dependent on efficient and customized resources such as sensors' power processing, memory, transmission speed, and energy.
Heart	(+) Utilizing IoT healthcare devices in order to improve heart diseases detection. (-) Building efficient detectors still a challenge due to the large diversity of physical signs that need to be monitored.
Medicine	(+) Utilizing IoT healthcare devices to collect, analyze, monitor, and manage patients' health information in order to prescribe medicines without jeopardizing patients' health. (-) Applicability, such systems needs high accuracy and flexibility which is a challenge.
Age	(+) Utilizing the huge amount of information that is captured and collected using IoT devices to improve population ageing. (-) Further investigation is needed due to lack of research methods.
Medical emergency decision support systems	(+) Analyzing and managing the massive amount of data collected using IoT devices to enhance the quality of healthcare services. (-) Managing such amount of data requires robust and efficient platforms.

4.5 Evolutionary Computing Algorithms

This part considers evolutionary algorithms to improve the efficiency of using IoT in healthcare industry by performing different data analysis such as prediction and optimization on the collected data.

Bhatia and Sood [15] proposed an IoT healthcare framework for ubiquitous healthcare during workout sessions. The proposed model begins by accruing data from different attributes throughout workout sessions. The collected data are then transferred to cloud in order to analyze the real time health situations and calculate the vulnerability of health state using Artificial Neural Networks (ANN) model.

Man et al. [78] developed a roadmap for assessing IoT in the context of healthcare industry during the period (2010-2020). The proposed model consists of seven modules, including Radio-Frequency Identification (RFID) and Wireless Sensor Network (WSN) devices, IoT middleware, Graphic User Interface (GUI), cloud database, core management, ANN and Fuzzy Logic (FL). The ANN is used to predict the demand of healthcare assets and FL is used to observe the balance between early results from ANN, emergency level, stock level, and available loan with a high rank of accuracy. In another study, Zhang et al. [139] used Genetic Algorithm GA to observe the best possible data replica replacement solution for cloud storage. Authors aimed to improve the user time accessibility, load balancing, system scalability, and reliability of cloud storage. The proposed scheme optimizes the replica placement strategy through creating different mathematical models according to the different data types using GA in order to figure out the suitable data center.

4.6 Fog and Cloud Computing

Fog and cloud systems are essentially incorporated in IoT-healthcare domain. The data gathered from IoT-medical devices are allocated in Fog and cloud systems for storing, analysis, prediction, and other processing operations. The processed data are then delivered to users who have the privilege to access it.

4.6.1 Cloud Computing

A platform is designed by Doukas and Maglogiannis [23] to manage patient records on the cloud, and utilize hardware and software resources. The proposed system architecture collects patient data from mobile and wearable sensors and send the collected information and sensors status to cloud via mobile phone or special-purpose microcontroller. The cloud hosts an Application Programming Interface (API) to provide a real-time data visualization about the patient and sensors status.

Garai et al. [31] propose a crowd-sourcing telemedicine system that is integrated with the IoT platform. The aim of this research is to establish general interoperability among devices of eHealth IoT, telemedicine tools and healthcare information systems. The proposed system has the ability to capture the intercepted information, processed, and evaluated immediately.

A cloud centric architecture is proposed by Gupta et al. [40] to predict physical activities of users on a regular basis. The proposed architecture used embedded equipment sensors rather than wearable sensors to record physical activities of users while they are using treadmill in a healthcare center. The recorded data is transferred first to local data base servers and then to centric data center using eXtensible Markup Language (XML) web services. The stored data can be used to visualize results and alerts according to the users health condition.

Hassan et al. [44] addressed in their study some challenges of integrating IoT and cloud computing in healthcare domain including reliable data transmission to cloud, dynamic resource allocation, and effective data mining tools. The proposed system uses wearable sensors and mobile devices to gather patient data . The collected data is sent to a portable computing device through bluetooth mobile device via bluetooth and thereafter to the server on the internet or cloud. Representational State Transfer (REST) web services are used to send data and receiving information from cloud. The collected data can be shared with licensed social networks and medical societies to looking for personalized trend, growth of disease, process of rehabilitation, and pharmacotherapy effects.

Hassanalieragh et al. [45] discuss a system architecture for IoT with cloud-based processing in healthcare field. The proposed system consists of three main components: *Data Acquisition* which uses a patient smart mobile device to acquire physiological biomarkers measured by wearable sensors; *data transmission* that is used to send gathered data to healthcare organization data center with assuring security and privacy; and *Cloud Processing* which is responsible for storing patients information, analytics the patients health condition, and visualization that makes the analytical data readily comprehend and recognized.

Green IoT agriculture and healthcare application using sensor-cloud integration model are introduced by Nandyala and Kim [87]. Sensor-cloud employs physical sensors for data collection and data transfer to the cloud. The general requirements of the proposed architecture are turning off the unneeded facilities; sending needed data only; minimizing data path and wireless data path lengths; trading off processing for communications; emerging advanced communication techniques; and utilizing renewable green power sources.

Plageras et al. [96] propose a surveillance IoT framework to widespread monitoring of healthcare. The proposed system architecture composed of three layers: home environment which uses 6LoWPAN mesh network to connect IoT devices including sensors edge router, cameras, and local server; the gateway; and cloud which is responsible for storing and analyzing data and video. Doctors and caregivers can provide advices to patients according to the analyzed data.

Sermakani [111] discusses in his research: the IoT applications in healthcare domain; a case study for real-time remote diagnostics at the Syrian refugee camp in Duhok; a real-world project experience on developing products for rural healthcare; the IoT healthcare challenges; and the IoT roadmap and the healthcare future.

Strielkina et al. [117] discuss the possibilities of applying the queuing theory for modelling IoT system. The authors represented the IoT system process as a Markov stochastic procedure with discrete conditions and continuous time.

A cloud based conceptual framework was proposed by Tyagi et al. [121]. The research aimed to enhance the services provided to patients through improving the communication and collaboration between patients and the healthcare actors. The provider of cloud service offers a platform and infrastructure as services to host IoT health applications.

Verma et al. [128] propose an IoT cloud-centric based smart student m-healthcare monitoring system. The proposed system explores the diseases status of student through predicting the level of potential disease. The authors discussed the temporal data mining for the information gathered by medical and IoT devices, and the decision-making according to various critical circumstances.

In another work, an electrocardiogram monitoring based on IoT techniques were proposed in [135]. Patients data are gathered using wearable sensors, and then send to cloud server via WIFI. The authors used HTTP and MQTT protocols to offer visual and timely electrocardiogram information to certain users and to store the data for further analysis.

4.6.2 Fog Computing

Fog computing provides may advantages that can improve the system performance including low latency, network bandwidth efficiency, mobility, location awareness,, better response time, and high service quality.luding low latency, network bandwidth efficiency, mobility, location awareness,, better response time, and high service quality. A demo system for IoT-healthcare in a hybrid cloud/Fog environment is proposed in [16]. The proposed demo aimed to employ the application system of IoT healthcare in hybrid environment, deploy applications components via cloud and Fog nodes, and mange and execute the demo with respect to orchestration techniques.

Mahmud et al. [77] study the integration services of cloud-Fog environment in interoperable healthcare. The proposed architecture forms a number of clusters that containing multiple fog nodes from the same or different levels. Nodes are assigned to perform three tasks: executing applications, hosting database, or maintaining communication with other clusters. All communication within a cluster is the responsibility of cluster head node. The cluster represents the cloud datacenter whereas Fog nodes are employed as server nodes. The cluster head node executes as a manager of resoursce for the cluster. Fog nodes are responsible of executing the healthcare applications and handling database operations.

Elmisery et al. [28] propose a method to preserve the health records privacy which are used by a recommender healthcare system in the cloud. The authors employed Fog nodes at the client side to host a privacy middleware, which perform concealment operation using distributed data collection protocol.

Gia et al. [34] discuss the possibilities for improving the healthcare monitoring system. The authors employed Fog nodes to support advanced services including distributed storage, location awareness, embedded data mining, and real-time notification service.

Sood and Mahajan [116] propose an IoT health care system to identify and control the spread of Chikungunya virus (CHV) in the affected region. Fuzzy-Cmeans method is employed to detect the users who are possibly infected by CHV and send urgent notifications to users from fog layer. Moreover, social network analysis at the cloud side is responsible to represent the spreading status of the CHV.

Table 9 summarizes the advantages/disadvantages of different computing techniques.

Table 9 A comparative evaluation of different computing techniques

Cloud computing	(+) Accessibility of data and services anywhere and anyplace using internet connection. (+) Users are free from worrying about several issues including storage resource, network communication, and computation requirements. (-) Dependency of network connection. (-) losing the full control of data. (-) Less security and privacy concerns.
Fog computing	(+) Efficient transmission and processing time. (+) Cost efficient in deploying new data-centers (+) High mobility. (-) Hard to detect a hacker attack. (-) Hard to detect the hacked file.
Evolutionary computing	(+) Can be used to improve system extensibility and reliability of cloud storage. (+) Optimized resources and quick access purposes. (+) Can be employed to predict probabilistic health state vulnerability. (-) More research investigations in this area are required. (-) The accuracy result of the evolutionary algorithms are highly dependent on parameter setting.

4.7 Network and communication

This section includes three main subsections namely (1) Data handling techniques (2) Energy consumption which argues the possibilities of improving the consumption rate, decreasing overall delay, and enhancing the overall reliability; the last section named (3) Combined techniques which are applied various approaches to manipulate health data measurements from collecting data, sending, storing, and analyzing stages.

4.7.1 Data handling techniques

Data handling techniques focused on the communication protocols that are employed to transfer health data.

This section includes three main subsections namely, (1) Network and communication protocols; (2) Scalability and fault tolerance; (3) Scheduling.

Network and communication protocols Various types of sensors used in home appliances and IoT medical devices are integrated in the sensing layer in [60]. The research aimed to transmit health-data in an efficient way, with considering the limitation of the infrastructure of existing network. The authors deployed Constrained Application Protocol (CoAP) and Hyber Text Transfer Protocol (HTTP) at the home gateway layer to reduce bandwidth and the amount of data generated .

In another work,Oryema et al. [91] designed and implemented a messaging system using a constrained application protocol for IoT healthcare services. The proposed system combines the advantages of CoAP and Message Queuing Telemetry Transport (MQTT) protocols in constrained environments such as small message size and QoS, and supports many to many communications in IEEE 11073.

Ugrenovic and Gardasevic [122] proposed an IoT healthcare system to monitor the patient's health condition and to access health indicators using web browser at any time at any place. The research is focused on implementing CoAP protocol in Mozilla Firefox web browser. The objective is to overcome the issues associated with the classical routing protocols.

Scalability and fault tolerance Gia et al. [35] introduced a fault tolerance technique to cover many system faults in healthcare domain. The research aimed to overcome the bottleneck at edge routers, and to improve network fault tolerance. The proposed monitoring system starts by acquisition bio-signal using analog devices integrated in IPv6 medical sensor nodes to data representation stored in the cloud server.

OneM2M-based IoT system is proposed by Woo et al. [129] for healthcare monitoring device. The proposed system aims to improve the gateway procedure in converting ISO/IEEE 11073 protocol messages from PHDs to the IoT servers oneM2M protocol messages, and vice versa. Also, the authors propose an algorithm for fault-tolerant to support the system reliability such that fault tolerant daisy chaining are created at the same layer and the gateway stores a backup copy in order to recover from faults on gateways.

Scheduling Scheduling sensors technique for nullify interference in IoT healthcare environment is proposed by Dhar et al. [22]. The proposed technique aims to keep the interference away among different sensors in to guarantee the validity of health data and to ensure the efficiency of transferring data. The healthcare parameters are passed through shared channel with an equal priority. In case the parameter data cannot be fitted to time slots of sensors parameters, then the data will be split to a number of parts in order to fit between time slots.

Hindia et al. [46] propose a dynamic scheduling approach with the ability to serve different sensor category. The proposed approach employs android application to collect health information using sensors. The application then sends the data over Femto-LTE network according to the sensitivity of the patients condition which are classified to three main categories: (Class A; pressure of blood , heart rate , and temperature), chronic (Class B; ECG data), and normal (Class C; glucose data).

4.7.2 Energy consumption

In healthcare organizations, the energy consumption is about 6.5 billion each year, that amount is increasing to meet patients' needs [1]. Therefore, new ways should be founded to maintain or minimize the level of consumption. This section shows some of the relevant research on this issue.

Qiu et al. [98] focus on the instability energy sources of the body sensors, where the nodes may fail because of insufficient energy supplies. The authors introduced a self-recoverable time synchronization method (STSM) for health IoT. The STSM selects the candidate nodes dynamically, and then the candidate node selects new source node for charging. In the same time, the STSM joins the MAC layer timestamp the two-point least-squares method to safely enhance the precision of Pair Broadcast Synchronization (PBS) protocol. It worth to mention that the Sender-to-Receiver Protocol (SRP) model and Receiver-to-Receiver Protocol (RRP) are utilized in STSM. Therefore, the STSM provides more accuracy than PBS with the same amount of consumed energy [97].

In the wireless connections of the e-healthcare, a fast, reliable and energy-efficient fashion should exist. Thus, in [20], the authors divided the work into three parts. (i) Selecting the best level of power for every node by proposing a Power Level Decision (PLD) algorithm. Therefore, transmitting data per bit will consume minimum energy. (ii) Determining the optimal packet size by introducing a power level and Packet Size Decision (PPD) algorithm. Thus, reducing the consumption of energy or reducing the transmission power delay. (iii) Increasing the capability of battery energy within nodes by designing a Global Link Decision (GLD) scheme that leads to decreasing overall delay and enhancing the overall reliability at the same time. The energy efficiency is very important for Wireless Body Area Network (WBAN) which is considered as a highly convenient connection instrument for IoT healthcare devices.

Consequently, Kim et al. [62] propose a multi-hop WBAN structure scheme for to minimize the total control messages number as an energy efficient feature. The proposed scheme contains three operations: mobility support, setup the clustered topology, and improvement of transmission efficiency [62]. In the same context (i.e., WBAN), Wu et al. [131] propose a combination of a wearable sensor node, Bluetooth low energy, and solar energy harvesting which can be implemented on the autonomous WBAN. The multiple sensor nodes enable to measure the subjects body such as heartbeat and temperature distribution. Because of the possibility of deploying them on various body positions. In addition, there is a tracking technique that is used to utilize power of the sensor node [131].

A prototype for the IoT is introduced in [118], where the authors proposed a routing protocol to choose the appropriate neighbor to forward data, which was gathered and kept in the neighbor discovery process. While [132], review the radar sensors for IoT, especially high-accuracy low-power low-cost indoor positioning and healthcare monitoring sensors [132].

4.7.3 Combined technology

Almobaideen et al. [8] develop a system designated to tourist people who have chronic diseases to encourage them to go on a trip with a more enjoyable and safer as well. The proposed system employed wireless sensors to collect tourists health information and send them via cellular networks to a serving unit exist on the cloud. The serving unit performs analysis according to the geographical and transportation, health care, and tourism location databases. The system then offers the best road trip paths that is supported by health care centers.

Catarinucci et al. [18] offered a system that is used ultra-low-power hybrid network to gather ecological conditions and health information in real time through ultra-low-power hybrid network that consists of combining 6LoWPAN nodes with UHF RFID functionalities. The users either local or far used the web services and REST to access data at the control center

Chandel et al. [19] employ mobile devices for monitoring in healthcare domain. Authors introduced an improved sensing algorithm using single Inertial Measurement Units (IMU) for sensing of the fundamental events, such as fall, stride length, step count, and immobility.

Elhayatmy et al. [26] Introduced a mini review for the IoT depending on the wireless network of the body area and its architecture, routing, physical layer (PHY), MAC layer, and security.

Jimenez and Torres [56] implement an IoT-aware healthcare monitoring system Using the current IoT technologies and low-cost wireless sensors. The aim is to maximize the required for specialized personnel, at the same time minimize the expenditure of healthcare. Integrating the RFID, ubiquitous technology and machine reasoning in the IoT healthcare domain is discussed in [113]. In addition, authors presented how adaptive care can utilize the broadband communication over powerline.

Thangaraj et al. [120] provide an explanation for the IoT and healthcare technology drivers with the information from medical devices, validation of critical data, technical operation for remote devices, the network architecture, middleware, databases, and application services.

Al-Majeed et al. [3] propose a low-cost of the analytics device, communication, medical sensing. An IoT device is developed called "CogSense" to support real-time care for patients. The CogSense device consists of communication, sensors, and data analytics modules. The developed device includes specific machine-learning engine to analysis patient data and to suggest appropriate treatment. Table 10 show the features/weaknesses of different network and communication techniques.

Table 10 A comparative evaluation of different network and communication techniques

Data handling technique	(+) Utilizing the way of data handling to improve the performance of packet communications. (+) Reducing the volume of produced data and bandwidth requirements. (-) Diverse IoT technologies for a small constrained device designed for communication across sophisticated network.
Energy consumption	(+) An efficient energy consumption of IoT devices can avoid premature death of any device in the network system. (+) Reducing the number of total control messages. (-) An inappropriate selection of transmission power will degrade the network system performance.
Combined technique	(+) Multiple technology can be employed to facilitate the mobile location based services. (+) Automatic tracking and controlling of the biomedical devices for patients. (-) Some systems during the runtime of some systems, it's difficult to insert the new IoT sensors.

4.8 System design and architecture

4.8.1 Electrocardiogram

Electrocardiogram (ECG) is the procedure of tracking and save the electrical activity of the heart by employing the electrodes placed on the specific areas in the patient's body. Huge data is expected to be generated from this process. Gupta et al. [39] store and display these data on a website and make it available for the authorized personnel. The authors used Raspberry pi that is a substantive, inexpensive, and have much scope in future.

Satija et al. [108] propose a new quality-aware ECG monitoring system (ECG-SQA) that contains of transmission module, assessment module, and sensing module. New assessment method has been designed for the light-weight ECG signal quality, which can enable the android phone, ECG sensors, as well as the cloud server for ECG controlling framework. While in [126], the authors extracted the amount of entropy from heart rate to estimate the collision entropy, values of min-entropy, and Shannon entropy using created mathematical models.

4.8.2 Monitoring

There are many cases in which patients need long-term monitoring such as the patients with chronic diseases. Hence, the provision of constant monitoring is necessary. This Section shows some IoT works that concentrate on this issue. For example, Anumala and Busetty [10] classify smart devices as health devices like a micro oven. They extracted a significant amount of data from the smart devices for monitoring the health status of a patient. The working principle of the smart devices is to store and manage the health information.

Jabbar et al. [51] employ heterogeneous IoT devices by proposing Semantic Interoperability Model (IoT-SIM) to monitor the current health status of the patients. The authors used the Resource Description Framework (RDF) that is considered as a lightweight model, for relating things through triples to make it semantically meaningful. While Azimi et al. [12] adopted a hierarchical computing architecture, namely HiCH, concerning IoT-based health monitoring systems. The proposed system includes two main points: (i) introduces a suitable computing architecture for hierarchical partitioning. (ii) creates a management technique that is able to make autonomous adjustments to the patient status system.

The elderly patients need special treatment. For that, both of Pinto et al. [95] and Ray [104] propose an IoT-based health care system for elderly patients. Where Pinto et al. [95] introduce an IoT-ready solution through monitoring, supplying the techniques to activate alarms in emergencies and enrolling vital information of patients. As for Ray, he proposed a Home Health Hub Internet of Things (H^3IoT) framework. H^3IoT is effective for monitoring the health status of elderly patients.

Zois [140] applied sequential decisionmaking such as observable MDPs (POMDPs) and Markov Decision Processes (MDPs) on the realtime health monitoring, and treat it if necessary.

4.8.3 Mobile Applications

Mobile applications have paved a way for digital revolution in the healthcare industry by enableing healthcare professionals to quickly cater to medical emergencies and provide improved patient services.

Alex et al. [5] propose an intelligence medicine box platform. The box connected with the internet wirelessly using an android application (Health-iot), which gives the patient automatically alarm at the time of taking the medicine. On other hands, the system sends SMS alerts to the predefined guardian in case there are any vital signs.

In the [67], a binding protocol was suggested which authorizes the patients to utilize a general public medical devices in the same way like private medical devices for IoT Healthcare. This protocol deals with mobile phones, where is supplies real-time transmission function between them through two types: (i) transmission of streaming data (i.e., continuously transmitted), for example oxygen saturation or heart rate; (ii) transmission of one-time data (i.e., measuring data is changed every time), for example weight and blood pressures. As well Gelogo et al. [33] discuss the backdrop of IoT, especially its applications in the u-healthcare area. The authors planned to make the mobile as an integrated gateway to enable the heterogeneous devices for u-healthcare convergence.

Utilization of the smartphone fundoscopy to capture super-resolution images is proposed by Jebadurai and Peter [54]. They enhance the resolution of the captured images by using multi-kernel Ssupport Vector Regression (SVR). The proposed hybrid architecture helps to improve the diagnosis of ophthalmologists by providing them with high-resolution retinal images. While Saxena et al. [109] develop an IoT architecture for smart mobile healthcare using Named Data Networking (NDN). The proposed architecture solves the problems of the healthcare IoT exchanged data over the IP-centric Internet.

Lee [69] proposes a healthcare platform IoT-based mobile application through designing and processing a mobile device protocol, which allows the sharing of a medical device between multiple users. This protocol divided into: (i) Registration the patients in the medical device; (ii) a protocol used to register a medical device in the platform. The same author proposed a new service model for smartphones and wearable devices that based on distributed processing and connection protocols between the different devices. This service allows to recognize the user's function and processes the measured data such as blood pressure to show it on a healthcare service platform. In addition, the users can organize the service configurations in their mobile, handle services, and send the information for the participants in IoT-based healthcare service platform.

Talpur et al. [119] propose a system for the chronic cardiac healthcare monitoring. The capabilities of the proposed system are: (i) data acquisition of the body sensors; (ii) analyzing health situation by a smartphone; and (iii) transporting the bodily data to smartphones by sensors and a wireless body area network through bluetooth technology and ZigBee. After that, the bodily data is stored in a secure database in the external memory of the smartphone. Therefore, the proposed system allows to all smartphone devices to be utilized in healthcare monitoring.

4.8.4 Sensor Technology

The sensors are small devices that used to discover data (heat, moisture, light, motion ... etc) from the physical environment and change it to readable data using an instrument or an observer.

Neagu et al. [89] focused on enhancing the effectiveness of the used sensor data in the sensing service. Thus, they proposed a Health Monitoring oriented Sensing Service scenario (HM-SS) to improve the service quality and accessibility. HM-SS method highlighted the features of cloud-IoT. For example, the easy of the data sharing and accessibility, scalable data storage and processing resources, disaster recovery and advanced data governance. Whereas, the main objective in [74], is to minimize the consuming power of loT sensor nodes through reducing the designing a digital block by the hardware architecture system. The design has been executed on FPGA device to evaluate the functional then using ASIC to implement the silicon.

Miranda et al. [83] study the Common Recognition and Identification Platform (CRIP) from difference sides, such as the planning, evolution, implementation, as well as verification of the CRIP. It's worth to mention that the CRIP provides sensor-based support to determine the patients and health devices. In addition, different technologies have been used to design and implement the CRIP, which permits seamless interaction and combining of users and sensors. For instance, Bluetooth for connection with health devices and face recognition for authentication.

Rasid et al. [101] proposed a global healthcare system characterized in intelligent and automated monitoring. The contents of the proposed system: (i) Internet service to provide communication. (ii) IP addresses to enable patients to connect and view their medical information using portable devices such as mobiles. The 6LoWPAN sensor nodes have been used for communications as a short range. Thus, provides the possibility to introduce healthcare monitoring systems for patient-centric.

The efficiency of sensor data management using IoT has been presented in [2]. To achieve the purpose of this work, the authors used a generic system-level framework, which helps self-serve health monitoring system. The work summarized in three points: Starting in transport the data of sensors into a remote server. Then, analyzing these data remotely using a distributed manner. Finally, presenting the patient status in real-time.

Jeong et al. [55] introduced a new method for the execution of IoT healthcare, which includes: continuity, capability, privacy, reliability, and stability. In gathering data, it necessary to have the sensors in the cloud computing environments for operating and managing the data properly. Thus, the manipulating data are done by the sensors remotely distributed.

Karamitsios and Orphanoudakis [58] focused on current stacks which was suggested for personal health devices (PHDs), by utilizing the IEEE 11073 (main protocol stack) criterion healthcare implementations and healthcare data collecting. In this work, the sensor data is collected from patients and healthcare service providers.

Recently, the home caring services are very important, especially with increasing the proportion of elderly people who live alone. In addition, it has been noted that many patients (especially elderly patients) do not remember the time of taking their medicine. Accordingly, Sohn et al. [115] propose a self-alarm system for medication. The system tracks the status of medicine bottles weight. The huge amount of data generated by sensor devices has been stored in the cloud such as a smart home, road traffic management, and continuous health monitoring of individuals.

In according to that, Manogaran et al. [80] proposed a new method for IoT to save and manipulate scalable a big data of the healthcare sensors. The proposed method includes Grouping and Choosing (GC) and MetaFog-Redirection (MF-R) for solving the problem of the huge amount of data from the sensor devices.

4.8.5 Wearable Device

The usage of wearable healthcare devices through the IoT is the best way for long-term medical care because it allows patients to get their health information. In addition, for the patients' health, it's necessary to monitor the environmental criterions which affecting them health. Additionally, ease of use for elderly patients. Therefore, the wearable devices have become the focus of attention of many researchers. Basanta et al. [14] introduce a new method to improve the goodness of services for the elderly health care system and integrating various technologies of wearable devices. The authors collected the data in real time, through different wearable devices, and kept in the central database. This data connects patients and doctors at the time of an emergency. In the [75], the authors focus on the challenge of identifying in real time the owner of data. This challenge is very important due to the fact that healthcare facilities support a large number of users who possess various devices, thus leading to complexities in the streaming process. In other words, forming an N x M data source heterogeneity.

To address this matter (i.e., the complexities of mapping), the authors developed a Petri Nets service model to help in creating a transparent path to track outgoing data from wearable devices. While Lian [73] focuses on the challenges in designing low power chips, in particular, in designing self-powered wearable wireless sensors that can be used in healthcare IoT. The author introduced a new system architecture in continuous-in-time and discrete-in-amplitude (CTDA) domain. The main objective is to improve power efficiency by reducing the number of data points for transmission with adapting the sampling rate. The objectives of monitoring the patients body with high efficiency, and studying the patients risk factors on one hand of foods and drugs were addressed by Ali et al. [7]. The authors introduced a type-2 fuzzy ontology-aided recommender system by using wearable sensors to locate the patients health condition, and then suggest diabetes-specific prescriptions. Mora et al. [86] propose an IoT based distributed framework for controlling biomedical signals of human when conducting physical activities, such as heart rates of footballers throughout a football match. The authors used the wearable devices to build the health application. The proposed framework is available to other mobile environments (i.e., extensive data attainment and high processing needs take place). The high percentage of elders cannot follow the traditional health care. Therfore, Salunke and Nerkar [106] propose an IoT driven healthcare system to manage and record, for long time, the patients physiological information by using wearable sensors. The proposed system follows, captures, and describes the health trends recorded from contextual and physiological sensors in order to identify and prevent health episodes.

4.8.6 Smart Systems

This section introduces the smart healthcare systems utilizing IoT. Starting with [88], the authors increased the efficiency of the health care data communication in machine-to-machine environments. Granados et al. [38] benefited from merging data and power into one cable called power over ethernet that authorizes IoT gateway. In other words, it transports both energy and cloud connectivity to smart hospital appliances and medical sensors (smart gateway). The benefit of this method is to relive the processing overhead and increase the overall system energy performance and efficiency. IoT-based smart rehabilitation system is introduced by Fan et al. [29] by proposing an ontology-based Automation Design Methodology (ADM). The system helps the understanding of the medical resources and symptoms by computers.

In addition, it presents an efficient platform to connect all the resources and provides instant information interaction. Elanthiraiyan and Babu [25] present a physical health system and smart medicine using IoT. The system has two advantages: (i) easy allotment of domain knowledge; and (ii) rapid creation of restoration system. In other words, the system is outstanding and impressive, as ontology and IoT have an important role in the method. Table 11 reviews the advantages/disadvantages of diverse system design and architecture techniques.

Table 11 A comparative assessment of different system design and architecture techniques

ECG	(+) Acquiring digitized ECG potentials from the body, that lead to creating integrated electrical action potentials through various heart muscles or anatomy. Furthermore, the possibility of predicting the nature of the diseases. (-) It should be used during security products' development and certification, and be helpful for entropy's practical measurements.
Monitoring	(+) Early detection of disease and scheduling of screening examinations. Also, enhance the quality of life, especially for elderly people. (-) The remote health monitoring systems need to be reliable thus providing high level of accuracy and availability. In addition, utilizing the edge of the network to perform data analytics can result in reducing the level of adaptability and accuracy due to the insufficient computational capacity in edge nodes.
Mobile applications	(+) Mobile applications provide valuable healthcare services for patients with chronic diseases. Also, extend the duration of smartphone battery in healthcare monitoring. (-) Privacy issues where there is always the possibility of hackers breaking into the system and stealing the data.
Sensor technology	(+) It can significantly help people. This is mainly suitable for individuals who cannot pay attention of themselves and must have continuous care, such as the elderly. (-) Depends heavily on the wireless network. Therefore, any problem happens, leads to losing the data.
Wearable device	(+) Utilized for collecting and transmitting personal medical data into healthcare information systems for the purposes of competent diagnosis and health monitoring. (-) The inability of identifying in real time the owner of data.
Smart systems	(+) Helps to establish a treatment strategy and reconfigure medical resources in accordance with explicit requirements of patients rapidly and constantly. (-) The key problems remain in enabling such systems to react to the requirements of patients in short time.

5 Conclusion and future outlook

The IoT has enabled communications with and amid smart objects, hence leading to the vision of anywhere, anytime, anymedia, anything communications. Healthcare technologies represent one of the most attractive applications that are enabled by the IoT. Accordingly, several researchers across the world have recently explored a range of solutions that would improve the provision of healthcare services by exploiting the potentials of the IoT. This paper provides an informative survey of several aspects of IoT healthcare technologies and classifies them on a number of axes to show up their similarities and differences. In overall, the outcomes of this survey are likely to be valuable for researchers, policymakers, and healthcare professionals working in the fields of IoT and healthcare technologies.

To conclude, a brief summary of future research directions is presented as follows:

Driven Connected Healthcare Henceforth, privacy and security features for network, users, data and applications should be addressed using novel technologies and standards. As for network security, the IPv6 (Internet Protocol Version 6) is the upcoming generation Internet protocol that includes security control and addressing information to route packets through the Internet. In general, the main issues that need to be addressed include device capabilities, security, closing the gap between individuals, sensors production and safety.

Big data Future proposed models of Big data should focus in providing syntactic interoperability along with various IoT devices. One of the most serious challenges of the syntactic interoperability among heterogeneous IoT devices is the security aspect that should be carefully considered in the in the near future.

Cloud-Centric IoT based Disease Diagnosis (COND) Healthcare Framework A novel COND can be integrated to the previous proposed diagnosis systems to provide more adaptability. Frequency-COND, Pattern-COND, and Scale-COND can be enhanced henceforth for effective assessment. The proposed platform can be deployed in the physical world in order to develop statistical measurements. Furthermore, the proposed system can be evaluated in terms of accuracy with benchmark evaluation methods that are used by medical professionals.

Focusing in improving the quality of pervasive healthcare services like early warning support to patients that trigger the healthcare service based on patients' physical status rather than their feelings. The proposed IoT-based disease monitoring systems could be benefited from the integration of the Data Stream Management System (DSMS) technologies to enhance its functions. In addition, context awareness and data stream mining technologies can also be taken into account to provide more robust pervasive healthcare services.

References

1. Healthcare: An overview of energy use and energy efficiency opportunities, https://www.energystar.gov/ia/partners/publications/pubdocs/Healthcare.pdf, 2016 .
2. Mobyen Uddin Ahmed, Mats Björkman, and Maria Lindén. A generic system-level framework for self-serve health monitoring system through internet of things (iot). In *pHealth*, pages 305–307, 2015.
3. Salah S Al-Majeed, Intisar S Al-Mejibli, and Jalal Karam. Home telehealth by internet of things (iot). In *Electrical and computer engineering (CCECE), 2015 IEEE 28th Canadian conference on*, pages 609–613. IEEE, 2015.
4. Norah Alassaf, Basem Alkazemi, and Adnan Gutub. Applicable lightweight cryptography to secure medical data in iot systems. *Arabia*, 2003.

5. Gipsa Alex, Benitta Varghese, Jezna G Jose, and A Abraham. A modern health care system using iot and android. *International Journal on Computer Science and Engineering (IJCSE) ISSN*, 8(4), 2016.
6. Nawaf Alharbe, Anthony S Atkins, and Akbar Sheikh Akbari. Application of zigbee and rfid technologies in healthcare in conjunction with the internet of things. In *Proceedings of International Conference on Advances in Mobile Computing & Multimedia*, page 191. ACM, 2013.
7. Farman Ali, SM Riazul Islam, Daehan Kwak, Pervez Khan, Niamat Ullah, Sang-jo Yoo, and KS Kwak. Type-2 fuzzy ontology–aided recommendation systems for iot–based healthcare. *Computer Communications*, 119:138–155, 2018.
8. Wesam Almobaideen, Rand Krayshan, Mamoon Allan, and Maha Saadeh. Internet of things: Geographical routing based on healthcare centers vicinity for mobile smart tourism destination. *Technological Forecasting and Social Change*, 123:342–350, 2017.
9. Alba Amato and Antonio Coronato. An iot-aware architecture for smart healthcare coaching systems. In *2017 IEEE 31st International Conference on Advanced Information Networking and Applications (AINA)*, pages 1027–1034. IEEE, 2017.
10. Hariprasad Anumala and Shiva Murthy Busetty. Distributed device health platform using internet of things devices. In *Data Science and Data Intensive Systems (DSDIS), 2015 IEEE International Conference on*, pages 525–531. IEEE, 2015.
11. Dimitra Azariadi, Vasileios Tsoutsouras, Sotirios Xydis, and Dimitrios Soudris. Ecg signal analysis and arrhythmia detection on iot wearable medical devices. In *Modern Circuits and Systems Technologies (MOCAST), 2016 5th International Conference on*, pages 1–4. IEEE, 2016.
12. Iman Azimi, Arman Anzanpour, Amir M Rahmani, Tapio Pahikkala, Marco Levorato, Pasi Liljeberg, and Nikil Dutt. Hich: Hierarchical fog-assisted computing architecture for healthcare iot. *ACM Transactions on Embedded Computing Systems (TECS)*, 16(5s):174, 2017.
13. S Balamurugan, R Madhukanth, VM Prabhakaran, and R Gokul Kruba Shanker. Internet of health: Applying iot and big data to manage healthcare systems. *International Research Journal of Engineering and Technology*, 310:732–735, 2016.
14. Haobijam Basanta, Yo-Ping Huang, and Tsu-Tian Lee. Intuitive iot-based h2u healthcare system for elderly people. In *Networking, Sensing, and Control (ICNSC), 2016 IEEE 13th International Conference on*, pages 1–6. IEEE, 2016.
15. Munish Bhatia and Sandeep K Sood. A comprehensive health assessment framework to facilitate iot-assisted smart workouts: A predictive healthcare perspective. *Computers in Industry*, 92:50–66, 2017.
16. Ons Bibani, Carla Mouradian, Sami Yangui, Roch H Glitho, Walid Gaaloul, Nejib Ben Hadj-Alouane, Monique Morrow, and Paul Polakos. A demo of iot healthcare application provisioning in hybrid cloud/fog environment. In *Cloud Computing Technology and Science (CloudCom),*

2016 IEEE International Conference on, pages 472–475. IEEE, 2016.
17. Vishnu Prasad C and Arun Raj Kumar P. Secret sharing scheme based on cauchy matrix for data outsourcing. In *Proceedings of the 10th International Conference on Security of Information and Networks*, pages 315–318. ACM, 2017.
18. Luca Catarinucci, Danilo De Donno, Luca Mainetti, Luca Palano, Luigi Patrono, Maria Laura Stefanizzi, and Luciano Tarricone. An iot-aware architecture for smart healthcare systems. *IEEE Internet of Things Journal*, 2(6):515–526, 2015.
19. Vivek Chandel, Arijit Sinharay, Nasimuddin Ahmed, and Avik Ghose. Exploiting imu sensors for iot enabled health monitoring. In *Proceedings of the First Workshop on IoT-enabled Healthcare and Wellness Technologies and Systems*, pages 21–22. ACM, 2016.
20. Xi Chen, Ming Ma, and Anfeng Liu. Dynamic power management and adaptive packet size selection for iot in e-healthcare. *Computers & Electrical Engineering*, 65:357–375, 2018.
21. Caroline Chibelushi, Alan Eardley, and Abdullahi Arabo. Identity management in the internet of things: The role of manets for healthcare applications. *Computer Science and Information Technology*, 1(2):73–81, 2013.
22. Sourav Kumar Dhar, Suman Sankar Bhunia, and Nandini Mukherjee. Interference aware scheduling of sensors in iot enabled health-care monitoring system. In *Emerging Applications of Information Technology (EAIT), 2014 Fourth International Conference of*, pages 152–157. IEEE, 2014.
23. Charalampos Doukas and Ilias Maglogiannis. Bringing iot and cloud computing towards pervasive healthcare. In *Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), 2012 Sixth International Conference on*, pages 922–926. IEEE, 2012.
24. Charalampos Doukas, Ilias Maglogiannis, Vassiliki Koufi, Flora Malamateniou, and George Vassilacopoulos. Enabling data protection through pki encryption in iot m-health devices. In *Bioinformatics & Bioengineering (BIBE), 2012 IEEE 12th International Conference on*, pages 25–29. IEEE, 2012.
25. P Elanthiraiyan and Dr S Babu. Smart medicine and physical health system using iot. *International Journal of Computer Science and Mobile Computing*, 4(3):333–338, 2015.
26. G Elhayatmy, Nilanjan Dey, and Amira S Ashour. Internet of things based wireless body area network in healthcare. In *Internet of Things and Big Data Analytics Toward Next-Generation Intelligence*, pages 3–20. Springer, 2018.
27. Mohamed Elhoseny, Gustavo Ramírez-González, Osama M Abu-Elnasr, Shihab A Shawkat, N Arunkumar, and Ahmed Farouk. Secure medical data transmission model for iot-based healthcare systems. *IEEE Access*, 6:20596–20608, 2018.
28. Ahmed M Elmisery, Seungmin Rho, and Dmitri Botvich. A fog based middleware for automated compliance with oecd privacy principles in

internet of healthcare things. *IEEE Access*, 4:8418–8441, 2016.
29. Yuan Jie Fan, Yue Hong Yin, Li Da Xu, Yan Zeng, and Fan Wu. Iot-based smart rehabilitation system. *IEEE transactions on industrial informatics*, 10(2):1568–1577, 2014.
30. Bahar Farahani, Farshad Firouzi, Victor Chang, Mustafa Badaroglu, Nicholas Constant, and Kunal Mankodiya. Towards fog-driven iot ehealth: Promises and challenges of iot in medicine and healthcare. *Future Generation Computer Systems*, 78:659–676, 2018.
31. Ábel Garai, Adamkó Attila, and István Péntek. Cognitive telemedicine iot technology for dynamically adaptive ehealth content management reference framework embedded in cloud architecture. In *Cognitive Infocommunications (CogInfoCom), 2016 7th IEEE International Conference on*, pages 000187–000192. IEEE, 2016.
32. Yvette E Gelogo, Ha Jin Hwang, and Haeng-Kon Kim. Internet of things (iot) framework for u-healthcare system. *International Journal of Smart Home*, 9(11):323–330, 2015.
33. Yvette E Gelogo, Jung-Won Oh, Jin Woo Park, and Haeng-Kon Kim. Internet of things (iot) driven u-healthcare system architecture. In *Bio-Science and Bio-Technology (BSBT), 2015 8th International Conference on*, pages 24–26. IEEE, 2015.
34. Tuan Nguyen Gia, Mingzhe Jiang, Amir-Mohammad Rahmani, Tomi Westerlund, Pasi Liljeberg, and Hannu Tenhunen. Fog computing in healthcare internet of things: A case study on ecg feature extraction. In *Computer and Information Technology; Ubiquitous Computing and Communications; Dependable, Autonomic and Secure Computing; Pervasive Intelligence and Computing (CIT/IUCC/DASC/PICOM), 2015 IEEE International Conference on*, pages 356–363. IEEE, 2015.
35. Tuan Nguyen Gia, Amir-Mohammad Rahmani, Tomi Westerlund, Pasi Liljeberg, and Hannu Tenhunen. Fault tolerant and scalable iot-based architecture for health monitoring. In *Sensors Applications Symposium (SAS), 2015 IEEE*, pages 1–6. IEEE, 2015.
36. Tianhe Gong, Haiping Huang, Pengfei Li, Kai Zhang, and Hao Jiang. A medical healthcare system for privacy protection based on iot. In *2015 Seventh International Symposium on Parallel Architectures, Algorithms and Programming (PAAP)*, pages 217–222. IEEE, 2015.
37. Prosanta Gope and Tzonelih Hwang. Bsn-care: A secure iot-based modern healthcare system using body sensor network. *IEEE Sensors Journal*, 16(5):1368–1376, 2016.
38. Jose Granados, Amir-Mohammad Rahmani, Pekka Nikander, Pasi Liljeberg, and Hannu Tenhunen. Towards energy-efficient healthcare: An internet-of-things architecture using intelligent gateways. In *Wireless Mobile Communication and Healthcare (Mobihealth), 2014 EAI 4th International Conference on*, pages 279–282. IEEE, 2014.
39. M Surya Deekshith Gupta, Vamsikrishna Patchava, and Virginia Menezes. Healthcare based on iot using raspberry pi. In *2015 International Conference on Green Computing and Internet of Things (ICG-*

CIoT), pages 796–799. IEEE, 2015.

40. Praveen Kumar Gupta, BT Maharaj, and Reza Malekian. A novel and secure iot based cloud centric architecture to perform predictive analysis of users activities in sustainable health centres. *Multimedia Tools and Applications*, 76(18):18489–18512, 2017.
41. Punit Gupta, Deepika Agrawal, Jasmeet Chhabra, and Pulkit Kumar Dhir. Iot based smart healthcare kit. In *Computational Techniques in Information and Communication Technologies (ICCTICT), 2016 International Conference on*, pages 237–242. IEEE, 2016.
42. Kashif Habib, Arild Torjusen, and Wolfgang Leister. A novel authentication framework based on bio-metric and radio fingerprinting for the iot in ehealth. In *Proceedings of International Conference on Smart Systems, Devices and Technologies (SMART)*, pages 32–37, 2014.
43. Kun-Hee Han and Woo-Sik Bae. Proposing and verifying a security-enhanced protocol for iot-based communication for medical devices. *Cluster Computing*, 19(4):2335–2341, 2016.
44. Mohammad Mehedi Hassan, Hanouf Saad Albakr, and Hmood Al-Dossari. A cloud-assisted internet of things framework for pervasive healthcare in smart city environment. In *Proceedings of the 1st International Workshop on Emerging Multimedia Applications and Services for Smart Cities*, pages 9–13. ACM, 2014.
45. Moeen Hassanalieragh, Alex Page, Tolga Soyata, Gaurav Sharma, Mehmet Aktas, Gonzalo Mateos, Burak Kantarci, and Silvana Andreescu. Health monitoring and management using internet-of-things (iot) sensing with cloud-based processing: Opportunities and challenges. In *2015 IEEE international conference on services computing (SCC)*, pages 285–292. IEEE, 2015.
46. MN Hindia, TA Rahman, H Ojukwu, EB Hanafi, and A Fattouh. Enabling remote health-caring utilizing iot concept over lte-femtocell networks. *PloS one*, 11(5):e0155077, 2016.
47. Jia-Li Hou and Kuo-Hui Yeh. Novel authentication schemes for iot based healthcare systems. *International Journal of Distributed Sensor Networks*, 11(11):183659, 2015.
48. Jin-Xin Hu, Chin-Ling Chen, Chun-Long Fan, and Kun-hao Wang. An intelligent and secure health monitoring scheme using iot sensor based on cloud computing. *Journal of Sensors*, 2017, 2017.
49. Muhammad A Iqbal and Magdy Bayoumi. Secure end-to-end key establishment protocol for resource-constrained healthcare sensors in the context of iot. In *High Performance Computing & Simulation (HPCS), 2016 International Conference on*, pages 523–530. IEEE, 2016.
50. SM Riazul Islam, Daehan Kwak, MD Humaun Kabir, Mahmud Hossain, and Kyung-Sup Kwak. The internet of things for health care: a comprehensive survey. *IEEE Access*, 3:678–708, 2015.
51. Sohail Jabbar, Farhan Ullah, Shehzad Khalid, Murad Khan, and Kijun Han. Semantic interoperability in heterogeneous iot infrastructure for healthcare. *Wireless Communications and Mobile Computing*, 2017,

2017.
52. Antonio J Jara, Alberto F Alcolea, MA Zamora, AF Gómez Skarmeta, and Mona Alsaedy. Drugs interaction checker based on iot. In *Internet of Things (IOT), 2010*, pages 1–8. IEEE, 2010.
53. Antonio J Jara, Miguel A Zamora, and Antonio F Skarmeta. Drug identification and interaction checker based on iot to minimize adverse drug reactions and improve drug compliance. *Personal and ubiquitous computing*, 18(1):5–17, 2014.
54. Jebaveerasingh Jebadurai and J Dinesh Peter. Super-resolution of retinal images using multi-kernel svr for iot healthcare applications. *Future Generation Computer Systems*, 83:338–346, 2018.
55. Joon-Soo Jeong, Oakyoung Han, and Yen-You You. A design characteristics of smart healthcare system as the iot application. *Indian Journal of Science and Technology*, 9(37), 2016.
56. Freddy Jimenez and Romina Torres. Building an iot-aware healthcare monitoring system. In *Chilean Computer Science Society (SCCC), 2015 34th International Conference of the*, pages 1–4. IEEE, 2015.
57. KANG Kai, Zhi-bo PANG, and WANG Cong. Security and privacy mechanism for health internet of things. *The Journal of China Universities of Posts and Telecommunications*, 20:64–68, 2013.
58. Konstantinos Karamitsios and Theofanis Orphanoudakis. Efficient iot data aggregation for connected health applications. In *2017 IEEE Symposium on Computers and Communications (ISCC)*, pages 1182–1185. IEEE, 2017.
59. K Keerthana, N Kiruthikanjali, G Nandhini, G Yuvaraj, et al. Secured smart healthcare monitoring system based on iot. 2017.
60. Ngo Manh Khoi, Saguna Saguna, Karan Mitra, and Christer Ahlund. Irehmo: an efficient iot-based remote health monitoring system for smart regions. In *E-health Networking, Application & Services (HealthCom), 2015 17th International Conference on*, pages 563–568. IEEE, 2015.
61. Jung Tae Kim. Privacy and security issues for healthcare system with embedded rfid system on internet of things. *Advanced Science and Technology Letters*, 72:109–112, 2014.
62. Tae-Yoon Kim, Sungkwan Youm, Jai-Jin Jung, and Eui-Jik Kim. Multi-hop wban construction for healthcare iot systems. In *Platform Technology and Service (PlatCon), 2015 International Conference on*, pages 27–28. IEEE, 2015.
63. Evdokimos I Konstantinidis, Giorgos Bamparopoulos, Antonis Billis, and Panagiotis D Bamidis. Internet of things for an age-friendly healthcare. In *MIE*, pages 587–591, 2015.
64. Er Kritika, Harjit Pal Singh, Er Narinder Pal Singh, and Er Mamta. Multivariate authentication and encryption scheme for data privacy in iot healthcare monitoring. *Imperial Journal of Interdisciplinary Research*, 2 (8), 2016.
65. Priyan Malarvizhi Kumar and Usha Devi Gandhi. Enhanced dtls with coap-based authentication scheme for the internet of things in healthcare

application. *The Journal of Supercomputing*, pages 1–21, 2017.

66. Vinoth Kumar et al. Ontology based public healthcare system in internet of things (iot). *Procedia Computer Science*, 50:99–102, 2015.
67. Byung Mun Lee. Dynamic data binding protocol between iot medical device and iot medical service for mobile healthcare. *International Journal of Smart Home*, 9(6):141–150, 2015.
68. Byung Mun Lee. Personalized service model for sharing medical devices in iot health-platform. *Advanced Science and Technology Letters*, 99: 180–182, 2015.
69. Byung Mun Lee. Registration protocol for health iot platform to share the use of medical devices. *International Journal of Bio-Science and Bio-Technology*, 7(4):1–10, 2015.
70. Byung Mun Lee and Jinsong Ouyang. Intelligent healthcare service by using collaborations between iot personal health devices. *blood pressure*, 10(11), 2014.
71. Jae Dong Lee, Tae Sik Yoon, Seung Hyun Chung, and Hyo Soung Cha. Service-oriented security framework for remote medical services in the internet of things environment. *Healthcare informatics research*, 21(4): 271–282, 2015.
72. Chao Li, Xiangpei Hu, and Lili Zhang. The iot-based heart disease monitoring system for pervasive healthcare service. *Procedia Computer Science*, 112:2328–2334, 2017.
73. Yong Lian. Challenges in the design of self-powered wearable wireless sensors for healthcare internet-of-things. In *ASIC (ASICON), 2015 IEEE 11th International Conference on*, pages 1–4. IEEE, 2015.
74. YangWei Lim, SB Daas, SJ Hashim, RM Sidek, NA Kamsani, and FZ Rokhani. Reduced hardware architecture for energy-efficient iot healthcare sensor nodes. In *Circuits and Systems Symposium (ICSyS), 2015 IEEE International*, pages 90–95. IEEE, 2015.
75. Richard K Lomotey, Joseph Pry, and Sumanth Sriramoju. Wearable iot data stream traceability in a distributed health information system. *Pervasive and Mobile Computing*, 40:692–707, 2017.
76. Entao Luo, Md Zakirul Alam Bhuiyan, Guojun Wang, Md Arafatur Rahman, Jie Wu, and Mohammed Atiquzzaman. Privacyprotector: Privacy-protected patient data collection in iot-based healthcare systems. *IEEE Communications Magazine*, 56(2):163–168, 2018.
77. Redowan Mahmud, Fernando Luiz Koch, and Rajkumar Buyya. Cloud-fog interoperability in iot-enabled healthcare solutions. In *Proceedings of the 19th International Conference on Distributed Computing and Networking*, page 32. ACM, 2018.
78. Lee Carman Ka Man, Cheng Mei Na, and Ng Chun Kit. Iot-based asset management system for healthcare-related industries. *International Journal of Engineering Business Management*, 7:19, 2015.
79. Mamidi Manisha, Katakam Nerraja, Vemuri Sinhura, and Paruchuri Ramya. Iot on heart attack detection and heart rate monitoring. *International Journal of Innovation in Engineering and Technology (IJIET)*,

2016.

80. Gunasekaran Manogaran, Daphne Lopez, Chandu Thota, Kaja M Abbas, Saumyadipta Pyne, and Revathi Sundarasekar. Big data analytics in healthcare internet of things. In *Innovative healthcare systems for the 21st century*, pages 263–284. Springer, 2017.
81. Gunasekaran Manogaran, R Varatharajan, Daphne Lopez, Priyan Malarvizhi Kumar, Revathi Sundarasekar, and Chandu Thota. A new architecture of internet of things and big data ecosystem for secured smart healthcare monitoring and alerting system. *Future Generation Computer Systems*, 82:375–387, 2018.
82. Avijit Mathur, Thomas Newe, and Muzaffar Rao. Defence against black hole and selective forwarding attacks for medical wsns in the iot. *Sensors*, 16(1):118, 2016.
83. Jorge Miranda, Jorge Cabral, Stefan Rahr Wagner, Christian Fischer Pedersen, Blaise Ravelo, Mukhtiar Memon, and Morten Mathiesen. An open platform for seamless sensor support in healthcare for the internet of things. *Sensors*, 16(12):2089, 2016.
84. Sanaz Rahimi Moosavi, Tuan Nguyen Gia, Ethiopia Nigussie, Amir-Mohammad Rahmani, Seppo Virtanen, Hannu Tenhunen, and Jouni Isoaho. Session resumption-based end-to-end security for healthcare internet-of-things. In *Computer and Information Technology; Ubiquitous Computing and Communications; Dependable, Autonomic and Secure Computing; Pervasive Intelligence and Computing (CIT/IUCC/DASC/PICOM), 2015 IEEE International Conference on*, pages 581–588. IEEE, 2015.
85. Sanaz Rahimi Moosavi, Tuan Nguyen Gia, Amir-Mohammad Rahmani, Ethiopia Nigussie, Seppo Virtanen, Jouni Isoaho, and Hannu Tenhunen. Sea: a secure and efficient authentication and authorization architecture for iot-based healthcare using smart gateways. *Procedia Computer Science*, 52:452–459, 2015.
86. Higinio Mora, David Gil, Rafael Muñoz Terol, Jorge Azorín, and Julian Szymanski. An iot-based computational framework for healthcare monitoring in mobile environments. *Sensors*, 17(10):2302, 2017.
87. Chandra Sukanya Nandyala and Haeng-Kon Kim. Green iot agriculture and healthcare application (gaha). *Int J Smart Home*, 10(4):289–300, 2016.
88. K Natarajan, B Prasath, and P Kokila. Smart health care system using internet of things. *Journal of Network Communications and Emerging Technologies (JNCET)*, 6(3), 2016.
89. Gabriel Neagu, Ştefan Preda, Alexandru Stanciu, and Vladimir Florian. A cloud-iot based sensing service for health monitoring. In *E-Health and Bioengineering Conference (EHB), 2017*, pages 53–56. IEEE, 2017.
90. S Niranjana and A Balamurugan. Intelligent e-health gateway based ubiquitous healthcare systems in internet of things. *International Journal of Scientific Engineering and Applied Science (IJSEAS)-Volume-I, Issue-9*, 2015.

91. Brian Oryema, Hyun-Su Kim, Wei Li, and Jong Tae Park. Design and implementation of an interoperable messaging system for iot healthcare services. In *Consumer Communications & Networking Conference (CCNC), 2017 14th IEEE Annual*, pages 45–52. IEEE, 2017.
92. Zhibo Pang. *Technologies and Architectures of the Internet-of-Things (IoT) for Health and Well-being.* PhD thesis, KTH Royal Institute of Technology, 2013.
93. Pravanjan Patra, Kunal Yadav, Jairaj Naik, and Ashudeb Dutta. A true 1v 1μw biomedical front end with reconfigurable adc for self powered smarter iot healthcare systems. In *TENCON 2015-2015 IEEE Region 10 Conference*, pages 1–4. IEEE, 2015.
94. Loreto Pescosolido, Riccardo Berta, Lorenzo Scalise, Gian Marco Revel, Alessandro De Gloria, and Gianni Orlandi. An iot-inspired cloud-based web service architecture for e-health applications. In *Smart Cities Conference (ISC2), 2016 IEEE International*, pages 1–4. IEEE, 2016.
95. Sandro Pinto, Jorge Cabral, and T Gomes. We-care: An iot-based health care system for elderly people. In *Industrial Technology (ICIT), 2017 IEEE International Conference on*, pages 1378–1383. IEEE, 2017.
96. Andreas P Plageras, Kostas E Psannis, Yutaka Ishibashi, and Byung-Gyu Kim. Iot-based surveillance system for ubiquitous healthcare. In *Industrial Electronics Society, IECON 2016-42nd Annual Conference of the IEEE*, pages 6226–6230. IEEE, 2016.
97. Tie Qiu, Xize Liu, Min Han, Mingchu Li, and Yushuang Zhang. Srts: A self-recoverable time synchronization for sensor networks of healthcare iot. *Computer Networks*, 129:481–492, 2017.
98. Tie Qiu, Xize Liu, Min Han, Mingchu Li, and Yushuang Zhang. Srts: A self-recoverable time synchronization for sensor networks of healthcare iot. *Computer Networks*, 129:481–492, 2017.
99. Amir M Rahmani, Tuan Nguyen Gia, Behailu Negash, Arman Anzanpour, Iman Azimi, Mingzhe Jiang, and Pasi Liljeberg. Exploiting smart e-health gateways at the edge of healthcare internet-of-things: A fog computing approach. *Future Generation Computer Systems*, 78:641–658, 2018.
100. Amir-Mohammad Rahmani, Nanda Kumar Thanigaivelan, Tuan Nguyen Gia, Jose Granados, Behailu Negash, Pasi Liljeberg, and Hannu Tenhunen. Smart e-health gateway: Bringing intelligence to internet-of-things based ubiquitous healthcare systems. In *Consumer Communications and Networking Conference (CCNC), 2015 12th Annual IEEE*, pages 826–834. IEEE, 2015.
101. MFA Rasid, WMW Musa, NAA Kadir, AM Noor, F Touati, W Mehmood, L Khriji, A Al-Busaidi, and A Ben Mnaouer. Embedded gateway services for internet of things applications in ubiquitous healthcare. In *Information and Communication Technology (ICoICT), 2014 2nd International Conference on*, pages 145–148. IEEE, 2014.
102. M Mazhar Rathore, Awais Ahmad, and Anand Paul. The internet of things based medical emergency management using hadoop ecosystem.

In *SENSORS, 2015 IEEE*, pages 1–4. IEEE, 2015.

103. M Mazhar Rathore, Awais Ahmad, Anand Paul, Jiafu Wan, and Daqiang Zhang. Real-time medical emergency response system: exploiting iot and big data for public health. *Journal of medical systems*, 40(12):283, 2016.
104. Partha P Ray. Home health hub internet of things (h 3 iot): An architectural framework for monitoring health of elderly people. In *Science Engineering and Management Research (ICSEMR), 2014 International Conference on*, pages 1–3. IEEE, 2014.
105. Anass Rghioui, Aziza L'aarje, Fatiha Elouaai, and Mohammed Bouhorma. The internet of things for healthcare monitoring: security review and proposed solution. In *Information Science and Technology (CIST), 2014 Third IEEE International Colloquium in*, pages 384–389. IEEE, 2014.
106. Prashant Salunke and Rasika Nerkar. Iot driven healthcare system for remote monitoring of patients. *Journal for Modern Trends in Science and Technology*, 3(06):100–103, 2017.
107. Danilo FS Santos, Angelo Perkusich, and Hyggo O Almeida. Standard-based and distributed health information sharing for mhealth iot systems. In *e-Health Networking, Applications and Services (Healthcom), 2014 IEEE 16th International Conference on*, pages 94–98. IEEE, 2014.
108. Udit Satija, Barathram Ramkumar, and M Sabarimalai Manikandan. Real-time signal quality-aware ecg telemetry system for iot-based health care monitoring. *IEEE Internet of Things Journal*, 4(3):815–823, 2017.
109. Divya Saxena, Vaskar Raychoudhury, and Nalluri SriMahathi. Smarthealth-ndnot: Named data network of things for healthcare services. In *MobileHealth@ MobiHoc*, pages 45–50, 2015.
110. R Senthilkumar, RS Ponmagal, and K Sujatha. Efficient health care monitoring and emergency management system using iot. *International Journal of Control Theory and Applications*, 9(4):137–145, 2016.
111. Vijayakannan Sermakani. Transforming healthcare through internet of things. In *of Project Management Practitioners' Conference*, 2014.
112. Sagar Sharma, Keke Chen, and Amit Sheth. Toward practical privacy-preserving analytics for iot and cloud-based healthcare systems. *IEEE Internet Computing*, 22(2):42–51, 2018.
113. Mikhail Simonov, Riccardo Zich, and Flavia Mazzitelli. Personalized healthcare communication in internet of things. *Proc. of URSI GA08*, 7, 2008.
114. Rashmi Singh. A proposal for mobile e-care health service system using iot for indian scenario. *J. Network Commun. Emerg. Technol*, 6(1), 2016.
115. Soo Yeon Sohn, Mungyu Bae, Dong-kyu Roy Lee, and Hwangnam Kim. Alarm system for elder patients medication with iot-enabled pill bottle. In *Information and Communication Technology Convergence (ICTC), 2015 International Conference on*, pages 59–61. IEEE, 2015.
116. Sandeep K Sood and Isha Mahajan. Wearable iot sensor based healthcare system for identifying and controlling chikungunya virus. *Computers in Industry*, 91:33–44, 2017.

117. Anastasiia Strielkina, Dmytro Uzun, and Vyacheslav Kharchenko. Modelling of healthcare iot using the queueing theory. In *Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS), 2017 9th IEEE International Conference on*, volume 2, pages 849–852. IEEE, 2017.
118. Haoru Su, Zhiliang Wang, and Sunshin An. Maeb: routing protocol for iot healthcare. 2013.
119. Mir Sajjad Hussain Talpur, Md Zakirul Alam Bhuiyan, and Guojun Wang. Energy-efficient healthcare monitoring with smartphones and iot technologies. *International Journal of High Performance Computing and Networking*, 8(2):186–194, 2015.
120. Muthuraman Thangaraj, Pichaiah Punitha Ponmalar, and Subramanian Anuradha. Internet of things (iot) enabled smart autonomous hospital management system-a real world health care use case with the technology drivers. In *Computational Intelligence and Computing Research (ICCIC), 2015 IEEE International Conference on*, pages 1–8. IEEE, 2015.
121. Sapna Tyagi, Amit Agarwal, and Piyush Maheshwari. A conceptual framework for iot-based healthcare system using cloud computing. In *Cloud System and Big Data Engineering (Confluence), 2016 6th International Conference*, pages 503–507. IEEE, 2016.
122. Dejana Ugrenovic and Gordana Gardasevic. Coap protocol for web-based monitoring in iot healthcare applications. In *Telecommunications Forum Telfor (TELFOR), 2015 23rd*, pages 79–82. IEEE, 2015.
123. Arijit Ukil, Soma Bandyoapdhyay, Chetanya Puri, and Arpan Pal. Iot healthcare analytics: The importance of anomaly detection. In *Advanced Information Networking and Applications (AINA), 2016 IEEE 30th International Conference on*, pages 994–997. IEEE, 2016.
124. Farhan Ullah, Muhammad Asif Habib, Muhammad Farhan, Shehzad Khalid, Mehr Yahya Durrani, and Sohail Jabbar. Semantic interoperability for big-data in heterogeneous iot infrastructure for healthcare. *Sustainable Cities and Society*, 34:90–96, 2017.
125. Kaleem Ullah, Munam Ali Shah, and Sijing Zhang. Effective ways to use internet of things in the field of medical and smart health care. In *Intelligent Systems Engineering (ICISE), 2016 International Conference on*, pages 372–379. IEEE, 2016.
126. Ihor Vasyltsov and Seunghwan Lee. Entropy extraction from bio-signals in healthcare iot. In *Proceedings of the 1st ACM Workshop on IoT Privacy, Trust, and Security*, pages 11–17. ACM, 2015.
127. Prabal Verma and Sandeep K Sood. Cloud-centric iot based disease diagnosis healthcare framework. *Journal of Parallel and Distributed Computing*, 116:27–38, 2018.
128. Prabal Verma, Sandeep K Sood, and Sheetal Kalra. Cloud-centric iot based student healthcare monitoring framework. *Journal of Ambient Intelligence and Humanized Computing*, pages 1–17, 2017.
129. Min Woo Woo, JongWhi Lee, and KeeHyun Park. A reliable iot system for personal healthcare devices. *Future Generation Computer Systems*,

78:626–640, 2018.
130. Paul A Wortman, Fatemeh Tehranipoor, Nima Karimian, and John A Chandy. Proposing a modeling framework for minimizing security vulnerabilities in iot systems in the healthcare domain. In *Biomedical & Health Informatics (BHI), 2017 IEEE EMBS International Conference on*, pages 185–188. IEEE, 2017.
131. Taiyang Wu, Fan Wu, Jean-Michel Redoute, and Mehmet Rasit Yuce. An autonomous wireless body area network implementation towards iot connected healthcare applications. *IEEE Access*, 5:11413–11422, 2017.
132. Chen Xican, RHEE Woogeun, and Wang Zhihua. Low power sensor design for iot and mobile healthcare applications. *China Communications*, 12(5):42–54, 2015.
133. Boyi Xu, Li Da Xu, Hongming Cai, Cheng Xie, Jingyuan Hu, Fenglin Bu, et al. Ubiquitous data accessing method in iot-based information system for emergency medical services. *IEEE Trans. Industrial Informatics*, 10 (2):1578–1586, 2014.
134. Geng Yang, Li Xie, Matti Mäntysalo, Xiaolin Zhou, Zhibo Pang, Li Da Xu, Sharon Kao-Walter, Qiang Chen, and Li-Rong Zheng. A health-iot platform based on the integration of intelligent packaging, unobtrusive bio-sensor, and intelligent medicine box. *IEEE transactions on industrial informatics*, 10(4):2180–2191, 2014.
135. Zhe Yang, Qihao Zhou, Lei Lei, Kan Zheng, and Wei Xiang. An iot-cloud based wearable ecg monitoring system for smart healthcare. *Journal of medical systems*, 40(12):286, 2016.
136. Zhe Yang, Qihao Zhou, Lei Lei, Kan Zheng, and Wei Xiang. An iot-cloud based wearable ecg monitoring system for smart healthcare. *Journal of medical systems*, 40(12):286, 2016.
137. Zhe Yang, Qihao Zhou, Lei Lei, Kan Zheng, and Wei Xiang. An iot-cloud based wearable ecg monitoring system for smart healthcare. *Journal of medical systems*, 40(12):286, 2016.
138. Kuo-Hui Yeh. A secure iot-based healthcare system with body sensor networks. *IEEE Access*, 4:10288–10299, 2016.
139. Bang Zhang, Xingwei Wang, and Min Huang. A data replica placement scheme for cloud storage under healthcare iot environment. In *Fuzzy Systems and Knowledge Discovery (FSKD), 2014 11th International Conference on*, pages 542–547. IEEE, 2014.
140. Daphney-Stavroula Zois. Sequential decision-making in healthcare iot: Real-time health monitoring, treatments and interventions. In *2016 IEEE 3rd World Forum on Internet of Things (WF-IoT)*, pages 24–29. IEEE, 2016.