The Internet of Things for Health Care: A Comparative Survey

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ABSTRACT *The Internet of Things (IoT) makes smart objects the ultimate building blocks in the development of cyber-physical smart pervasive frameworks. The IoT has a variety of application domains, including health care. The IoT revolution is redesigning modern health care with promising technological, economic, and social prospects. This paper surveys advances in IoT-based health care technologies and reviews the state-of-the-art network architectures/platforms, applications, and industrial trends in IoT-based health care solutions. In addition, this paper analyzes distinct IoT security and privacy features, including security requirements, threat models, and attack taxonomies from the health care perspective. Further, this paper proposes an intelligent collaborative security model to minimize security risk; discusses how different innovations such as big data, ambient intelligence, and wearables can be leveraged in a health care context; addresses various IoT and eHealth policies and regulations across the world to determine how they can facilitate economies and societies in terms of sustainable development; and provides some avenues for future research on IoT-based health care based on a set of open issues and challenges.*

INDEX TERMS *Internet of things, health care, services, applications, networks, architectures, platforms, security, technologies, industries, policies, challenges.*

I. INTRODUCTION

The Internet of Things (IoT) is a concept reflecting a connected set of anyone, anything, anytime, anyplace, any service, and any network. The IoT is a megatrend in next-generation technologies that can impact the whole business spectrum and can be thought of as the interconnection of uniquely identifiable smart objects and devices within today's internet infrastructure with extended benefits. Benefits typically include the advanced connectivity of these devices, systems, and services that goes beyond machine- to-machine (M2M) scenarios [1]. Therefore, introducing automation is conceivable in nearly every field. The IoT pro- vides appropriate solutions for a wide range of applications such as smart cities, traffic congestion, waste management, structural health, security, emergency services, logistics, retails, industrial control, and health care. The interested reader is referred to [1]–[5] for a deeper understanding of the IoT.

Medical care and health care represent one of the most attractive application areas for the IoT [6]. The IoT has the potential to give rise to many medical applications such as remote health monitoring, fitness programs, chronic diseases, and elderly care. Compliance with treatment and medication at home and by healthcare providers is another important potential application. Therefore, various medical devices, sensors, and diagnostic and imaging devices can be viewed as smart devices or objects constituting a core part of the IoT. IoT-based healthcare services are expected to reduce costs, increase the quality of life, and enrich the user's experience. From the perspective of healthcare providers, the IoT has the potential to reduce device downtime through remote provision. In addition, the IoT can correctly identify optimum times for replenishing supplies for various devices for their smooth and continuous operation. Further, the IoT provides for the efficient scheduling of limited resources by ensuring their best use and service of more patients. Fig. 1 illustrates recent healthcare trends [7]. Ease of cost-effective interactions through seamless and secure con- nativity across individual patients, clinics, and healthcare organizations is an important trend. Up-to-date healthcare networks driven by wireless technologies are expected to support chronic diseases, early diagnosis, real-time monitoring, and medical emergencies. Gateways, medical servers, and health databases play vital roles in creating health records and delivering on-demand health services to authorized stakeholders.

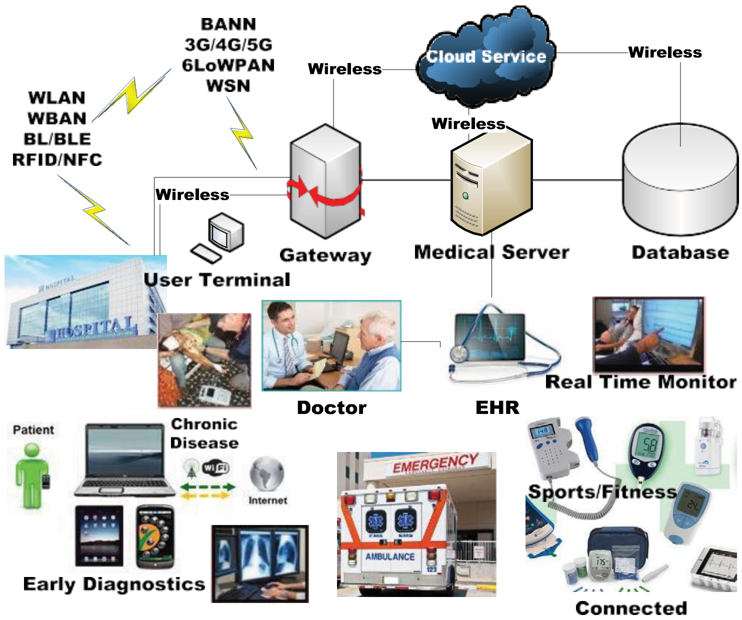

FIGURE 1. *Healthcare trends.*

In the last few years, this field has attracted wide attention from researchers to address the potential of the IoT in the healthcare field by considering various practical challenges. As a consequence, there are now numerous applications, services, and prototypes in the field. Research trends in IoT-based health care include network architectures and platforms, new services and applications, interoperability, and security, among others. In addition, policies and guide-lines have been developed for deploying the IoT technology in the medical field in many countries and organizations across the world. However, the IoT remains in its infancy in the healthcare field. At this stage, a thorough understanding of current research on the IoT in the healthcare context is expected to be useful for various stakeholders interested in further research. This paper examines the trends in IoT-based healthcare research and uncovers various issues that must be addressed to transform healthcare technologies through the IoT innovation. In this regard, this paper contributes by

- *Classifying existing IoT-based healthcare network studies into three trends and presenting a summary of each.*
- *Providing an extensive survey of IoT-based healthcare services and applications.*
- *Highlighting various industrial efforts to embrace IoT-compatible healthcare products and prototypes.*
- *Providing extensive insights into security and privacy issues surrounding IoT healthcare solutions and proposing a security model.*
- *Discussing core technologies that can reshape healthcare technologies based on the IoT.*
- *Highlighting various policies and strategies that can support researchers and policymakers in integrating the IoT innovation into healthcare technologies in practice.*
- *Providing challenges and open issues that must be addressed to make IoT-based healthcare technologies robust.*

It should be noted that R&D activities in the field of healthcare services based on the wireless sensor net- work (WSN) [8], [9] can be considered as initial IoT-based healthcare research efforts. However, the ongoing trend is to shift away from registered standards and adopt IP-based sensor networks using the emerging IPv6-based low-power wireless personal area network (6LoWPAN). If WSNs become a core part of the Internet, then a careful analysis is necessary. To better understand the evolution of WSNs toward the IoT and thus their fundamental differences, the reader is referred to [10]–[12].

II. IoT HEALTHCARE NETWORKS

The IoT healthcare network or the IoT network for health care (hereafter "the IoThNet") is one of the vital elements of the IoT in health care. It supports access to the IoT backbone, facilitates the transmission and reception of medical data, and enables the use of healthcare-tailored communications. As shown in Fig. 2, this section discusses the IoThNet topology, architecture, and platform. However, it should be mentioned that the proposed architectures in [13] and [14] can be considered as a good starting point for developing insights into the IoT network.

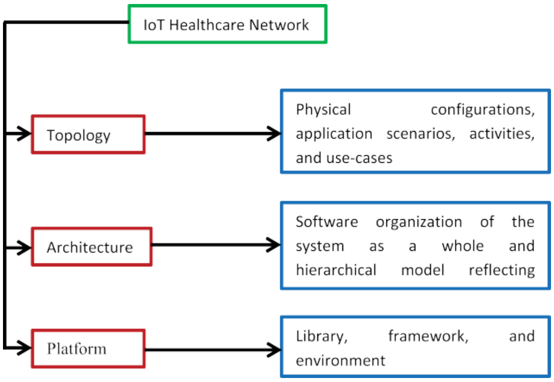

FIGURE 2. *IoT healthcare network (IoThNet) issues.*

A. THE IoThNet TOPOLOGY

The IoThNet topology refers to the arrangement of different elements of an IoT healthcare network and indicates representative scenarios of seamless healthcare environments. Fig. 3 describes how a heterogeneous computing grid collects enormous amounts of vital signs and sensor data such as blood pressure (BP), body temperature, electrocardiograms (ECG), and oxygen saturation and forms a typical IoThNet topology. It transforms the heterogeneous computing and storage capability of static and mobile electronic devices such as laptops, smartphones, and medical terminals into hybrid computing grids [15].

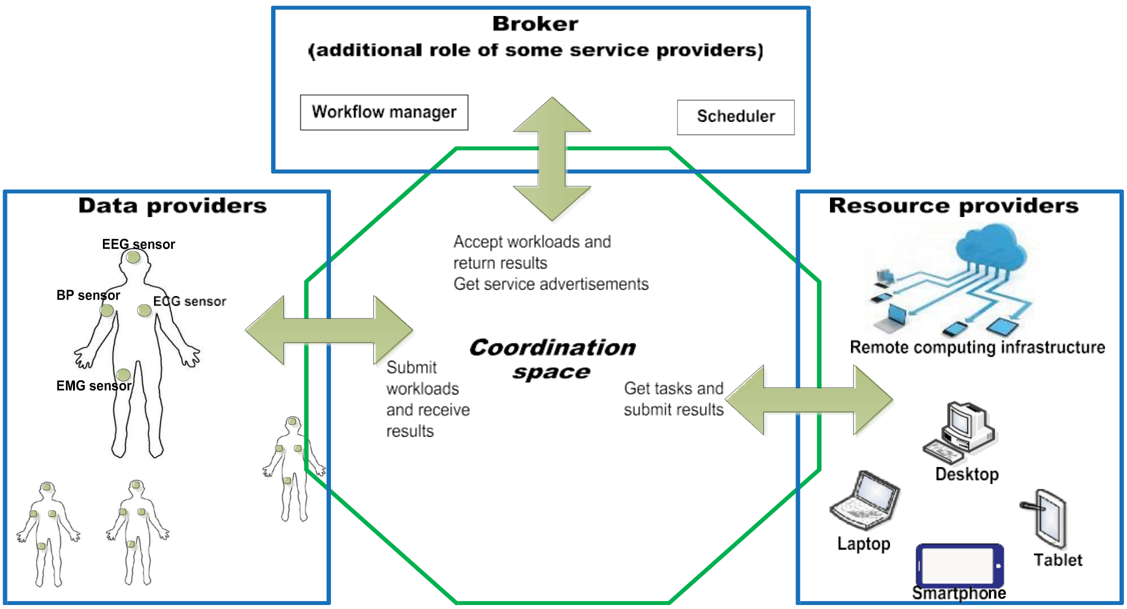

FIGURE 3. *A conceptual diagram of IoT-based ubiquitous healthcare solutions.*

Fig. 4 visualizes a scenario in which a patient's health profile and vitals are captured using portable medical devices and sensors attached to his or her body. Captured data are then analysed and stored, and stored data from various sensors and machines become useful for aggregation. Based on analyses and aggregation, caregivers can monitor patients from any location and respond accordingly. In addition, the topology includes a required network structure for supporting the streaming of medical videos. For example, the topology in Fig. 4 supports the streaming of ultrasound videos through an interconnected network with worldwide interoperability for microwave access (WiMAX), an internet protocol (IP) network, and a global system for a mobile (GSM) network as well as usual gateways and access service networks. Similar conceptual structures are found in [16]_[19].

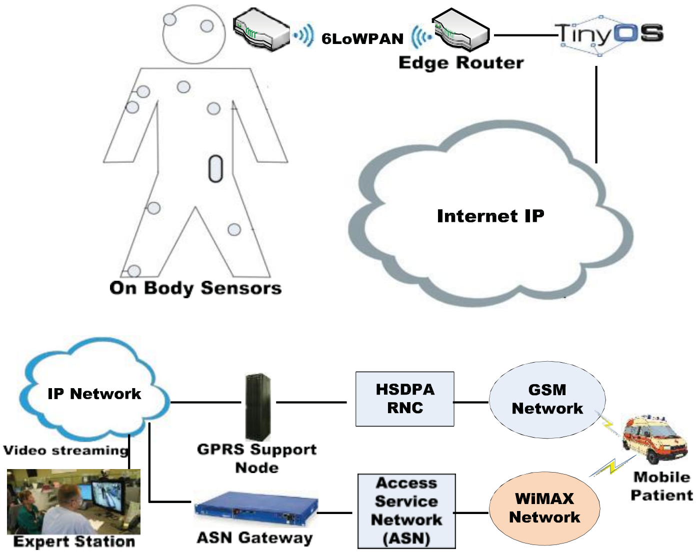

***FIGURE 4.** Remote monitoring in wearables and personalized health care.*

Fig. 5 presents an IoThNet topology showing the role of a gateway. Here intelligent pharmaceutical packaging (iMedPack) is nothing but an IoT device that manages the problem of medicine misuse, thereby ensuring pharmaceutical compliance. The intelligent medicine box (iMedBox) is considered a healthcare gateway with an array of various required sensors and interfaces of multiple wireless standards. Various wearable sensors and IoT devices are wirelessly connected to healthcare gateways connecting the patient's environment to the health-IoT cloud, a heterogeneous network (HetNet) that enables clinical diagnosis and other analyses. The gateway itself can investigate, store,

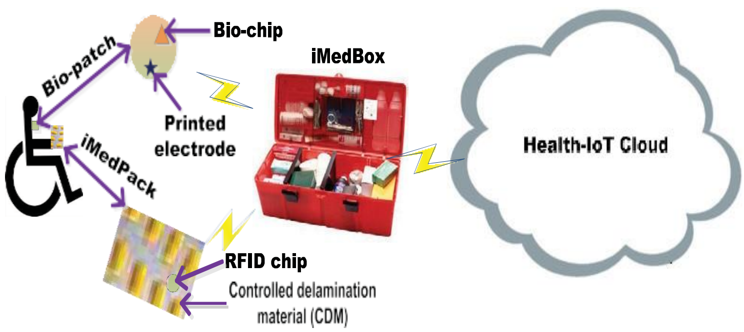

***FIGURE 5.** An IoThNet topology with an intelligent healthcare gateway.*

III. IoT HEALTHCAREAPPLICATIONS

In addition to IoT services, IoT applications deserve closer attention. It can be noted that services are used to develop applications, whereas applications are directly used by users and patients. Therefore, services are developer-centric, whereas applications, user-centric. In addition to applications covered in this section, various gadgets, wearables, and *other healthcare devices currently available in the market are dis- cussed. These products can be viewed as IoT innovations that can lead to various healthcare solutions. The next subsections address various IoT-based healthcare applications, including both single- and clustered-condition applications.*

1) GLUCOSE LEVEL SENSING

Diabetes is a group of metabolic diseases in which there are high blood glucose (sugar) levels over a prolonged period. Blood glucose monitoring reveals individual patterns of blood glucose changes and helps in the planning of meals, activities, and medication times. An m-IoT configuration method for noninvasive glucose sensing on a real-time basis is proposed in [28]. In this method, sensors from patients are linked through IPv6 connectivity to relevant healthcare providers. The utility model in [65] unveils a transmission device for the transmission of collected somatic data on blood glucose based on IoT networks. This device includes a blood glucose collector, a mobile phone or a computer, and a background processor. A similar innovation is found in [66]. In addition, a generic IoT-based medical acquisition detector that can be used to monitor the glucose level is proposed in [67].

2) ELECTROCARDIOGRAM MONITORING

The monitoring of the electrocardiogram (ECG), that is, the electrical activity of the heart recorded by electrocardiog- raphy, includes the measurement of the simple heart rate and the determination of the basic rhythm as well as the diagnosis of multifaceted arrhythmias, myocardial ischemia, and prolonged QT intervals [68]. The application of the IoT to ECG monitoring has the potential to give maximum information and can be used to its fullest extent [69]. A number of studies [20], [31], [33], [35], [40], [56], [70] have explicitly discussed IoT-based ECG monitoring. The innovation in [71] introduces an IoT-based ECG monitoring system composed of a portable wireless acquisition transmitter and a wireless receiving processor. The system integrates a search automation method to detect abnormal data such that cardiac function can be identified on a real-time basis. There exists a comprehensive detection algorithm of ECG signals at the application layer of the IoT network for ECG monitoring [72].

3) BLOOD PRESSURE MONITORING

The question of how the combination of a KIT blood pressure (BP) meter and an NFC-enabled KIT mobile phone becomes part of BP monitoring based on the IoT is addressed in [47]. A motivating scenario in which BP must be regularly controlled remotely is presented by showing the communications structure between a health post and the health center in [73]. The question of how the Withings BP device operates depends on the connection to an Apple mobile computing device is addressed in [74]. A device for BP data collection and transmission over an IoT network is proposed in [75]. This device is composed of a BP apparatus body with a communication module. A location-intelligent terminal for carry-on BP monitoring based on the IoT is proposed in [76].

4) Body Temperature Monitoring

Body temperature monitoring is an essential part of health- care services because body temperature is a decisive vital sign in the maintenance of homeostasis [77]. In [28], the m-IoT concept is verified using a body temperature sensor that is embedded in the TelosB mote, and a typical sample of attained body temperature variations showing the successful operation of the developed m-IoT system is presented. A tem- perature measurement system based on a home gateway over the IoT is proposed in [78]. The home gateway transmits the user's body temperature with the help of infrared detection. Another IoT-based temperature monitoring system is pro- posed in [79]. The main system components responsible for temperature recording and transmission are the RFID module and the module for monitoring body temperature.

5) OXYGEN SATURATION MONITORING

Pulse oximetry is suitable for the noninvasive nonstop mon- itoring of blood oxygen saturation. The integration of the IoT with pulse oximetry is useful for technology-driven medical healthcare applications. A survey of CoAP-based healthcare services discusses the potential of IoT-based pulse oximetry [80]. The function of the wearable pulse oximeter Wrist OX2 by Nonin is illustrated in [31]. This device comes with connectivity based on a Bluetooth health device profile, and the sensor connects directly to the Monere platform. An IoT-optimized low-power/low-cost pulse oximeter for remote patient monitoring is proposed in [81]. This device can be used to continuously monitor the patient's health over *an IoT network. An integrated pulse oximeter system for telemedicine applications is described in [82]. A wearable pulse oximeter for health monitoring using the WSN can be adapted to the IoT network [83].*

6) REHABILITATION SYSTEM

Because physical medicine and rehabilitation can enhance and restore the functional ability and quality of life of those with some physical impairment or disability, they represent a vital branch of medicine. The IoT has the potential to enhance rehabilitation systems in terms of mitigating problems linked to aging populations and the shortage of health experts. An ontology-based automating design method for IoT-based smart rehabilitation systems is proposed in [42]. This design successfully demonstrates that the IoT can be an effective platform for connecting all necessary resources to offer real-time information interactions. IoT-based technologies can form a worthwhile infrastructure to support effective remote consultation in comprehensive rehabilitation [84]. There are many IoT-based rehabilitation systems such as an integrated application system for prisons [85], the rehabilitation training of hemiplegic patients [86], a smart city medical rehabilitation system [87], and a language-training system for childhood autism [88].

7) MEDICATION MANAGEMENT

The noncompliance problem in medication poses a serious threat to public health and causes huge financial waste across the world. To address this issue, the IoT offers some promising solutions. An intelligent packaging method for medicine boxes for IoT-based medication management is proposed in [89]. This method entails a prototype system of the I2Pack and the iMedBox and verifies the system by field trials. This packaging method comes with con- trolled sealing based on delamination materials controlled by wireless communications. The eHealth service architecture based on RFID tags for a medication control system over the IoT network is presented in [90]. Here the prototype implementation is demonstrated, and this ubiquitous medi- cation control system is designed specifically for providing AAL solutions.

8) WHEELCHAIR MANAGEMENT

Many researchers have worked to develop smart wheelchairs with full automation for disabled people. The IoT has the potential to accelerate the pace of work. A healthcare system for wheelchair users based on the IoT technology is proposed in [40]. The design comes with WBANs integrated with various sensors whose functions are tailored to IoT requirements. A medical support system considering peer-to-peer (P2P) and the IoT technology is implemented in [91]. This system provides for chair vibration control and can detect the status of the wheelchair user. Another noteworthy example of IoT-based wheelchair development is the connected wheelchair designed by Intel's IoT department [92]. This development eventually shows that standard "things" can evolve into connected machines driven by data. This device can monitor vitals of the individual sitting in the chair and collect data on the user's surroundings, allowing for the rating of a location's accessibility.

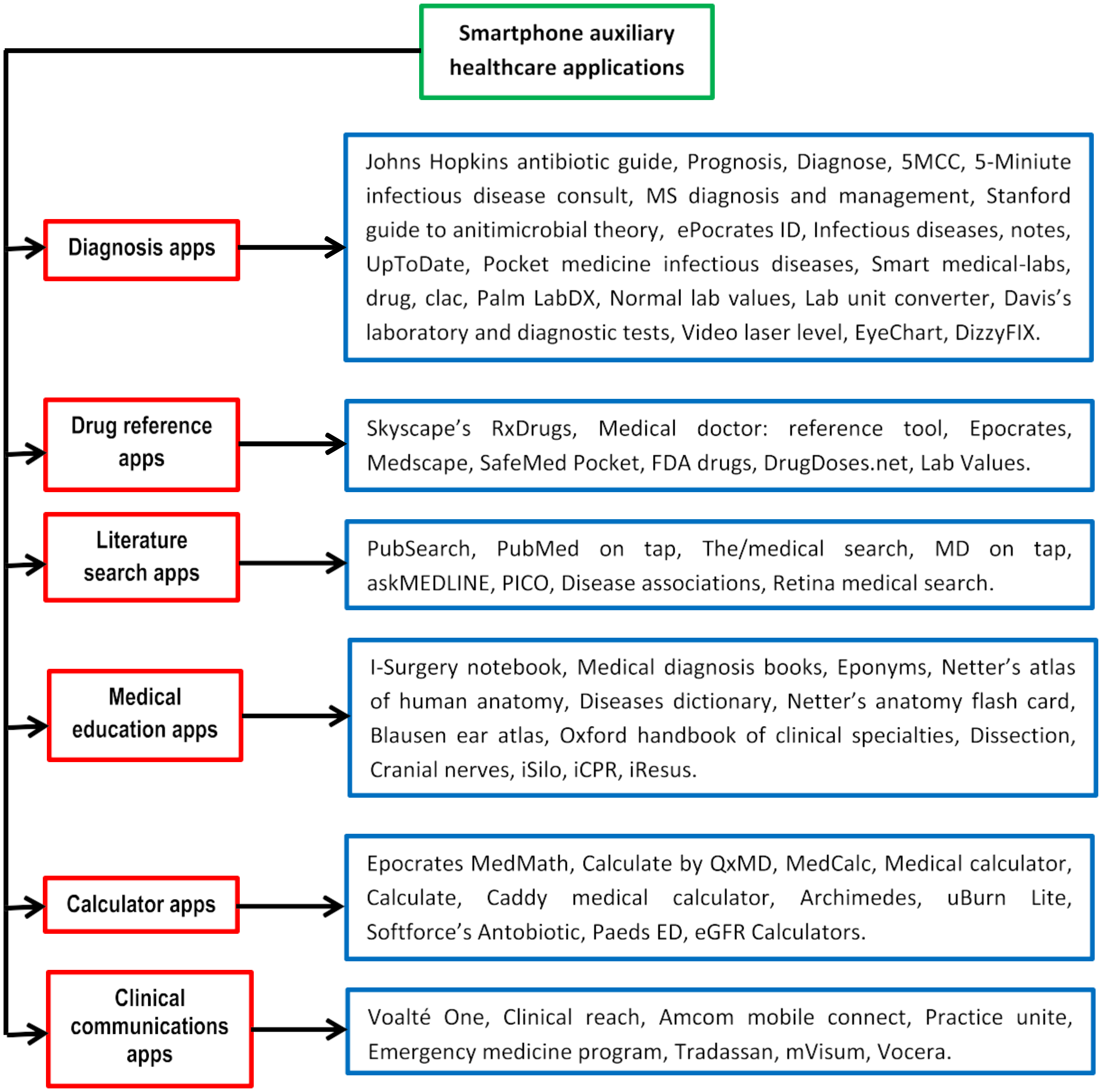

FIGURE 14. *Auxiliary healthcare apps for smartphones.*

9) IMMINENT HEALTHCARE SOLUTIONS

Many other portable medical devices are available though there is no explicit demonstration of the integration of those devices into IoT networks. That is, it is only a matter of time before these devices become embedded with IoT functions. Increasing numbers of medical healthcare applications, devices, and cases have kept pace with the growing demand for IoT-based services across the world. Some healthcare areas whose integration with the IoT appears imminent include hemoglobin detection, peak expiratory flow, abnormal cellular growth, cancer treatment, eye disorder, skin infection, and remote surgery [52], [93], [94]. Most devices today are portable diagnostic devices with conventional connectivity.

HEALTHCARE SOLUTIONS USING SMARTPHONES *Recent years have witnessed the emergence of electronic devices with a smartphone-controlled sensor, which high- lights the rise of smartphones as a driver of the IoT. Various hardwire and software products have been designed to make smartphones a versatile healthcare device. An extensive review of healthcare apps for smartphones is systematically provided in [95], including a discussion on apps for patients and general healthcare apps as well as on medical education, training, information search apps, and others (collectively referred to as auxiliary apps). In addition, there are many recent apps serving similar purposes [96]–[101]. Based on these references, Fig. 14 presents a classification diagram of auxiliary apps. Note that this figure includes no general healthcare apps and apps for patients, which are addressed later in this section. Diagnostic apps are used to access diagnostic and treatment information. Drug reference apps typically provide names of drugs, their indications, dosages, costs, and identifying features. Literature search apps facilitate searches for biomedical literature databases to find appropriate medical information. Medical education apps typically deal with tutorials, training, various surgical demonstrations, color illustrations of different images, and medical books. Calculator apps come with various medical formulas as well as equations and calculate respective parameters of interest (e.g., the body surface burn percentage). Clinical communication apps simplify communication between clinicians within a hospital. A number of image analysis algorithms for smartphones that facilitate noncontact measurements useful for healthcare applications are introduced in [102]. A good (but not complete) sur- vey of smartphone apps providing healthcare solutions is presented [70]. Smartphones can effectively perform the following healthcare diagnosis and/or monitoring: the detection of asthma, chronic obstructive pulmonary disease, cystic fibrosis, coughing, allergic rhinitis, nose-related symptoms of the respiratory tract, the heart rate, BP, blood oxygen saturation, and melanoma and the analysis of wounds in advanced diabetes patients [81]–[83], [103]–[107]. In addition to its ubiquitous deployment capability and availability for users, there is a great advantage of using smartphone healthcare apps in terms of providing low-cost solutions. However, many challenges remain, including computational complexity, power consumption, and noisy environments around smartphones, which should be easy to solve. In addition, there are many health and fitness accessories suitable for smartphones that can help individuals achieve their best shape. For example, Fitbit Flex, a fitness tracking wristband, keeps track of steps taken, the distance travelled, and calories burned. A separate section of this paper provides a more detailed discussion on existing commercial healthcare products that can be viewed as a foundation of IoT healthcare devices.*

Table 1 lists various healthcare applications and discusses their required sensors, operations, and IoT associations, but it does not focus on any smartphone health- care apps. For this, Table 2 includes various smartphone- based healthcare apps with a short description of each. Although there are many apps by developers across the world, this paper discusses some selected apps based on their type, popularity, and intuitive analysis. Most of the apps listed here can be used easily. The interested reader is encouraged to find up-to-date apps similar to those listed here.

Infirmity/condition	**Sensors used; operations; IoT roles/connections**
Diabetes Wound analysis for advanced diabetes patients Heart rate monitoring BP monitoring Body temperature monitoring Rehabilitation system Medication management Wheelchair management Oxygen saturation monitoring Eye disorder, skin infection	A non-invasive opto-physiological sensor; the sensor's output is connected to the TelosB mote that converts an analog signal to a digital one; IPV6 and 6LoWPAN protocol architectures enabling wireless sensor devices for all IP-based wireless nodes. A smartphone camera; image decompression and segmentation; the app runs on the software platform in the smartphone's system-on-chip (SoC) to drive the IoT. Capacitive electrodes fabricated on a printed circuit board; digitized right on top of the electrode and transmitted in a digital chain connected to a wireless transmitter; BLE and Wi-Fi connect smart devices through an appropriate gateway. A wearable BP sensor; oscillometric and automatic inflation and measurement; WBAN connects smart devices through an appropriate gateway. A wearable body temperature sensor; skin-based temperature measurement; WBAN connects smart

	devices through an appropriate gateway.
Asthma, chronic obstructive pulmonary disease, cystic fibrosis Cough detection	A wide range of wearable and smart home sensors; cooperation, coordination, event detection, tracking, reporting, and feedback to the system itself; Interactive heterogeneous wireless networks enable sensor devices to have various access points.
Allergic rhinitis and nose-related symptoms	Delamination materials and a suit of wireless biomedical sensors (touch, humidity, and CO)i the diagnosis and prognosis of vitals recorded by wearable sensors; the global positioning system (GPS), database access, web access, RFIDs, wireless links, and multimedia transmission.
Melanoma detection	WBAN sensors (e.g., accelerometers, and ECG, and pressure); nodes process signals, realize abnormality, communicate with sink nodes wirelessly, and perceive surroundings; smart devices and data center layers with heterogeneous connectivity.
Remote surgery	A pulse oximeter wrist by Nonin; intelligent pulse-by-pulse filtering; ubiquitous integrated clinical environments.

TABLE 1. IoT applications in health care.

IoT HEALTHCARE CHALLENGES AND OPEN ISSUES *Many researchers have worked on designing and implement- ing various IoT-based healthcare services and on solving various technological and architectural problems associated with those services. In addition to research concerns in the literature, there are several other challenges and open issues that need to be carefully addressed. This section briefly presents both explored and unexplored issues surrounding IoT healthcare services.*

1. *STANDARDIZATION*

In the healthcare context, there are many vendors that manufacture a diverse range of products and devices, and new vendors continue to join this promising technological race. However, they have not followed standard rules and regulations for compatible interfaces and protocols across devices. This raises interoperability issues. To address device diversity, immediate efforts are required. For exam- ple, a dedicated group can standardize IoT-based healthcare technologies. This standardization should consider a wide range of topics such as communications layers and protocol stacks, including physical (PHY) and media access control (MAC) layers, device interfaces, data aggregation interfaces, and gateway interfaces. The management of various value-added services such as electronic health records is another standardization issue. This management comes in various forms, including access management and healthcare professional registration. Various mHealth and eHealthorganizations and IoT researchers can work together, and existing standardization bodies such as the Information Technology and Innovation Foundation (IETF), the Internet Protocol for Smart Objects (IPSO) alliance, and the European Telecommunications Standards Institute (ETSI) can form IoT technology working groups for the standardization of IoT-based healthcare services.

2. *IoT HEALTHCAREPLATFORMS*

Because the architecture of IoT-based healthcare hardware is more sophisticated than that of usual IoT devices and requires a real-time operating system with more stringent requirements, there is a need for a customized computing platform with run-time libraries. To build a suitable platform, a service-oriented approach (SOA) can be taken such that services can be exploited by using different application package interfaces (APIs). In addition to a specialized platform, libraries and appropriate frameworks should be built so that healthcare software developers and designers can make efficient use of given documents, codes, classes, message templates, and other useful data. Further, a particular class of disease-oriented libraries can be useful.

3. *COST ANALYSIS*

Researchers may perceive IoT-based healthcare services as a low-cost technology, but to the authors' knowledge, no comparative study has offered any evidence of this. In this regard, a cost analysis of a typical IoThNet may be useful.

4. *THE APP DEVELOPMENT PROCESS*

There are four basic steps in developing an app on the android platform: the setup, development, debugging and testing, and publishing. Similar approaches are generally taken on other platforms. In the process of healthcare app development, the participation of an authorized body or association of medical experts is typically required to ensure an app of acceptable quality. In addition, regular updates on healthcare apps based on the due consideration of recent advances in medical science are vital.

5. *TECHNOLOGY TRANSITION*

Healthcare organizations can modernize their existing devices and sensors across the healthcare field for smart resources by incorporating IoT approaches into the existing network configuration. Therefore, a seamless transition from the legacy system and setup to an IoT-based configuration is a major challenge. In other words, there is a need to ensure backward compatibility and flexibility in the integration of existing devices.

6. *THE LOW-POWER PROTOCOL*

There are many devices in IoT healthcare scenarios, and such devices tend to be heterogeneous in terms of their sleep, deep-sleep, receive, transmit, and composite states, among others. In addition, in terms of service availability, each communications layer faces an additional challenge in terms of power requirements. For example, finding an appropriate device discovery protocol that requires less power while ensuring service availability at the MAC layer is a difficult task.

7. *NETWORK TYPE*

In terms of the design approach, an IoT healthcare network can be of one of three fundamentally different types: data-, service-, and patient-centric architectures. In the data-centric scheme, the healthcare structure can generally be separated into objects based on captured health data. In a service-centric scheme, the healthcare structure is allocated by the assem- bly of characteristics that they must provide. In the patient- centric scheme, healthcare systems are divided according to the involvement of patients and their family members they consider for treatment. In this regard, answering the question of what network type is appropriate for IoT-basedhealthcare solutions becomes an open issue.

8. *SCALABILITY*

IoT healthcare networks, applications, services, and back-end databases should be scalable because related operations become more complex with the addition of diverse applications as a result of the exponential growth of demands from both individuals and health organizations.

9. *CONTINUOUS MONITORING*

There are many situations in which patients require long-term monitoring (e.g., a patient with a chronic disease). In this regard, the provision of constant monitoring and logging is vital.

10. *NEW DISEASES AND DISORDERS*

Smartphones are being considered as a frontier IoT healthcare device. Although there are many healthcare apps and new apps are being added to the list every day, the trend has been limited to a few categories of diseases. R&D activities for new types of diseases and disorders are essential, and the discovery of methods that can make the early detection of rare diseases mobile has long been an important task.

11. *IDENTIFICATION*

Healthcare organizations generally deal with multi-patient environments in which multiple caregivers discharge their duties. From this perspective, the proper identification of patients and caregivers is necessary.

12. *THE BUSINESS MODEL*

The IoT healthcare business strategy is not yet robust because it involves a set of elements with new requirements such as new operational processes and policies, new infrastructure systems, distributed target customers, and transformed orga- nizational structures. In addition, doctors and nurses gener- ally avoid learning and using new technologies. Therefore, there is an urgent need for a new business model.

13. *THE QUALITY OF SERVICE (QoS)*

Healthcare services are highly time sensitive and require QoS guarantees in terms of important parameters such as reliabil- ity, maintainability, and the service level. In this regard, the quantitative measurement of each such parameter within the IoThNet framework may be useful. In addition, system avail- ability and robustness are central to offering QoS guarantees because any type of system disaster can put lives at danger in medical situations. Here the feasibility of plan B in the case of a system failure becomes an interesting issue.

14. *DATA PROTECTION*

The protection of captured health data from various sensors and devices from illicit access is crucial. Therefore, stringent policies and technical security measures should be introduced to share health data with authorized users, organizations, and applications. Here introducing an optimal algorithm for collaboration between protection, detection, and reaction ser- vices to prevent various attacks, threats, and vulnerabilities is an open challenge. Based on the discussion on IoT healthcare security in Section V, several research problems in this area are outlined as follows.

a) *RESOURCE-EFFICIENT SECURITY*

Because of resource (power, computation, and memory) con- straints, IoT healthcare security schemes should be designed to maximize security performance while minimizing resource consumption.

b) *PHYSICAL SECURITY*

Because an attacker may tamper with and capture physical health devices and extract cryptographic secrets, the attacker may modify programs or replace captured devices with malicious ones. Therefore, devices should include tamper- resistant packaging.

c) *SECURE ROUTING*

Routing protocols for the IoT health network are particularly susceptible to device-capture attacks. Therefore, proper routing and forwarding methods are vital for real-time or semi-real-time communication in the desired network.

d) *DATA TRANSPARENCY*

IoT medical devices deal with personal heath data that may be used in IoT cloud services. Therefore, data-transparent services should be designed and developed such that the life cycle of personal data can be traced and data use can be controlled.

e) *THE SECURITY OF HANDLING IoT BIG DATA*

Biomedical sensors and devices generate huge amounts of health data, and there is a need to securely store captured data. Providing security measures for handling such data, including date transfer and maintenance, without compromising integrity, privacy, and confidentiality requires close attention and much effort.

1. *MOBILITY*

The IoT healthcare network must have the ability to support the mobility of patients such that they can be connected any- where, anytime. This mobility feature is ultimately responsible for connecting dissimilar patient environments.

2. *EDGE ANALYTICS*

In the IoT health space, edge analytics such as analytics in edge devices plays an important role and can improve the feature of gateway devices. In this context, there is a need to examine healthcare data analytics to help system designers to optimize the data traffic and IoThNet architecture.

3. *ECOLOGICAL IMPACT*

The full-scale deployment of IoT-based healthcare services requires many biomedical sensors embedded in semiconductor-rich devices. These sensors and devices also include rare earth metals and severely toxic chemicals. This has substantially unfavorable impacts on the environment, users, and human health, and for this reason, guidelines are needed for device manufacturing, the use of devices, and their proper disposal.

CONCLUSIONS

Researchers across the world have started to explore various technological solutions to enhance healthcare provision in a manner that complements existing services by mobilizing the potential of the IoT. This paper surveys diverse aspects of IoT-based healthcare technologies and presents various healthcare network architectures and platforms that sup- port access to the IoT backbone and facilitate medical data transmission and reception. Substantial R&D efforts have been made in IoT-driven healthcare services and applications. In addition, the paper provides detailed research activities concerning how the IoT can address pediatric and elderly care, chronic disease supervision, private health, and fitness management. For deeper insights into industry trends and enabling technologies, the paper offers a broad view on how recent and ongoing advances in sensors, devices, internet applications, and other technologies have motivated afford- able healthcare gadgets and connected health services to limitlessly expand the potential of IoT-based healthcare services for further developments. To better understand IoT healthcare security, the paper considers various security requirements and challenges and unveils different research problems in this area to propose a model that can mitigate associated security risks. The discussion on several important issues such as standardization, network type, business models, the quality of service, and health data protection is expected to facilitate the provide a basis for further research on IoT-based healthcare services. This paper presents eHealth and IoT policies and regulations for the benefit of various stakeholders interested in assessing IoT-based healthcare technologies. In sum, the results of this survey are expected to be useful for researchers, engineers, health professionals, and policymakers working in the area of the IoT and healthcare technologies

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