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ORIGINAL ARTICLE

Internet of things based distributed healthcare systems: a review

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Abstract

To strengthen healthcare industry, lot of research work is being done to explore new, accurate and efficient technology for healthcare industry that can monitor and keep track of health of patients in everyday life or in case of accidents and emergencies. Internet of Things based distributed healthcare system interconnects various medical resources using IoT, distributed databases and distributed DBMSs to provide reliable, effective and smart healthcare service to the elderly and patients with a chronic illness. Internet of Things based distributed healthcare system (IoT-DHS) is a technology that has made major impact on healthcare industry but still there are many challenges and open issues that need to be addressed and find solutions. In IoT-DHS, all available medical resources are interconnected to provide effective and efficient healthcare services to everyone, who is in need of medical assistance. This paper reviews state-of-the-art works in IoT-DHSs, based on which the taxonomy of these systems is proposed considering various aspects such as monitoring methods, communication technologies, computing techniques and low-power protocols. A comparative study of these IoT-DHSs is made to know the suitability of various healthcare systems. The challenges and open issues associated with existing IoT-DHSs are also discussed in detail. This paper helps technical people of medical industry, researchers and scientists interested in cloud computing and IoT technologies for medical field.

Keywords Internet of things · IoT · Distributed healthcare systems · Taxonomy · Cloud · Comparative study · Issues

1 Introduction

The incomparable advantage of IoT and diverse range of potential IoT applications are provoking its users to leverage in any domain such as healthcare system, domestic and home automation, industrial automation, smart enterprise, smart city, smart agriculture, and crisis response to natural and man-made disasters alerting and recovery system. In IoT, the networks of physical objects that contain embedded technology communicate and sense their internal states or the external environment (Gartner 2018).

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Indian healthcare sector is growing tremendously at a 15% Compound Annual Growth Rate (CAGR) to reach US$ 372 billion by 2022 (India Brand Equity Foundation 2019). Healthcare is the maintenance of health via the diagnosis, treatment, and prevention of disease, illness, injury, and other physical and mental impairments in human beings (Wikipedia 2018a). A healthcare system is intended to deliver various healthcare services to meet the health needs of the target populations (Wikipedia 2018b). Aging of people, extension of living expectation, enhancing lifestyle and income growth have brought change in pattern of healthcare service which led to smart healthcare system. Smart healthcare system can be used to monitor health of patients in everyday life or in case of accidents and emergencies.

Growth of advanced devices such as sensors, actuators, advanced communication networks and their reduced price has increased their usage promoting fast development in embedded systems. Healthcare industry is on the rise at tremendous pace strengthening its coverage and services. The healthcare system enabled problems of time and space constraints that occur in medical service for promotion of health that requires a medical doctor to examine bio-signal related information of a patient while facing a patient. It also saves many patients lives in case of emergency or accidents. IoT based distributed healthcare system interconnects various medical resources embedded with sensors such as BP, glucometer, ECG, EMG and so on using IoT, distributed databases and distributed DBMSs to provide reliable, effective and smart healthcare service to the elderly and patients with a chronic illness. The IoT-DHS helps in acquiring various parameters related to patients through different health monitoring devices, communicates to doctor or nurse or hospital or to the relevant ones in time using which first aid actions can be taken up and also a doctor can recommend corresponding prescriptive measures. Hence, there is a need of IoT-DHS to provide efficient solution for healthcare domain.

A thorough review of state-of-the-art IoT-based healthcare systems is done by referring research articles of conferences, journals, books, magazines, etc. in various standard digital sources. Table 1 shows details of digital libraries referred for searching required relevant research articles.

Through the literature survey it is found that existing IoT-DHSs models are applied for specific application like tele medicine, tele-health, PHR and so on. Table 2 in section 3 gives the development tendency of IoT-DHSs. The driving motivation of this paper is to: propose a novel IoT-DHSs which integrates tele medicine, tele health, PHR and so on; derive taxonomy considering various dimensions such as monitoring methods, communication technologies, computing techniques and low-power protocols applicable for IoT-DHSs; consolidate all challenges and open issues associated with existing IoT-DHSs. A comparative study of these IoT-DHSs is made to know the suitability of various healthcare systems.

The main contributions of this paper are:

a. Detailed taxonomy of IoT-DHS is proposed considering various dimensions such as monitoring methods, communication technologies, computing techniques and low-power protocols applicable for IoT-DHSs.
b. A novel architecture of IoT-DHS is proposed which integrates tele medicine, tele health, PHR and so on.
c. Summarizes the development tendency and application of IoT-DHS.
d. Consolidates all challenges and open issues existing in IoT-DHS.

This paper is organized as follows: Section 2 gives brief background of IoT, distributed systems and proposed architecture of IoT-DHS. Section 3 presents the state-of-the-art IoT-DHS and proposed taxonomy of these systems based on various aspects. Section 4 and 5 discuss challenges and open issues respectively associated with existing IoT-based distributed healthcare systems in detail.

Table 1 Referred digital libraries

Digital libraries	Springer	IEEE Xplore	Elsevier	Others
Number of Papers referred	40	37	10	57

2 Background

This section provides a brief background of IoT, Distributed Systems and IoT-DHS.

2.1 Internet of things (IoT)

IoT is an emerging technology that aims to integrate diverse physical objects with embedded technology that communicate and sense or interact with their internal states or external environment. The IoT synergistically includes several other technologies like big data analytics, cloud computing, fog computing, RFID, smart sensors, communication technologies and internet protocols (Ala et al. 2015). Along with the inherited features of these technologies, the IoT also inherits challenges and open issues from all of these technologies. Research in IoT aims to augment distributed processing and distributed storage capability. Centralized systems in IoT possess inefficiencies in terms of latency, network traffic management, computational processing, and power consumption (Ahmed et al. 2016). Hence there is great demand for IoT-DHS.

2.2 Distributed systems

Distributed systems are collection of independent computers which appears to its users as a single coherent computing system (Andrew and Maarten 2007). Distributed systems are used for high-performance computing jobs. The main goals of distributed systems are easy access to remote resources by users or applications. Figure 1 shows types of Distributed Systems: Distributed Computing Systems, Distributed Information Systems, and Distributed Embedded Systems.

Distributed computing systems is collection of workstations or personal computers all running same operating systems called as Cluster computing systems or different administrative domain, hardware, software and deployed network topology called Grid computing system. Distributed information systems have transaction processing systems and enterprise application systems to support concurrency and business processes respectively (Wikipedia 2018c). Distributed embedded systems collaborate among connected devices. These include Home system, electronic healthcare systems and so on (Arvindra 2008).

Table 2 Development tendency of healthcare systems

Year	Healthcare Systems	Description
2010	Pharmaceutical Supply Chain, System for Locating Emergency Personnel (Xiaomu et al. 2012)	System applies Auto-identification technologies such as Radio Frequency Identification (RFID).
2011	Interoperable Hospital Information System (Touati and Tabish 2013; Felipe and George 2014)	A new methodology is designed to process heterogeneous data.
2012	Wearable Health Monitoring Systems (Dario et al. 2012; Carlos et al. 2014; Paez et al. 2014)	Using RFID and sensors.
2013	IoT for healthcare systems (Xican et al. 2015)	These systems include mobile and ubiquitous Telemedicine, integrated with Wireless Body Area Network (WBAN).
2014	Real time IoT-based healthcare systems (Luca et al. 2015; Suciu et al. 2015; Cristian and Heiko 2015)	Due to rapid growth in development of data i.e. Big data, IoT-based healthcare systems were integrated with Cloud.
2015	Automatic healthcare monitoring system (Dimiter 2016; Diah and Muhammad 2016 ; Amine et al. 2016; Prayoga and Abraham 2016)	These systems generate automatic alert alarms.
2016	Enhanced automatic healthcare monitoring systems (Andre et al. 2016; Jaewoon et al. 2016; Mahmood et al. 2016; Wencheng et al. 2016; Min et al. 2017; Phillip et al. 2018; Zulfiqar et al. 2017; Alba and Antonio 2017; Marques et al. 2020)	Automatic healthcare monitoring systems with advanced services in tele medicine and tele health via the medical Internet of Things (mIoT).
2017-till date	Advanced IoT-based distributed healthcare systems (Grishma et al. 2019; Rickey and Santosh 2019; Tu et al. 2015; Weinstein et al. 2013; Chellaiyan et al. 2019; Zhelong and Hong 2009; Syed et al. 2019; Baig et al. 2019; Arup et al. 2018)	Safe, efficient and secure healthcare systems are being developed by addressing the existing open issues and challenges discussed in section 4 and section 5 respectively.

2.3 IoT-based distributed healthcare system (IoT-DHS)

IoT in healthcare domain is used to interconnect various medical resources and provide effective and efficient healthcare service to everyone who is in need of medical assistance. The proposed architecture of IoT-DHS is as shown in Fig. 2. The whole architecture has been dedicated to extending the healthcare services from different branches of hospital to home. The architecture of IoT-DHS system can be segregated into five layers. First layer consists of users/things connected to IoT-DHS. These typically include patients at home, hospitalized patients, medical equipments, mobile patient and clinical staff. The second layer includes all health application hosting devices like laptop, desktop, mobile phone and PDA. Healthcare data generated from sensors attached to users are sent to layer 2. Health application hosting devices interface with gateway through BSC or switch/router i.e. layer 3. The gateways are used to perform protocol conversion, analytics closer to the IoT devices. Through layer 4 i.e. internet data is sent to IoT healthcare cloud which is layer 5. IoT healthcare cloud functionality includes: data storage, pre-processing, data analysis, report generation and decision making. The IoT healthcare data is accessed by local or remote doctors, expert specialist, healthcare service providers and caregivers.

3 State-of-the-art IoT-DHS

Lot of survey is carried out on current existing IoT-DHS.

A novel conceptual framework is proposed in (Ahmed et al. 2016) that overcome some shortcoming of existing IoT architecture that are heavily centralized and rely more on back-end core network for all decision making processes. In this proposed architecture, more computational power is at

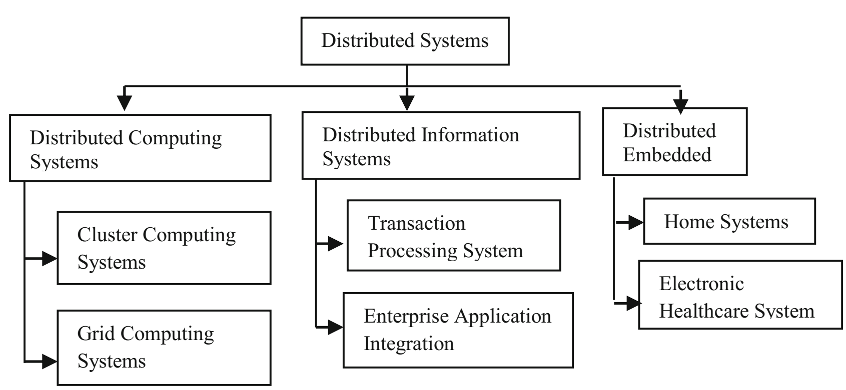

Fig. 1 Types of Distributed Systems

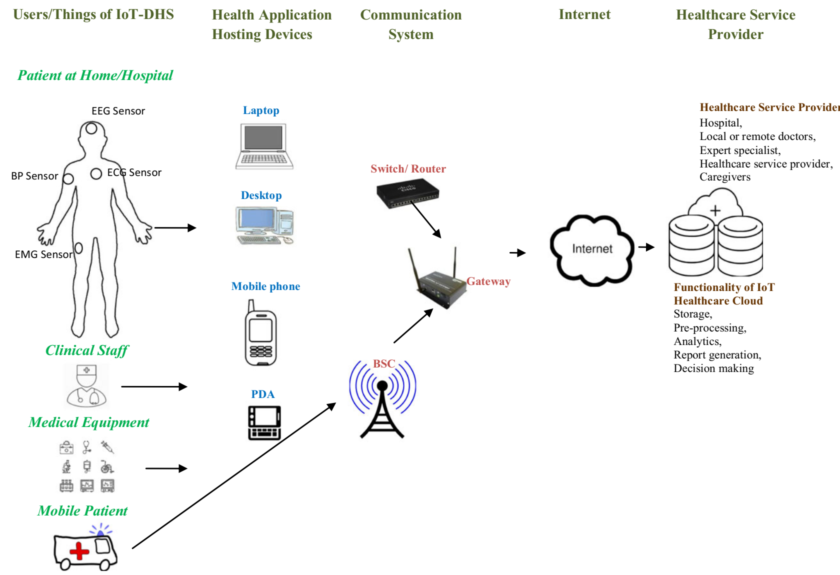

Fig. 2 Proposed Architecture of IoT-DHS

front end which is referred to as "edge computing" or "front-end intelligence". These front-end IoT devices permit fast, trustworthy, and intelligent management of diverse IoT-based applications. Various IoT-based healthcare technologies, healthcare network architectures and platforms are surveyed in (Riazul et al. 2015). Several important issues such as standardization, network type, business models, the quality of service, and health data protection are also discussed.

The smart healthcare devices and systems, standards used for identification of healthcare equipments in IoT-based distributed healthcare system and technologies used for communication are discussed in (Yuehong 2016). The ontology based healthcare system in IoT is proposed in (Abinaya 2015), where the clinic data about patient are accessed from heterogeneous hospital information systems using Sparql query or OWL/RDF file from databases to build ontology. PROTEGE is used to coordinate data across organizations to denote relationships. This system helps doctors in case of emergency cases, shorten death rate, cure patients quickly. The smart rehabilitation framework with automating design methodology (ADM) is illustrated in (Yuan et al. 2014). The framework consists of three levels interfaces for human- machine interaction, the platform for ADM multidisciplinary optimization, and the management of design information and applications. The proposed framework helps quick diagnosis; rehabilitation solution can be made as earlier as possible, quick availability of medical resources to patients, efficient management of information.

A system implemented in (Ni et al. 2014) support daily activities healthcare assistants in ALFs. This system alerts caregivers of hazardous activities faced by inhabitant and inhabitants are assisted from any place. In (Fulvio et al. 2016), a healthcare support system is designed, implemented and evaluated which is supports daily activities of healthcare assistants that operate in ALFs (Assisted Living Facility) for cognitive and disabled people using wearable and mobile technologies. The system helps caregivers by alerting of hazardous situations when inhabitants are out of sight and also gives instant assistance. The design of system is mainly focused on portability and ubiquity. The requirements in design of the system are system ubiquity, system portability, robustness of devices, smart assistance, automatic recognition, assistance delivery confirmation, unobtrusiveness of the assistance request mechanism, emergency call, reliability and stability and internet availability.

The role of IoT in healthcare with focus from the Bottom of Pyramid (BoP) is explains in (Alok et al. 2016). Five practicing physician in Pune were interviewed. The interview focused on BoP rural healthcare practices, awareness of IoT and its acceptance such as remote monitoring by physicians. Challenges specified by physicians in establishing remote monitoring: system implementation, and set up, availability of internet connection, bandwidth, quality of data transfer and connectivity, educating the stakeholders of the systems, fear of clinical error by such devices, maintenance or repair of technological devices in rural areas, additional workload of remote monitoring, weakens strong doctor-patient relationship. Feasibility of application based on physicians: reduce manual workload and automating processes. The work given in (Rajeev et al. 2016) discusses challenges in networking, security, software development, distributed systems, and cyber-physical systems.

The system is designed and implemented for a unified IoT remote healthcare service using international standards CoAP and IEEE 11073 DIM/Service Model (Shu-yuan et al. 2016). The system enhances interoperability and reduces data loss between device and measured information while in transmission. IoT-healthcare system that uses parallel processing Task

Level Parallelism (TLP) to process different health parameter in parallel is implemented in (Niranjana and Muthuselvi 2016). The system uses resources in optimal way by improving the performance up to 65.5%, reduces power consumption of devices and also increases life time sensors. Communication delay is overcome by using standard protocol 6LoWPAN. Processing delay is reduced by using multi-core technology integrated with IoT. The system is suitable for small scale hospitals.

A secure IoT-based healthcare system that uses Body Sensor Network called BSN-Care is proposed in (Prosanta and Tzonelih 2016), an IoT-based system for emergency medical services is proposed in (Boyi et al. 2014), WSN for rehabilitation supervision is presented in (Abdelkrim et al. 2013) and WSN with solar energy harvesting and BLE transmission that enable autonomous WBAN is presented in (Taiyang et al. 2017).

An intelligent framework called Data Management Framework based Swarm Optimization (DMFSO) is proposed in (Chun-Wei et al. 2014). The authors reviewed standards used in IoT: Future Internet Architecture (FIA), Future Internet Design (FIND), Future Internet Research and Experimentation (FIRE), AKARI, Name Data Networking (NDN), SENSEI, Internet of Things Architecture (IoT-A), NEBULA, Man Like Nervous (MLN), Social Organization Framework (SOF), Social IoT (SIoT), PHEV (Plug-in Hybrid Electric Vehicle). Also presented computational intelligence can be added to IoT to solve complex problems using neural networks, fuzzy logic, evolutionary computation (or swarm intelligence). Open issues and challenges in IoT are discussed.

A review of modern requirements in hardware, communication and computing for next-generation u-health systems are presented in (Farid and Rohan 2013). The issues and needs if distributed embedded systems in different domains are presented in (Mishra and Tripathi 2014). The healthcare system is implemented in (Prashant and Rasika 2017) remotely monitor the cardiac patients using Intel Edison board, physiological and contextual sensors. The use of Edison board provides multitasking and uses less power consumption. A system is designed in (Jemal and Mohammad 2017) that manage patient's physiological information using wearable sensors. A systematic literature survey on PHR (Personal Health Record) is done in (Alex et al. 2017). Using PHR, patients can maintain drugs, medical conditions and behaviour related to self-monitoring and self-care of their health.PHR accepts data from health related equipments such as smart watches, wireless scales, accelerometers, gyroscopes, and wristbands. Data collected from PHR help to detect risks in patients. PHR inform small set of users health care needs, have limited intelligence, automatic processing of data stored in PHR and integrating sensor data with PHR stored records for knowledge discovery is another challenge. A real time glucose monitoring system is designed in (Tuan et al. 2017). The applications of depth imaging sensors in healthcare and workflow analysis are assessed in (Sebastian et al. 2013). In (Alexandros et al. 2012), a survey is made on human behaviour analysis (HBA), discovering solutions to its related problems: pose, gape and action estimation and action recognition, and human behaviour understanding.

A brief summary of Computer Vision methods required for data acquisition and procedure analysis in surgical process modelling is made in (Lalys and Jannin 2014). The paper (Nkenge et al. 2015) summarizes state-of-the-art hand-movement modelling and animation, including techniques for gesture recognition that can be directly applied to Healthcare environment monitoring. Survey on the applications of radiofrequency identification (RFID) in healthcare and hospitals is made in (Yao et al. 2012a). Studies on tracking methods based on RTLSs to watch the location of patients, healthcare equipment, and Clinical staff is done in (Kamel and Berry 2012). Estimation of different near field communication (NFC)–based sensing devices to monitor healthcare related issues, such as blood-glucose level of patients and medication dosage is done in (Stefan et al. 2013). Analysis on use of passive RFID to gather information about healthcare places, with centre of attention on patient's behaviour and environmental circumstances is made in (Lamonaca et al. 2015).

Survey of healthcare monitoring systems done in (Rodolfo et al. 2018) analyze monitoring technologies with a methodical literature review about sensors in workflow of healthcare environments and a taxonomy is derived to categorize work concerning sensing technologies and methods. Many researchers have explored the applications of SOA in IoT-based DHS. For example, (Firat et al. 2007) supported to adopt SOA to design, implement, deploy, invoke and manage the services in a DHS. The paper (Omar and Taleb-Bendiab 2006) explained an experimental e-health monitoring system (EHMS) where SOA was used as a platform for e-health services. In (Eugen and Seong 2006), the main characteristics, components and services of an SOA-based system are discussed. In particular, the challenges in SOA implementation for large-scale distributed health enterprises were examined from the perspectives of cost, risk, and profit. (Asadullah et al. 2009) Highlighted the importance of SOA in telemedicine applications.

The work given in (Amir et al. 2018) demonstrate fog computing concepts IoT-based healthcare systems called Smart gateways which tackled challenges such as mobility, energy efficiency, scalability, interoperability and reliability. A pervasive monitoring system is proposed in (Chao et al. 2017) that can send real time patients physical signs to remote medical applications. The identification technology is used to map a unique identifier or UID with a scope within particular area or globally, to an entity so as to identify device without ambiguity. UIDs can be generated using single quantity or out of a collection of attributes such that the combination of their values which is unique. Identification technologies addresses the global ID schemes, identity management, identity encoding/encryption, authentication and repository management using identification and addressing schemes and the creation of global directory lookup services and discovery for IoT applications with various unique identifier schemes (Debasis and Jaydip 2011). Table 3 gives the applications of IoT-DHSs.

The National Telemedicine Taskforce by the Health Ministry of India, in 2005, paved way for the success of various telemedicine projects like the National Telemedicine Portal, Electronic Health Records, National Rural AYUSH Telemedicine Network, Village Resource Center (VRC) and AROGYASREE (Ting et al. 2010). At present, China has three major telemedicine networks, including the Golden Health Network, the International MedioNet of China network and the People's Liberation Army telemedicine network. In recent years, China has been focusing on facilitating the development of platforms for telehealth by increasing availability of wireless data transmission networks. Rising up with the trend, the market for remote monitoring devices is believed to continue growing and adoption will increase (Malik 2007). An emerging tele medicine innovation in china is Hospital Internet. (Jingzhao et al. 2011). Telehomecare programs are also initiated in countries, including whole system demonstrator (WSD) project in the United Kingdom, veterans health segmentation (VHA) project in the United States, and TELEKART program in Denmark (Vega 2020).

3.1 Proposed taxonomy of IoT-DHS

The paper reviews IoT-DHS with multiple perspectives. It review in terms of healthcare monitoring methods, communication technology, site of data processing and Low-power protocols as shown in Fig. 3.

3.2 Monitoring methods based IoT healthcare systems

Monitoring systems facilitate high precision tracking of actors and equipments in healthcare environment (Rodolfo et al. 2018). Activities of clinical staffs are tracked to ensure the quality of medical services. Patient's health parameters are also monitored using monitoring systems. These help in real-time analysis and feedback about clinical staff and patients in critical cases. Hence help to reduce death rate due to human error or patients in critical case. There are three novel methods to monitor patients and clinical staff in healthcare systems: Computer Vision and Real Time Location System and integrated CV - RTLS. Table 4 gives the comparative description of these methods.

3.3 Computing technologies based IoT healthcare systems

Based on application requirements the data is either processed at health application hosting devices (layer 2) or communication system (layer 3) or health service provider (layer 5). The data processed at health application hosting devices is also called as Edge computing. The data processed at layer 3 in gateway is called Fog Computing and the in cloud server is called Cloud computing.

Edge Computing refers to processing of the data at edge (or logical extreme) of the internet i.e. at health application hosting devices (layer 2) with respect to Fig. 2.

Fog Computing is a decentralized computing infrastructure in which data, compute, storage and applications are distributed in the most logical, efficient place between the data source and the cloud (Wikipedia 2019b) i.e. at communication system(layer 3) with respect to Fig. 2.

Table 3 Application of IoT-DHSs

Applications	Description
Tele medicine (Mordor Intelligence 2020)	Telemedicine allows **clinical services** to leverage information technologies, video imaging, and telecommunication linkages to enable doctors to provide healthcare services at a distance.
Tele health (Mordor Intelligence 2020)	tele health is an umbrella term that covers **tele medicine** and a variety of non physician services, including **tele nursing** and **tele pharmacy**
Mobile health (Mordor Intelligence 2020)	Mobile health is a newer concept that describes services supported by **mobile communication** devices, such as wireless patient monitoring devices, smart phones, personal digital assistants, and tablet computers.
Internet hospital (Javier and Andres 2012)	A new approach to outpatient service delivery has been developed in China. Patients go to a medical consultation facility near their home and meet through the internet with a doctor who is based in a top-level hospital in a big city.
eHealth (Mordor Intelligence 2020) (Alicia et al. 2019; Wlodarczak 2019; Izabella and Cees 2019; Samantha 2020; Victor et al. 2020; Sara et al. 2020; Chiara and Chiara 2020)	***eHealth*** is the use of information and communication technologies (ICT) for health.

Fig. 3 Proposed taxonomy of IoT-DHS

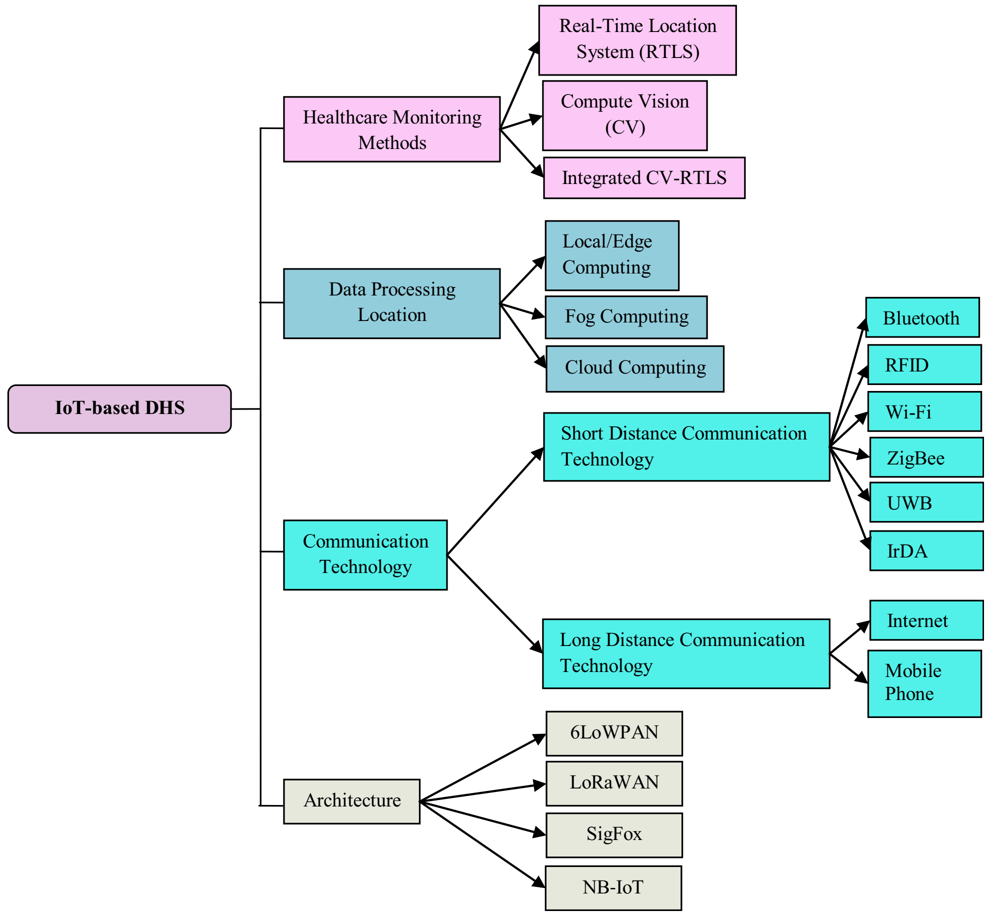

Table 4 Monitoring methods based IoT Healthcare Systems

Monitoring Methods	Functions	Technologies	Processing steps	Advantages	Disadvantages
Real-Time Location System	**Identification** (Javier and Andres 2012; Chen and Chang 2012; Chun et al. 2007; Lin et al. 2012), **Localization** (Cristina et al. 2009; Daniel et al. 2016; Priyanka et al. 2015; Kevin et al. 2015), **Patient State** (Daniel et al. 2016; Kevin et al. 2015; Oresti et al. 2014; Jean-Pierre and Hanhoon 2017), **Activity Monitoring (Javier and Andres 2012; Gimeno et al. 2013; Oresti et al. 2014; Filipe et al. 2014; Guo et al. 2016)**	RFID, WSN, NFC	Mobile antennas and Fixed tags, Fixed tags and mobile antennas, Signal strength analysis, Pulse radar sensing, Monitoring based on wearable sensors, Monitoring based on Portable Sensing Devices.	Provide identification and Localization at low computational requirement and storage space.	Hardware cost is limiting factor.
Computer Vision (CV)	**Location (Risto et al. 2016; Jorg et al. 2013; Beyl et al. 2016; Horst-Michael et al. 2017; Jun et al. 2014; Claudio et al. 2012; Wang et al. 2016; Zhang et al. 2017**), **State (Priyanka et al. 2015; Abdolrahim et al. 2015)** **Activity(Haikuo et al. 2014)**	Depth Imaging	Camera Calibration, Background removal, Feature detection and matching, Tracking, Pose and Shape estimation.	Enable acquisition of detailed information about location and state without necessity of sensors per asset.	Very high computational cost and storage space because of nature of input data.
Integrated CV and RTLS	**Identification, Localization, Patient State, Activity Monitoring** (Ni et al. 2015; Usman et al. 2017; Wikipedia 2019b)	Depth Imaging, WSN, RFID, NFC	Multimode analysis	Yield rich monitoring results and reduce required computational power.	Challenge is inference among technologies

Cloud computing is the delivery of computing services—servers, storage, databases, networking, software, analytics and more—over the cloud (Microsoft Azure 2019) i.e. at healthcare service provider (layer 5) with respect to Fig. 2. The advantages and disadvantages of these three computing technologies are given in Table 5.

3.4 Communication technology based IoT healthcare systems

Communication standards are categories into two types: Short distance communication and long distance communication (Yuehong 2016) (Stephanie et al. 2017).

Short distance communication technology: To communicate the data between devices within WBAN short range communication standards are used whereas later helps to provide communication between central node of WBAN and HIS. Table 6 and Table 7 shows the Comparison of short distance communication technologies used in healthcare system and their advantages and disadvantages respectively (Yuehong 2016) (Rodolfo et al. 2018) (Stephanie et al. 2017; Ilker et al. 2010; Wen et al. 2010; Yao-lin et al. 2011; Yao et al. 2012b; Omni-ID 2019; Hsi-Wen et al. 2010; AMI 2019; Wikipedia 2019a; Jean et al. 2002; FreeRTOS 2019; Maxim Integrated 2019; JUSTIA 2019; RF Wireless World 2019; Muhammad 2012).

Choosing short range communication technologies for healthcare environment requires their effect on human body, security and latency. The chosen communication technology should not have negative effects on patients or clinical staff body, to avoid additional health issues for patients, tough security mechanisms ensure that susceptible patient's data cannot be accessed by attacker. Finally, low latency is crucial for time-critical systems, the system that monitors critical health and calls for an ambulance if the need arises. In healthcare applications that are not time critical, low latency is not a high priority but still preferred.

Many short range communication technologies exits but most commonly used ones in IoT are Bluetooth Low Energy (BLE) and ZigBee (Stephanie et al. 2017).

Sensor data should be forwarded to a cloud database where relevant parties such as healthcare experts, caretakers or doctors can securely access for decision making. There are again several criteria when selecting a suitable long-range communications standard for use in a healthcare system, including security, robustness against interference, low-latency, and high availability. The most commonly used long distance communication technologies are internet and mobile phones.

3.5 Low-power protocols

To enable resource constrained devices such as sensors or others to be part of Internet so that these devices are capable of communicating with other devices by using low power and low data rate, few protocol stacks have been designed such as 6LoWPAN, LoRaWAN, SigFox, and NB-IoT. IPv6 over low-power wireless personal area network (6LoWPAN) are crucial in short range low power networks. Long Range Wide Area Networks (LoRaWAN), SigFox and narrow-band IoT are three most important networks in long-range low-power networks and often called as low power wide area networks (LPWAN). In general, LPWAN are more demanding in terms of node and link constraint than 6LoWPAN networks. Also, LPWAN networks don't have IPv6 addressing capabilities (Sofiane et al. 2012). The comparison between 6LoWPAN, SigFox, LoRaWAN, and NB-IoT is shown (Hayder and Andrew 2017) (Stephanie et al. 2017) in Table 8.

4 Challenges

Many challenges (i.e. obstacles to overcome) exist in IoT-DHS (Ala et al. 2015) (Riazul et al. 2015; Yuehong 2016) (Chun-Wei et al. 2014) (Farid and Rohan 2013) such as follows:

Table 5 Advantages and Disadvantages of Data Processing Location based IoT Healthcare Systems

Computing technologies	Advantages	Disadvantages
Local Processing (Ahmed et al. 2016**)** (Beyl et al. 2016; Horst-Michael et al. 2017)	In-situ decision making, Lower operating costs, reduced network traffic and improved application performance.	Limited computing power and storage.
Intermediate Processing (Amir et al. 2018**)**	More computational power and storage space compare to edge computing	Limited computing power and storage.
Cloud Server (Xiao and Ning 2011; Ni et al. 2014; Fulvio et al. 2016; Alok et al. 2016; Shu-yuan et al. 2016; Boyi et al. 2014; Farid and Rohan 2013; Prashant and Rasika 2017; Jemal and Mohammad 2017; Chen and Chang 2012; Chun et al. 2007; Lin et al. 2012; Filipe et al. 2014; Yao et al. 2012b; Mahantesh et al. 2017)	Very high computing power and large storage space.	Slow response time and require high bandwidth.

Table 6 Comparison of short distance communication technologies used in healthcare system

Technologies Features	Bluetooth Low Energy	ZigBee	Active RFID	Passive RFID	Wi-Fi	IrDA	UWB
Band of operation	2.4GHz	2.4GHz	433MHz	860-960 MHz,13.5 MHz	2.4GHz, 5GHz	850 nm–900 nm	3.1GHz–10.6GHz
Topology	Star	Mesh	Multipoint(2-way)	Multipoint(1-way)	Star	point-to-pont, point-to-multipoint	Multipoint
Range	150 m	30 m	0.01-100 m	0.01-3 m	50 m	0-1 m	0-10 m
Data Rate	1Mbps	250 kbps	10's of Mbps	869 kbps	1Mbps to 300Mbps	100Mbps	53Mbps-48Mbps
Network Nodes	8	65,000	1000 + tags/one time	1 tag/one time	50	2	unknown
Battery Life	Some days	6 months -2 years	Up to 100 days	N/A	Some hours	Some months	Some months
Stack Size	60-150 k	15-40 k	N/A	N/A	100-250 k	20 k flash memory+500 bytes RAM	Standardization is not complete
Latency	Up to 3 s	30 m	Less than 1 ms/read	Up to 0.1 s /read	1-35 ms based on band of operation	<10 ms	1.8 ms
Security Features	128-AES encryption	128-AES encryption.	Tame Transformation Signatures (TTS) algorithm.	Tame Transformation Signatures (TTS) algorithm.	SSID	IRFM	High
Power(mW)	1–100	0.5–3	< 1	**N/A**	**>1000**	**40–500**	**<1**
Cost	2–5$	5$	**15-20**	**<1$**	**25$**	**=1$**	**20$**

4.1 Unobtrusiveness

The capacity of battery in IoT devices is directly proportional to size of battery. The challenge is to develop batteries small in size with fair energy which is hard. The capacity of battery is directly proportional to size of battery.

4.2 Fixation

Sensors are placed in contact with skin. To get the accurate measurement, sensors should not drift from its position which results in poor quality of data.

4.3 Energy efficiency

The nodes of system require high rate sampling of sensors and generate high amount of data. This requires high energy from the batteries. Low duty cycling is not appropriate because they go off most of the time and since motion sensors are continuously sampled, it is not right one to use. Also wireless communication requires high energy for communication of data. Challenge is to develop a system that increases the sensor node life time and reduce charging overhead.

4.4 Body impact on signal propagation

Human body effects the signal propagation in wireless transmission. Signal propagation is affected by reflection from the body and diffraction around the body. Hence a realistic and accurate propagation model is required to develop a new communication device which is a major challenge.

4.5 Reliability

Since several nodes with different signal are used in healthcare system that generates continuous large volume of streaming data. This leads to collision of data and large energy consumption. The challenge is to develop a system with maximum throughput with low bandwidth in spite of severe interference.

4.6 Quality of service

In healthcare, the systems should support real time communication with guaranteed delay to deliver the real time feedback of patients in case of emergencies such as fall of patients. The communication protocol should implement data prioritization mechanism to implement service differentiation between low priority and high priority services.

4.7 Synchronization

Sensors used in healthcare systems are highly co-related. The sensed signals are used to generate or reconstruct the original

Table 7 Advantages and Disadvantages of Short distance communication technologies

Short distance communication technologies	Advantage	Disadvantage
Bluetooth Low Energy	These equipments are widely installed and have optimized ad-hoc network	These have small network capacity, high power consumption, more expensive and short transmission distance.
ZigBee	ZigBee consume low power, low cost, less space, strong anti-interference, high network capacity, a wide range of coverage and low transmission rate.	ZigBee need to stack on the host side and require a corresponding network.
Active RFID	These have extremely long read range, better tag abilities with combined technologies such as GPS, sensors, etc. and have extremely rugged tag options.	Active RFID are expensive compare to passive tags, large in size battery outages result in misread.
Passive RFID	Tags are small in size, inexpensive, flexible, options for higher range of tag, tags can last life time without the help of battery.	Electromagnetic Interference (EMI) issue
Wi-Fi	Wi-Fi offer good quality mobility, builds a network quickly and easily, high transmission rate compare to Bluetooth, wide coverage	High power consumption, Expensive, insecurity compare to Bluetooth
IrDA	**Does not** harm human body, data communication is fast, more secure than wireless communication	Transmitter and receiver has to be same line, device cannot move on when transmission is in progress, used for very short distance applications
UWB	Low transmission power, transmission rate is high, large bandwidth, tough anti-interference, large communication capacity	Low coverage, expensive, available to U.S only, not yet standardized.

movements. The nodes do not share common clock and hence synchronization problem has to be addressed.

Feedback: Feedback helps patients to correct in case of incorrect movement during their exercise. This requires efficient signal processing algorithm and novel modal of kinetic. Multi-sensor data fusion is another problem. Also these algorithms have to be real time with guaranteed delay and there is a need for adequate feedback presentation.

4.8 Scalability

In IoT based healthcare systems, network, services, applications and back end databases have to be scalable.

4.9 Identification

Since healthcare systems deals with multi-patient environment, there is a need for appropriate identification of patients in healthcare system.

5 Open issues

Open issues (i.e. needs to be addressed if there is to be a chance for a good outcome) in IoT-DHS is categorized based on different perspective: infrastructure, data management and computational (Riazul et al. 2015) (Alok et al. 2016) (Niranjana and Muthuselvi 2016) (Chun-Wei et al. 2014) (Reichman et al. 2011; Tomas et al. 2011; Parisa et al. 2011; Anthony et al. 2010; Quoc et al. 2009; Praveen and Mahantesh 2017; Praveen et al. 2017; Mahantesh and Sunilkumar 2014). Figure 4 shows categorization of open issues that exist in IoT-DHC.

5.1 Infrastructure perspective

In future an integrated IoT framework is likely to be developed to provide a combined solution. For this to happen, a common communication interface has to be developed to provide more feasible service for information exchange with different IoT systems. Some of issues with this perspective are:

5.2 Standardization

In existing IoT based healthcare system, there are no standard rules to protocols and interface to connect diverse devices connected to internet. Hence results interoperability problem. A dedicated group is required to standardize IoT based healthcare technology such as electronic health records, gateway interfaces, data aggregation interfaces, communication and protocol stack i.e. physical and MAC layer.

5.3 IoT healthcare platforms

IoT-based healthcare system require customized platform for computing with run time libraries and also sophisticated hardware. To help healthcare software developers and designers, specialized platforms, appropriate frameworks and libraries has to be built. So that software engineers can write efficient codes, message templates, classes of disease oriented libraries.

Table 8 Comparison between Low-power protocols

Architectures	Band of operation	Network capacity	Range	Data rate	Security Features
6LoWPAN	2400–2483.5 MHz(worldwide) 902–929 MHz(North America)	2^{64} nodes	10-100 m	250 kbps(for 2.4 GHz), 40 kbps(for 915 MHz band), 20 kbps (for 868.3 MHz band)	AES-128
SigFox	868 MHz(Eu) 915 MHz(US)	50,000 nodes	9.5 km	100 kbps	Messages signed with a private key Limit of 140 messages/day Encryption and scrambling methods supported
LoRaWAN	868 MHz(Eu) 915 MHz(US)	40,000 nodes	7.2 km	0.25–5.5 kbps	Unique key assigned to node, known only to the node and base station. Data encrypted using the unique key
NB-IoT	Various – can operate in LTE bands(in-band mode), in the guard bands of LTE(guard-band mode), or in re-farmes GSM bands(standalone mode)	53,547+ nodes	15 km	250 kbps	3GPP S3 security scheme-includes authentication of entity, identification of device, user identity confidentiality and integrity in data as mandatory security features.

5.4 Cost analysis

There is no complete comparative study to analyze the cost of IoT technology. This means that there is no proof to say IoT as low cost technology.

5.5 Application development process

To develop an acceptable quality healthcare app, participation of medical expert or authorized body is required.

5.6 Network type

Identifying the type of network suitable for IoT-based healthcare system is another issue.

5.7 New diseases and disorders

There is a need for R&D team to work on new diseases and to discover the method detect the rare disease in early stage.

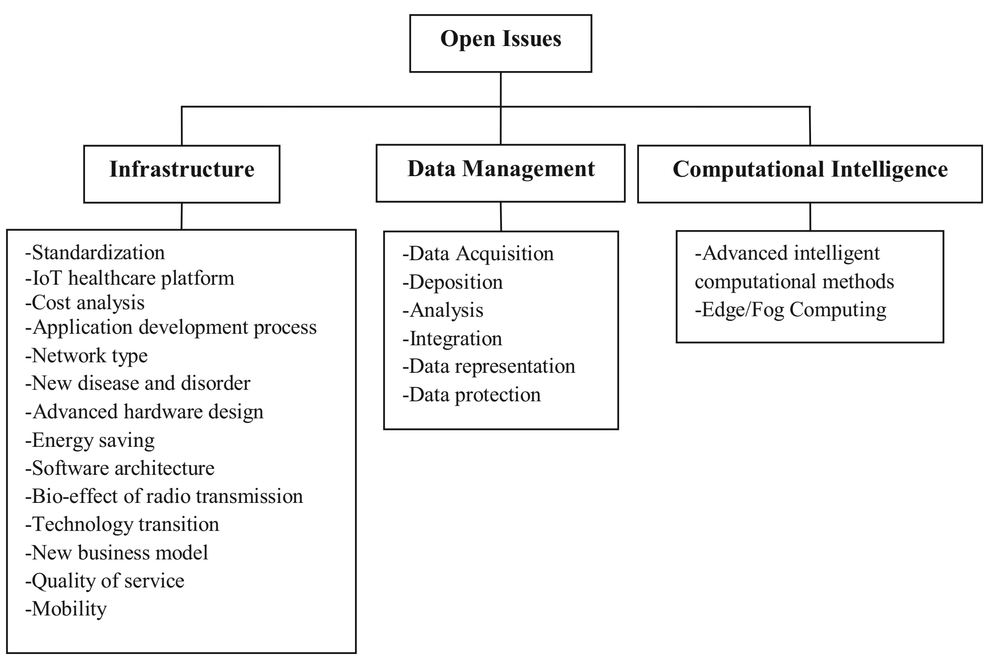

Fig. 4 Categorization of open issues that exist in IoT-DHS

5.8 Advanced hardware design

Lot of open issues still exit in design and miniaturized sensor nodes. Healthcare monitoring requires adoption of WSN with more miniaturized batteries, sensors, circuits and radio transceivers. Wired connections limit user activity hence has to be completely removed. Electrode with radio transceiver that connects wirelessly to ECG board remains a challenge.

5.9 Energy saving

For achieving prolonged monitoring, an optimal solution is required by combining optimal power hardware design and low power communications. Activity-aware energy models are an attractive research direction in order to minimize the power consumption. Context-aware episodic sampling can be used to alter performance to high or low which remains as an open issue. A novel battery can be charged to 90% in 2 min, developed by University of Illinois. Wireless powering methods i.e. light, capacitive or ultra sonic techniques are other hot research topics.

5.10 Software architecture

Not enough work is carried out in field of visualization of data such as data presentation, progress monitoring, and performance feedback.

5.11 Bio-effect of radio transmission

Disclosure to electromagnetic field rays has advert effect on human body that should be kept minimal. Some research has shown the effect of radio transmission on humans in WSN, but research is still incomplete. To protect people against electromagnetic fields, a standard is issued by IEEE that defines a threshold to electromagnetic fields.

5.12 Technology transition

There is a need for both forward and backward compatibility in existing healthcare sensors and devices.

5.13 New business model

There is a need for robust healthcare system and hence an urgent requirement lies in development of new business model.

5.14 Quality of services

Healthcare services are time sensitive and require guaranteeing Quality of Service with parameters such as service level, maintainability and reliability.

5.15 Mobility

The IoT network must be able to get connected anywhere and anytime. This feature is called mobility which connects patients IoT network to any other dissimilar patients environment.

5.16 Data management perspective

The developer of IoT-DHS have to focus on data extraction i.e. collecting the data from the various appliances and then to extract useful information from raw data. Data extraction have a strong impact on the performance of system.

5.17 Data acquisition

The data collected from sensor is incomplete, noisy and missing. Hence efficient methods are required to deal with these problems.

5.18 Deposition

Since the sensors are resource constrained, an efficient way to deal with storage of collected data is necessary.

5.19 Analysis

An efficient algorithm to analyze the collected data is required.

5.20 Integration

Assuring the accuracy, consistency of data throughout its life time is the integrity of data. There are still open issues exist in integrity of data.

5.21 Data representation

No much work is done in data transformation to higher level format.

5.22 Data protection

The protection of data from other things connected to the internet. Strict rules and security measures are required to share the data to authorized users, applications and organization. An optimal algorithm is required to protect data against various threats which detects, reacts and protects the data.

- **Resource Efficient Security:** The main issue is to design the security algorithm such that it maximises the security by minimizing resource consumption.

- **Physical Security:** Healthcare devices connected to the Internet should have tamper resistant packaging, which will avoid attacker to modify the program and replace it with the malicious devices.
- **Secure Routing:** Proper forwarding and routing algorithms are required since the devices in healthcare network are susceptible to device-capture attacks.
- **Data Transparency:** Healthcare services make use of IoT cloud, data transparency is required to trace the access of data and control its access use.
- **Security of handling big data:** The big data generated by IoT-DHS has to be securely stored. Security measures includes: managing big data, data transfer and maintenance, confidentiality, integrity and privacy.

5.23 Computational Intelligence perspective

Another cornerstone is to make IoT-DHS smart and construct them to take useful decisions. Computational intelligence technologies are still at their immaturity.

5.24 Advanced intelligent computational methods

Since the computational intelligence is at very early stage, advanced intelligent computational services are required for healthcare systems.

5.25 Edge/fog computing

To optimize the network data traffic, computing is done at the edge devices, this is an open issue since edge devices are resource constrained devices.

6 Conclusion

IoT-DHS are developing at tremendous pace strengthening its coverage and services. The healthcare system enabled problems of time and space constraints that occur in medical service for promotion of health. It also saves patients lives using advanced devices using which various parameters related to patients health are acquired to take first aid action in case emergency or accidents. Hence IoT-DHS acquires health related information of a patient in a short duration and saves the patients lives.

This paper reviews existing IoT-based distributed healthcare systems and taxonomy is derived considering existing IoT-based distributed healthcare system, and a comparative study is made between various prevailing IoT-based distributed healthcare systems. The challenges and open issues associated with existing IoT-based distributed healthcare systems are also discussed.

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