Chapter 3
Fog Computing Architectures and Frameworks for Healthcare 4.0

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3.1 Introduction

With advent of technology, with customer demand getting increased and the longing for cutting edge innovation to further augment advanced technological services, innovative and novel opportunities and challenges are getting emerged in an industry. This transformation endorses novel perspective in context configurations, environments, and motivations that in due course impacts performance of a company. In current era, technical innovations and advancements are increasing genuine significance in many industries such as IT industry, bio-technical industry, automotive industry, and so on. New technologies are being incorporated by these industries which utilize automation and intelligent solutions are outcome of the same. These changes are the antecedents to the growing and evolving changes which leads to a novel industrial revolution, namely "Industry 4.0" [1]. This power of revolution will produce an impact industry-wide.

3.1.1 Industry 4.0

Comparing the evolution of industry standards, Industry 1.0 evolved in eighteenth century focused on mechanization of production and steam power. Industry 2.0 was brought in nineteenth century began with advent of electricity which was followed by Industry 3.0 in twentieth century focusing on manufacturing of electronic devices

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and telecommunication. Lastly, the current evolution, i.e. Industry 4.0 in twenty-first century focusing on intelligent things. It is not only a technical improvement; it is a significant idea that can improve any industry's performance. Interoperability, decentralization, modularity, real-time capabilities, service orientation, and virtualization—these six standards constitute the pillars of Industry 4.0. Developing technologies such as Cyber Physical Systems (CPS), Cloud Computing (CC), Internet of Things (IoT), Internet of Services (IoS), and Artificial Intelligence (AI) drive the fundamental ideologies of Industry 4.0. Figure 3.1 [2] shows four revolutions of industry.

Being a core component of Industry 4.0, IoT [3] has gotten expanded attention from researchers, private users, industry experts, businessmen, etc. It is a network of interconnected devices which are heterogeneous in nature and are addressable and interconnected by means of a communication protocol (mutual). It provides a "smart" environment consisting of sensing devices that are connected by means of this communication protocol sharing data over multiple platforms in order to make an amalgamation between applications so as to generate some meaningful information. With introduction of keyword "smart," Fig. 3.2 [4] shows the various use cases of IoT in current era and also their market shares in Global IoT Sector as taken from Growth Enabler industrial survey [4]. This shows that global IoT market

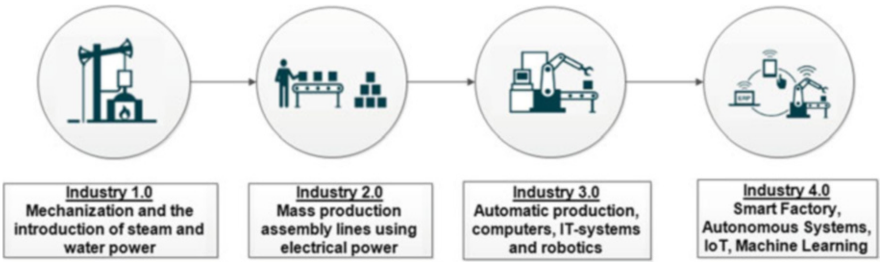

Fig. 3.1 Four industrial revolutions [2]

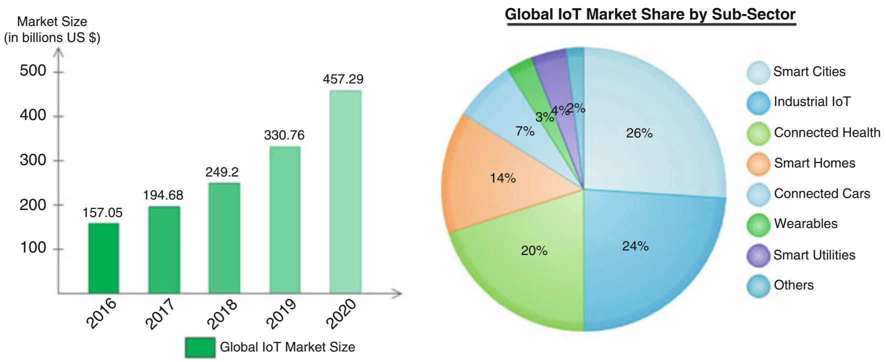

Fig. 3.2 (**a**) Global IoT market share, (**b**) Global IoT market share by sub-segment [4]

share is conquered by major sub-segments which are Smart Cities (26%), Industrial IoT (26%), and Connected Health (20%).

As already learned from Fig. 3.2 [4] that healthcare industry is third largest sub-sector getting affected by advent of Industry 4.0 and IoT, a revolutionary change is also anticipated in healthcare with new opportunities and challenges coming in its way.

3.1.2 Healthcare 4.0

Evolution of Industry 1.0 to Industry 4.0 acts as foundation of evolution of Healthcare 1.0 to Healthcare 4.0. Healthcare 1.0 blossomed in between 1970 and 1990 with an objective improving the efficiency by simple automation to reduce paper work. The limitation of Healthcare 1.0, i.e. stand-alone systems with limited functionality was overcome by Healthcare 2.0 evolved from the year 2000. It witnessed health IT systems getting networked and health data getting generated by means of integration with clinical imaging. Healthcare 3.0 emerged in the duration between 2006 and 2015 with the introduction of Electronic Health Records (EHR) along with emergence of wearables and implantables. EHR helped in storing genomic information of a patient in a digital way. What we are witnessing today is Healthcare 4.0 [5]. All the technologies that are part of Industry 4.0, i.e. computing environments such as cloud, fog, and edge, use of AI, and using invisible user interfaces supports Healthcare 4.0. Figure 3.3 [6] shows correlation between revolution of industry and healthcare. It is not only the improved measure of information that is accessible to doctors; however, the real critical factors here are

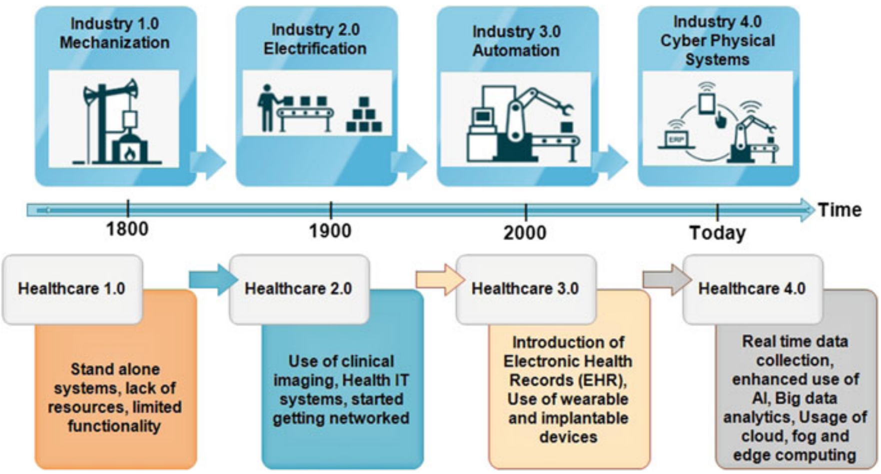

Fig. 3.3 Correlation between industry and healthcare revolution [6]

the capacity to extract bits of data captures and the sharing of this data. Portability of data enables patients and their doctors to get to it anytime anywhere and diagnosis and proper medical responses can be predicted in a timely and innovative manner by means of enhanced analytics. It can pinpoint regions of improvement and empower better decision making.

3.1.3 What Drives Healthcare 4.0 Towards Fog Computing?

Along with a technological revolution brought by IoT services such as storage capabilities, computation resources, high processing, heterogeneity, etc., the sensors being used as a part of IoT are increasing in number and consecutively getting smaller in size, so as to be worn by an individual without hindering everyday activities. These sensors are required because they collect data continuously. One such sensor as stated in BioStamp [7] is of a size of bandaid that can be attached to skin and measures biometric signals. Even contact lenses also provide the facility of sensing biometric characters [8]. In the current era, where people are contact lenses also provide the facility of sensing biometric characters [8]. In the current era, where by means of wearing fitness trackers. All the data gathered by these wearable and implantable devices is of use only if it can derive some insights from it by performing machine learning and data analytics. The accuracy of understanding the insights provided by these devices will exceed the humans, when big data analytics will be used to study the efficacy of medical treatments, accurately identify the patients who are vulnerable to chronic illness, provide treatment options to patients, make sure patients adhere to the treatments given, and optimize the entire process.

Immense amount of data, energy, processing capacity, and memory is generated by the sensors that are wearable and are wireless. Physically storing these data in a hospital is not a possible solution. The data is aggregated from all the sensors and sent to other computing devices for analysis, collection, and storage. Hence, connectivity between these computing devices and communication using a mutual standard protocol also plays a major role. With regard to all the said requirements, cloud computing (CC) [9] can handle the situation easily. Cloud computing offers following benefits [10] to healthcare industry:

(a) *Data storage capacity*: Healthcare industry produces tremendous amount of data which cannot be stored onsite. Health clouds allow storage of data off-site so as to avoid pain of handling physical servers and also help with the cost factor.
(b) *Scalability*: Since, healthcare industry requires services 24/7, cloud handles this requirement by scaling its servers with increasing or decreasing demand of the client. Thus, it fits into the network demands of the client.

(c) *Integration and collaboration*: Clients can easily transfer or share data who are using the same cloud environment. The data can be accessed by anyone who is intended user of that data.
(d) *Provision of AI and machine learning*: Massive amount of data generated requires to be analyzed in an accurate and in a timely manner so that unstructured data can be converted into structured one.

Along with benefits offered by cloud computing, it also brings hazards [10] to healthcare industry listed as below:

(a) *Implementation*: Handling of tasks efficiently requires implementation of a reliant and efficient cloud solution, otherwise, information leaks, business downtime, improper handling of data, etc. will be seen as an outcome of bad implementation.
(b) *Security*: Even though cloud networks provide measures of security that warns and deals for suspicious behavior, still they are not perfect. There have been many cases of security breaches in health information.
(c) *HIPAA Compliance*: Health Insurance Portability and Accountability Act (HIPAA) should be complied by all health cloud solution providers. This includes implying their protocols on security breaches, privacy of patient, law enforcement, and notification of breaches.
(d) *Control and availability*: Since EHR data needs to be available 24/7, hence, measures need to be taken so that when cloud platforms go down from time to time, healthcare professionals are still able to access the data required.

In 2012, announcement of an infrastructure paradigm called *fog computing* [11] was done by Cisco, in order to tackle the issues faced in cloud computing.

3.2 Fog Computing

Fog computing is based on the idea that fog nodes lie somewhere in between ground and cloud/data centers where end user's devices are geographically placed as shown in Fig. 3.4 [12]. A term called *edge computing* is also used synonymously, wherein edge devices are the ones that are end user's devices and the tasks done by the same is part of edge computing. Topology is the important characteristic of fog computing which means the distributed nodes are placed geographically who performs computation and offers network services and storage. It is such a distributed system that the application specific resides on the infrastructure components along with data centers as well as user devices. Theses infrastructure components include routers, gateways, and access points. Fog computing offers the following benefits [13, 14]:

(a) *Privacy*: Propagation of data can be reduced by means of fog computing. Sensitive data can be analyzed at local gateway rather than at a data center that is not in control of the user, so as to ensure privacy of user data.

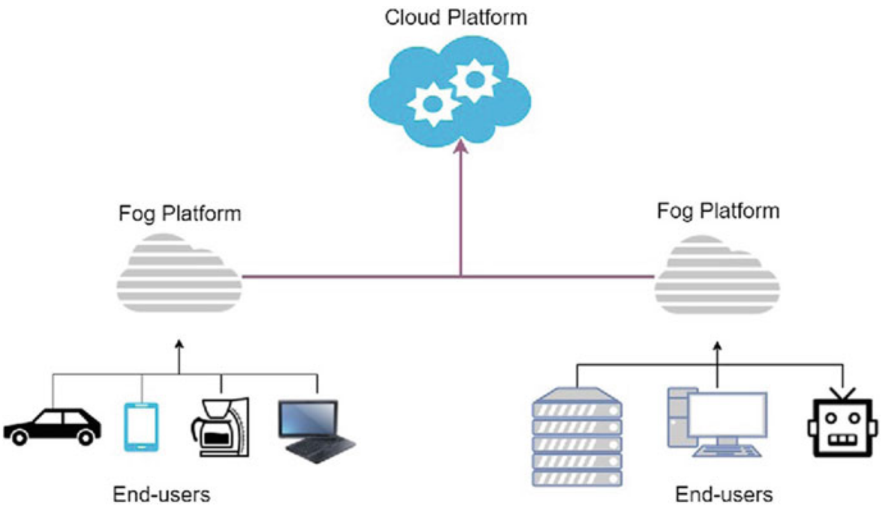

Fig. 3.4 Fog nodes—lies between cloud and ground [12]

(b) *Reduced latency*: Processing devices if placed closer to the devices reduces the latency as physical distance is reduced and response time will be much lesser as compared to when placed on data center.

(c) *Energy efficiency*: Instead of sensors actually working all the time, gateways can act as communication proxies which can handle any request when sensors are on sleep mode and can be processed when sensors wake up. This is how energy efficiency can be improved within sensor devices.

(d) *Bandwidth*: Instead of sending entire data to data center, large chunks of raw data can be processed at fog nodes, so as to reduce the volume of data sent to data center.

3.3 Fog Computing in Healthcare 4.0

Healthcare systems face massive challenges which keep on increasing due to increased population and proned risk to chronic illness.

(a) *Need of remote monitoring*: There is also a demand to maintain high quality care to patients but at the same time demand is to reduce the cost as well. Also, a shortage in efficient nursing staff is also seen in many years. Hence, healthcare industry is shifting to information-centric delivery model where remote monitoring [15] of patients is to be enabled anytime accessibility to the patients increasing the efficiency and reducing the overall cost of healthcare. Currently, much time is squandered in clinics by physically estimating parameters of biometric features and moving the information between systems, regularly including pen and paper. Instead of wasting time in manual supervision, automated supervision can also be an improvement in healthcare.

(b) *Improved procedures in hospitals*: Another challenge is the improvement of procedures inside the clinic. Numerous procedures are arranged physically, and subsequently done successively, of utilizing resources all the more viably. Moreover, sensors will make it less complex to provide precise data about the current status of patient's biometric features. Sensors will likewise give a progressively exact image of patients, as they can catch information ceaselessly and permit a knowledge into expanding assortment of biometric parameters. This will reform diagnostics and treatment.

(c) *Need of preventive care*: Another pattern is the takeoff from reactive treatment, where patients are treated in a medical clinic simply after an incident, towards a progressively preventive medicine [16]. This begins by checking healthy individuals, to keep them out of clinic for as long as could be expected under the circumstances. Also, expanding the potential outcomes to screen patients at home encourages discharging them prior from the clinic. All in all, this implies the fringes between clinic, home, and different purposes of care get progressively obscured: medicinal services happen constantly and all over the place.

The idea of fog computing was intended to fulfil applications which require real-time response with low latency such as healthcare systems [17]. Low latency can affect the performance of services of emergency and health monitoring. It can also delay the response time for sending data to cloud and receiving back instructions from the cloud to the application [18]. The amount of data produced as an outcome of healthcare applications is very large and to process them, fog computing is required rather than limited storage devices and computing resources. Fog computing is widely preferred for healthcare applications as these applications show lower response time, are latency-sensitive, and yield huge volumes of data. Real-time requirements are the need of such applications and hence, in E-health, streaming-based transmissions should be managed [19]. In fact, scalability, elasticity, redundancy can be improved using connected fog nodes forming a fog computing infrastructure [20]. All the issues in healthcare applications cannot be resolved by fog computing unless and until the architecture is not capable to do so. Issues such as low latency, low response time, handling huge amount of data, mobility, scalability, real-time monitoring, reliability, etc. are architecture based. Figure 3.5 [21, 22] shows the architectural layer of fog computing.

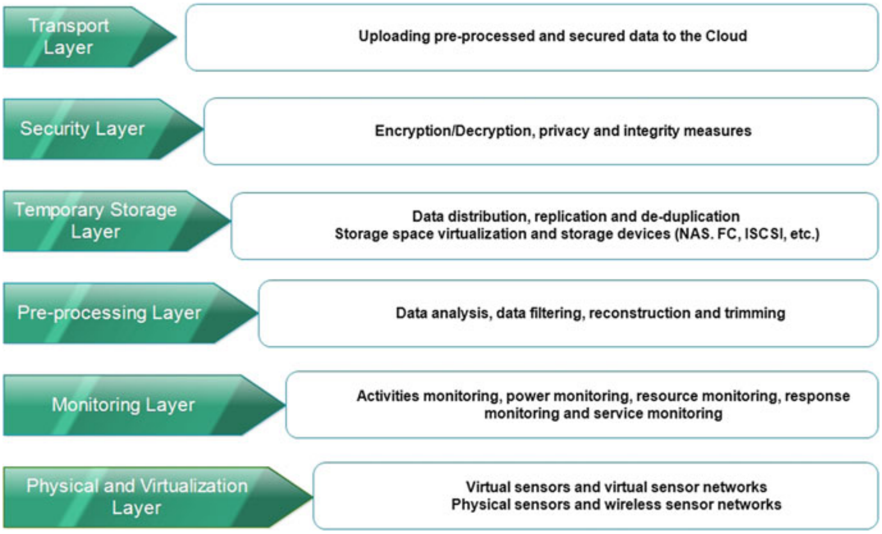

Fig. 3.5 Architectural layer of fog computing [21, 22]

3.4 Classification of Fog Computing in Healthcare 4.0

Many researchers have implemented frameworks and proposed architectures for fog computing environment with respect to health applications [23]. These implementations are categorized as the following classification shown in Fig. 3.6.

3.4.1 Data Management

3.4.1.1 Frameworks

Framework for heterogeneous resource sharing [24] is presented to produce optimized utility functions using convex optimization techniques. This framework ensures low latency and high energy efficiency, making it much more feasible to use in mobile cloud. With increasing amount of heterogeneous sensors, their corresponding protocols and data formats need to be efficiently management. In that case, Device Cloud approach is used [25], wherein cloud computing concepts are applied to IoT domain to solve IoT resource management issues. IoT devices are allocated from a shared pool on-demand. Framework [26] that supports exchange of data among healthcare applications and implementation of software tool to support interoperability between cloud and fog platforms by means of integrating with data dissemination protocols in healthcare. It proposes that "out-band" transport is better

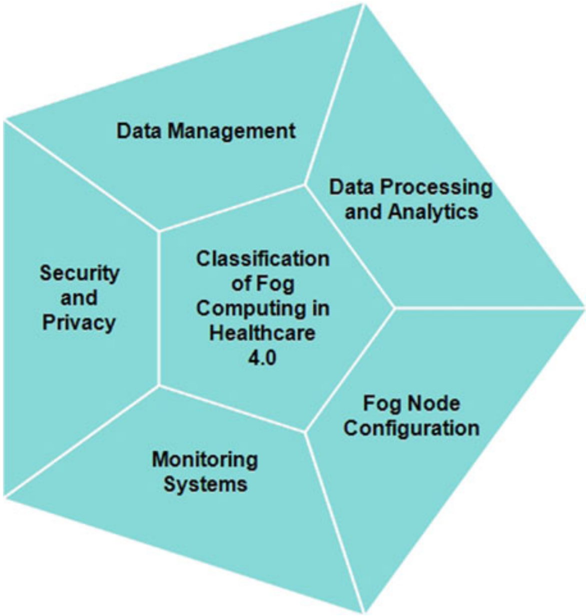

Fig. 3.6 Classification of fog computing in healthcare 4.0

than "in-band" transport when done over Wifi with translation of edge data into HL7 standard records.

3.4.1.2 Proposed Architectures

Physical sensors attached to human beings that generate data about incidents requires crowdsourcing [27] to get an insight of emergency situations and also to provide awareness in such situations. The infrastructure consists of large-scale sensing of human population and valuation of data quality, data integration and analytics of heterogeneous data, and performing decision making, giving alternate recommendations. Mobile IoT Federation as a Service—MIFaaS [28] facilitates delay sensitive requests for IoT devices in order to support 5G environments. LTE (Long Term Evaluation) and NB-IoT (Narrowband-IoT) are used in this paper for performance evaluation.

3.4.2 Data Processing and Analytics

3.4.2.1 Frameworks

Nebula [29] is a varied cloud infrastructure that supports computation and storage by means of deploying fog nodes at the edge in order to share resources. It uses

MapReduce framework for computing data-intensive applications taking care of optimizations including computation placement, location-aware data, recovery, and replication. Firework [30] developed to process huge amount of data and cut down volumes of data to be transmitted along with maintaining data integrity and privacy of user's data. It supports big data processing by means of predefined interfaces which exposes virtually shared views of data to the users. These interfaces take form of set of functions and datasets, wherein the functions are privacy preserved and are dataset bounded.

3.4.2.2 Proposed Architectures

Dubey et al. [31] presented a proposed service-oriented architecture whose objective is to process huge data and analyze the same using fog resources with reduced power. This paper presents a low power embedded computer that performs data mining and analytics of data on raw data that is collected from the sensors. It tries to find similar patterns from the collected data. Unique patterns are transmitted, the embedded computer finds clinically relevant information and sends to cloud. In order to perform data processing and analysis and local storage at real time, a smart e-health gateway called UT-GATE was implemented [32]. The gateways were positioned and distributed geographically. Each gateway is responsible for collecting data from the sensors connected to the patient and monitor the same irrespective of the patient's movement or location. Issues like mobility, energy efficiency, performance, reliability, etc. can be resolved using this fog based system. COLLECT—COLLaborative ConText Aware Service Oriented Architecture [33] facilitates context aware data processing by means of a light message broker for integration of heterogeneous IoT context data and making use of enterprise service bus for easy data delivery among agents and participants in system. A three-layer architecture, i.e. Medical device layer, fog layer, and cloud layer [34] that is patient driven for real-time data collection, data processing, data analytics, and data transmission. FIT [35], a low-power fog computing interface, built on previous work, EchoWear, which collects information from smartwatch will now be interconnected to cloud by means of smart gateway. The information collected will be speech data from disordered patients suffering from Parkinson's disease. IoT architecture [36] in order to process and store big data gathered from health sensors. Meta Fog-Redirection (MF-R) and Grouping and Choosing (GC) architecture are the two architectures used in here. MF-R architecture uses Apache HBase and Apache Pig for data collection and big data storage. GC architecture is utilized for integration between fog and cloud. MapReduce is also used in order to predict heart diseases.

3.4.3 Fog Node Configuration

In fog computing, there can be presence of shared fog nodes, fog nodes that work as smart gateways, either shared or individual, cloudlet/foglet, servers, networking devices, etc. These are used to increase the response time. They can work with heterogeneous configurations.

3.4.3.1 Frameworks

In a framework proposed [37] for time-sensitive healthcare applications, users are notified about heart attacks and brain strokes as early as possible. Two algorithms are developed in here. First is used for choosing whether a user is present in overlapping share of fogs. In order to find change in user's position and the shortest path between all the fogs, second algorithm is used. Edge Mesh [38], a software framework distributed all the decision making tasks across the smart gateways as well as shared fog nodes. Difficulty in clustering in radio access points especially when various user requests arrive for services of fog computing is solved by means of multiple user small cell clustering optimization algorithm [39] especially for geographically distributed fog nodes. Rahman et al. [40] presents a mobile edge computing framework that shows location-aware and real-time services when millions of people are mobile. It uses a concept of hybrid cloud at the server side and fog computing nodes at the edge side.

3.4.3.2 Proposed Architectures

Data centered fog computing platform [41] was proposed which scales down processing capability at cloud and keeps it to fog nodes so as to lower the data transmission time between smart objects and cloud. The idea is to bring computing power closer to users from the remote cloud. Cloud4IoT [42] platform supports vertical and horizontal, i.e. roaming and offloading movement of IoT functions by means of Kubernetes cluster so as to solve the challenge of confidentiality of data and performance of connected networks.

3.4.4 Monitoring Systems

3.4.4.1 Frameworks

A computational framework [43] was projected which enables real-time monitoring, performing high computing tasks, sensing of data for making diagnosis and prognosis. It uses wireless sensor networks (WSNs), machine learning, and cloud computing. TILAA [44], a framework for Tactile Internet-based Ambient

Assistance Living in fog environment facilitates posture detection and correction in early stages so as to prevent from falls and backaches. It provides continuous communication feedback between patients and doctors with minimum response time.

3.4.4.2 Proposed Architectures

Remote monitoring with efficiently low cost was exhibited in a fog based monitoring system [45]. In addition, this system is contained with smart gateways and energy-efficient wearable devices or IoT sensors. Moreover, body temperature, respiration rate, and ECG signals are gathered by means of sensors and are sent to gateways wirelessly so as to generate notifications along with an analysis which is automatic. For latency-sensitive healthcare requirements, a fog based architecture was proposed [46]. A programming model was used to manage large-scale geographically distributed application of healthcare. Delivery time of service can be enhanced and retainment of data accuracy and data consistency can take place. A system was designed [47] in order to detect and comprehend the occurrence of Chikungunya Virus (CHV). On cloud server, FCM (Fuzzy-C means) was made practical along with SNA (Social Network Analysis) in order to get a better insight of CHV outbreak. To support ambient assisted living (AAL), continuous patient monitoring system [48] was proposed, wherein Body Area Networks (BANs) are used in order to pass data of movement of patients suffering from neurological diseases to the fog gateways. Also, efficient clustering algorithm is proposed in order to reduce load on the communication infrastructure. HiCH architecture [49] developed for health monitoring systems has two core components. First one is an architecture for executing machine learning based analytics of data and for hierarchical computing. Another is a management technique which is closed loop capable of automatic adjustment with respect to a patient's condition.

3.4.5 Security and Privacy

3.4.5.1 Frameworks

Ahmad et al. [50] presented a fog based healthcare framework that represented security and privacy aspect of healthcare applications by employing fog as an intermediate layer between end devices and cloud. CASB, i.e. Cloud access security broker was used to enhance security at the edge of the network. It used a modular framework design. It was capable of fetching data from multiple places and also applying proper level of cryptographic algorithms. A fog based middleware [51, 52] hosted on fog nodes for collection of patient's health data along with maintaining privacy and confidentiality of their health data, this is done by implementing personal gateways at the side of patient which serves as intermediate node, i.e. fog nodes, rather than storing all the data in a centralized way. In order to prevent DDoS attacks, a certificate based DTLS handshake [53] is implemented for mutual authentication between client and smart e-health gateway. The interaction between medical sensors and client is made secure by ensuring that all the requests from the sensors go directly to the gateway and not to the client. It also condenses load on IoT sensors. AZSPM, a security provisioning model [54] is proposed, wherein it can built by use of dynamically composed atomic security components. There is no rely on certificate authority (CA). By deriving processor clock cycles from execution of service at a hardware platform, authenticity of atomic security components is achieved. Secure communication among participants is ensured by means of generating a session key between participants using tri-party one-round authentication key agreement protocol built on bilinear pairing cryptography [55]. BHEEM: Blockchain based framework [56] proposed for effective storage and preservation of EHR data cryptography [55]. BHEEM: Blockchain based framework [56] proposed for effective storage and clinical decision support system [57] for fog computing is proposed. Real-time monitoring of patients and hybrid privacy-preserving clinical decision support system [57] for fog computing is proposed. Real-time which is secure, design of new secure protocol is proposed.

3.4.5.2 Proposed Architectures

Moosavi et al. [58] proposed an end-to-end security scheme with help of set of interconnected gateways, which scales communication traffic and latency between smart gateways and end users. Use of Blockchain technology is used to improve interoperability between healthcare databases, to improve access to medical records in order to prescribe proper medication to patients, to track the devices etc. The paper [59] also proposes Access Control Policy Algorithm to improve accessibility os data between providers of healthcare. IoT-based health prescription assistant (HPA) [57] gives recommendations to doctors daily. Also, user authentication is provided by means of OpenID standard. After authentication is done, user is provided with SAT—security access token which gives them privileges to access medical IoT devices and their services.

Table 3.1 shows a comparative study of frameworks of fog computing in Healthcare and also the performance metrics each study impacts. Table 3.2 shows a comparative study of proposed architectures of fog computing in Healthcare and also the performance metrics each study impacts. Performance Metrics, i.e. (1) Low Latency and High Bandwidth, (2) Minimum Response Time, (3) Scalability, (4) Reliability, (5) High Mobility, (6) Time-Sensitivity, (7) Energy and Power Efficient, (8) Location Awareness, (9) Cost Effective, (10) Data Availability and Shareability are specified in both the tables.

Table 3.1 Frameworks of fog computing in healthcare

Authors	Issues addressed	Technique used	1	2	3	4	5	6	7	8	9	10
Nishio et al. [24]	Sharing of heterogeneous services such as CPUs, bandwidth, content, etc. and support services between mobile devices	Framework for heterogeneous resource sharing producing optimized service oriented utility functions using convex optimization techniques	✓						✓			
Kliem et al. [25]	Management of increasing amount of heterogeneous sensors, their corresponding protocols and data formats	IoT resource management issues are vindicated by means of Device Cloud approach where cloud computing concepts are applied to IoT domain										✓
Lubamba et al. [26]	Challenge of interoperability between cloud and fog platforms	Exchange of data among healthcare applications facilitated by a framework and implementation of a software tool to support interoperability by means of getting integrated with data dissemination protocols in healthcare										✓
Ryden et al. [29]	Mobility of data gets affected as high computation of data does not support it, reason being centralization of cloud resources, which are inappropriate for deployment of data-intensive applications	Nebula, varied cloud infrastructure that supports computation and storage by means of employing voluntary nodes at the edge in order to share resources								✓		✓
Zhang et al. [30]	Issue of processing huge data along with maintaining data privacy and data integrity of user's data	Firework in order to endorse data privacy along with cutting down the amount of data to be transmitted	✓								✓	
Zohora et al. [37]	For sensitive data such as brain stroke, heart attack, accident, etc., response time is slow	Two algorithms are developed in here. First is used for choosing whether a user is in overlapping share of fogs. In order to find change in position of user and the shortest path between all the fogs, second algorithm is used. This notifies the user in case of time-sensitive issues		✓		✓		✓	✓			

Sahni et al. [38]	Edge devices were not used in decision making	Tasks of decision making are distributed across smart gateways in Edge Mesh (software framework)	✓		✓							✓
Oueis et al. [39]	Difficulty in clustering in radio access points when various user requests for computing services	Formulation of various user small cell clustering optimization algorithm for geographically dispersed fog nodes							✓			
Rahman et al. [40]	Challenges faced for location-awareness, providing real-time services where millions of people are mobile at a time as per time and geographic location.	Framework which uses hybrid of cloud at the server side and computing fog nodes at edge side, capable of delivering real-time, location-aware services	✓				✓			✓		
Aazam et al. [60]	For urgent real-time responses, time-sensitive services are needed	Implementation of Micro Data Center						✓				
Wu et al. [43]	Inefficient monitoring systems for collecting huge amount of data and develop models for prediction for diagnosis and prognosis	Framework developed for real-time monitoring, sensing and performing high computing tasks	✓						✓			
Vora et al. [44]	Monitoring of patients for real-time detection and correction such as posture correction leading to backaches in Ambient Assisted Living (AAL)	TILAA, a framework for Tactile Internet-based Ambient Assistance Living in fog environment	✓	✓					✓		✓	
Ahmad et al. [50]	Security and Privacy	Usage of Cloud access security broker (CASB) to enhance security at the edge of network. Fog as an intermediate layer so as to avoid unnecessary flow of information. Use of homographic encryption										✓

(continued)

Table 3.1 (continued)

Authors	Issues addressed	Technique used	1	2	3	4	5	6	7	8	9	10
Elmisery et al. [51]	Privacy preservation of patient's data	To serve as intermediate nodes, i.e. fog nodes, personal gateways are situated at the patient's side				✓						✓
Rajagopalan et al. [53]	Prevention of DDoS Attack	For mutual authentication between client and Smart e-Health gateway, certificate based DTLS handshake takes place	✓				✓					
Elmisery et al. [52]	Privacy preservation of patient's data	To serve as intermediate fog nodes, personal gateways are situated at the patient's side				✓						✓
Chaudhry et al. [54]	In absence of universal certification authority (CA), security provisioning of health data is a concern	Implementation of Security Provisioning Model (AZSPM)				✓						
Al Hamid et al. [55]	Security Attacks on healthcare cloud	Ensuring secure communication among participants by means of generating a session key between participants using tri-party one-round authentication key agreement protocol built on bilinear pairing cryptography				✓						
Vora et al. [56]	Inefficient balance between data privacy, access to patient's data	BHEEM: Blockchain based framework for effective storage and preservation of EHR data along with maintaining balance between privacy and accessibility of EHR data										✓
J. Vora et al. [61]	Privacy preservation of healthcare records	Proposing blind signatures to ensure the anonymity of identities									✓	
R. Gupta et al. [62]	Issues of security, privacy, and interoperability in existing telesurgery system	HaBiTs, a framework that is blockchain based which is secure and flawless inter-operable telesurgery system based on Smart Contracts										✓
Liu et al. [57]	Leakage of privacy of patient's data to unauthorized parties	Hybrid privacy-preserving clinical decision support system (HPCS)										✓

Table 3.2 Proposed architectures of fog computing in healthcare

Authors	Issues addressed	Technique used	1	2	3	4	5	6	7	8	9	10
Abu-Elkheir et al. [27]	Scarcity of data management platforms in order to predict an emergency situation by processing huge amounts of data	Crowdsourcing human population and their physical sensors that generates data about incidents to get an understanding of emergency situations and also provide awareness in such situations	✓	✓				✓				
Farris et al. [28]	Delay sensitivity in IoT devices	MIFaaS, Mobile IoT Federation as a Service, that facilitates delay sensitive applications for IoT devices to support 5G environments	✓	✓								
Dubey et al. [31]	Collection and analytics of huge raw data collected from sensors	Service-oriented architecture is used. A low power embedded computer finds similar patterns from the collected data, stores unique patterns, and finds out clinically relevant information to send to cloud							✓			
Rahmani et al. [32]	Issues of data processing, data analysis, and local storage in real-time	E-health smart gateway was proposed in which fog computing is used as an intermediary intelligence layer between sensor nodes and cloud. Each gateway is responsible for collecting data from sensors	✓			✓	✓		✓			
Garcia-de-Prado et al. [33]	Context aware data processing	COLLECT—Collaborative Context Aware Service Oriented Architecture						✓				✓
Kumari et al. [34]	Issues of data collection, processing, and transmission	A three-layer architecture that is patient driven for real-time data collection, data processing, and data transmission						✓				
Monteiro et al. [35]	Processing of healthcare clinical speech data	FIT, fog computing interface built on previous work, EchoWear, provides interconnection between cloud and a smartwatch for collecting speech data of patients suffering from Parkinson's disease								✓		

(continued)

Table 3.2 (continued)

Authors	Issues addressed	Technique used	1	2	3	4	5	6	7	8	9	10
Manogaran et al. [36]	Because of increasing density of data, it is tough to analyze big data in order to produce some valuable insight	IoT architecture that processes and stores big data gathered from health sensors. Meta Fog-Redirection (MF-R) and Grouping and Choosing (GC) architecture are used in here	✓	✓								
Li et al. [41]	Data latency between cloud and smart objects	Data centered fog computing platform which scales down processing capability at cloud and keeps it to fog nodes so as to lower the data transmission time between cloud and smart objects	✓	✓								
Dupont et al. [42]	Confidentiality of data is a challenge when number of connected devices are increasing day by day and also impacts performance of the connected networks	Cloud4IoT platform which supports roaming and offloading movement of IoT functions by using Kubernetes cluster							✓			
Gia et al. [45]	Real-time monitoring and ECG analysis	Usage of smart gateways and energy efficient wearable devices. The sensor nodes collect information of body and sends it to gateways wirelessly in order to have notifications and for analysis that is automatic	✓	✓					✓		✓	
Chakraborty et al. [46]	Designing and developing real world data monitoring system	Dynamic fog model using a high level programming language that matches the needs of time-sensitivity which is latency-sensitive, on large scale and is distributed geographically	✓					✓				
Sood et al. [47]	Detect and contain the outbreak of Chikungunya Virus (CHV)	On cloud server, Fuzzy-C means (FCM) was applied along with SNA, Social Network Analysis, in order to get a better insight of CHV outbreak	✓	✓								

Vora et al. [48]	Neurological monitoring which requires real-time processing is time consuming and affects the performance	For ambient assisted living (AAL), continuous patient monitoring proposed using Wireless Body Area Networks (WBANs)	✓	✓				✓				
Tanwar et al. [63]	Monitoring of patients with joint problems to facilitate early detection of arthritis	Architecture using thread protocol and Bayesian classifier to get anomaly detection and achieve reliable communication		✓				✓				
Azimi et al. [49]	Centralized cloud based systems face issues like availability, accuracy, and reliability, also because of outsourcing analytics of data to edge of network because of inadequate computational capability at edge nodes	HiCH architecture provides efficient health monitoring system				✓						
Ali et al. [49]	Monitoring of heart attack patients	Real-time Heart Attack Mobile Detection Service (RHAMDS) to minimize the response time in case of heart attack incidents	✓	✓				✓		✓		
Moosavi et al. [58]	Security for mobile healthcare IoT	End-to-end security scheme using set of interconnected gateways	✓				✓		✓			
Tanwar et al. [59]	Continuous access to patient's private records and securing them	Use of blockchain technology to protect and provide continuous access to patient's private records, also implementation of Access Control Policy Algorithm for improvement of data accessibility between providers of healthcare	✓	✓								✓
Hossain et al. [64]	Security problems and telemedicine requirements	IoT-based health prescription assistant (HPA) which helps doctors by giving recommendations daily and also provides security	✓	✓		✓						✓
He et al. [65]	Challenges of security, safety, unpredictable delays, and high bandwidth requirements	Use of Field Programmable Gate Array (FPGA) technology	✓	✓								

3.5 Conclusion

Fog computing is well-thought-out of as a significant research bearings for numerous reasons in systems of IoT related to healthcare. Research efforts toward this path are under development till now. Be that as it may, appropriate illustrations and limits keep on being viewed as uncertain. By looking into and organizing research efforts, this study means to contribute to such comprehension and information. Henceforth, the study is divided into origin of industry 4.0 and healthcare 4.0, effect of fog computing in healthcare 4.0, frameworks for fog computing in the medicinal services applications, and proposed architectures in fog computing in the medicinal services applications. By genuine scrutinizing and examination of various research articles, more of review data was procured, for instance, the problems, troubles and difficulties, motivation, and points of interest, what's more, recommendations distinguished for future work in fog computing for healthcare applications. Also, frameworks and proposed architectures were compared based on the issues addressed in them and the technique used to address the challenge. Along with that, each study was classified on the basis of performance criteria such as low latency, minimum response time, time-sensitivity, mobility, scalability, reliability, location awareness, energy efficiency, power consumption, etc. All these factors are basic challenges of healthcare applications.

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