Architecture, Protocols, and Applications of the Internet of Medical Things (IoMT)

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Abstract**—**The Internet of Things (IoT) refers to the interconnected framework of web-connected objects that can collect and transfer information over a remote network without requiring any human intervention. The rapid progression in the development of IoT-based devices and their expansion towards making the medical care facility financially more savvy, proactive, and customized, has given rise to the development of the "Internet of Medical Things (IoMT)" that are assumed to function proactively in all domains of the healthcare industry. Within this framework, the IoMT-based healthcare system delivers various advantages, such as quick and unfailing treatment, enhanced communication, cost minimization, etc., through the exploitation of several new technologies. For instance, machine learning has significantly helped with the exploitation of various healthcare systems; fog computing not only minimises the cost of communication but also provides low latency; blockchain delivers its users a much better way of protecting sensitive and confidential information and data they possess. In this survey, a comprehensive elaboration of the IoMT-based healthcare systems based on modern technologies was conducted. This article describes various techniques and solutions of IoMT healthcare systems in the context of emerging technologies, and the related future trends and applications for a better understanding of how IoMT can enhance the healthcare industry now and in future.

Index Terms**—**IoMT healthcare, fog computing, Blockchain, machine learning, H-IoT, edge computing, internet of medical things.

I. Introduction

The increasing number of patients with chronic diseases, as well as the ageing population, demands an urgent deployment of smart healthcare systems based on modern technology. Disease prevention cannot be achieved only through proper diet and regular exercise, or by taking periodic preventive controls for maintaining a healthier environment; it also requires the development of different ways to keep serious health conditions from worsening.

In this context, the health sector must resolve the issue of an increasing number of patients with chronic diseases; it must also think about the fact that there are no enough modern technological devices to meet patients' needs.

Recently, the COVID-19 pandemic highlighted the significance of a comprehensive, quick, and accurate e-healthcare that also involves medical data for diagnosing the virus. The utilisation and deployment of emerging technologies in various behavioural systems, as well as the enactment of protective policies can assist in early identification of the health condition of an individual, and would help in scheduling the suitable and proper procedures, such as "concurrently monitoring treatments" and new evaluations. The world's health market, based on current technologies, has been estimated to reach more than 143.7 billion dollars by the end of 2019, with the prediction to expand at a growth rate of 16 percent from 2020 to 2027.

The progression of IoT, as well as cloud-based technologies, has significantly empowered ubiquitous communication by providing accessibility through various objects to share and disseminate information. It has offered different phases to link the heterogeneous devices and provided not only the preparation but cooperation capacities as well. It has also given some zones to assemble and build smart homes, smart healthcare, smart urban communities, and many more. In addition to these, it has also conferred scanned objects with the capability to detect, calculate, measure, communicate, and share data through a proper system of devices. All these interlinked devices and sensors collect relevant information, analyse it, and use it for other purposes, such as decision-making, classification, maintenance, etc. [3].

The healthcare system is now in dire need of the deployment of innovative technologies and applications for the provision of cost-effective and low-latency medical facilities to patients. Not only this, but new applications are also required to handle the increasing number of patients that are increasing daily. In several ways, the conventional medical healthcare has problems to overcome in obtaining reliable and sufficient healthcare

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facilities, not only at the clinical level but at the individual level as well. The ever-increasing population provides that the conventional or traditional medical institutions cannot provide the high-quality services people seek. Furthermore, in a traditional medical system, there is a substantial shortage of medical professionals, which results in delayed diagnosis and inadequate treatment for many patients. Moreover, several chronic and insidious ailments like Alzheimer's, cancer, etc., that require early detection and treatment, are not possible through traditional medical healthcare services because the conventional systems lack a proper and upgraded set-up for examining such diseases. Furthermore, emergency response to a few types of illness also becomes an intricate process in a traditional healthcare system that eventually leads to lethal and fatal consequences. Besides these, in rural areas, a big issue is transportation; on-time transportation to the main hospital takes much time, causing undesired outcomes, especially for the patients that require emergency help because of critical health conditions.

Low latency is considered the most important feature among others for IoT-based healthcare systems. The transmission time among the sensors (nodes) and that of the processing unit (sink) must be minimised to bring about all the requirements. It is possible to achieve this by either reducing the distance between the sink and nodes, or via a rapid transmission; the good thing is that both can be achieved with edge computing technologies as it provides the network's "computational power" locally. It is considered mandatory and highly demanding since the nodes have always been conventionally low powered as regards computational and energy resources. The transmission time among the edge devices and that of the processing units (PU) decreases significantly because the PU turns out to be the network part. Considering the data, it is processed or preprocessed at the edge and afterward offloaded to that of the "remote processing unit." In both situations, the performance of the network in terms of latency improves significantly. Edge computing also helps to make different devices work together by keeping edge devices separate from core network devices [4].

The sensors that are deployed within the IoT-based healthcare system generates a high volume of data per second. Sensor based data processing creates a mammoth stream of data that is somehow impossible to be done by the conventional "data processing techniques". Therefore, big data is considered a significant factor in IoT-based healthcare mechanisms and requires highly sophisticated and dedicated approaches for data processing. Both edge and cloud computing technologies highly support "big data analytics" within the IoT-based healthcare environment [5]. Using this technology creates an ample space for the storage of data. Besides the high volume, there are several data types that are created by a diverse range of device types; however, data interoperability is considered the major issue in the execution of IoT-based healthcare units. The incorporation of IoT and data analytics is facilitating "real-time" data analysis with context awareness and mobility [6].

Blockchain is now not restricted to only cryptocurrencies; it has been explored in various ways for diverse IT and other application scenarios. In the context of an IoT-based healthcare system, blockchain has the potential to provide a solution to several crucial challenges. Blockchain design is considered secure and transparent with all the features that can help in IoT-based healthcare system implementation. With blockchain in IoT-healthcare, not only will the data of patients be easy to secure across the platforms but will enhance the data interoperability and remove the third-party that gets involved in access control. Thus, blockchain technology generates an effective, rapid, and transparent system [7]. The list of abbreviations that are often used in this paper is in Table I.

TABLE I: LIST OF ABBREVIATIONS

Abbreviation	*Full form*
IoT	*Internet of Things*
IOMT	*Internet of Medical things*
H-IoT	*Healthcare Internet of Things*
RFID	*Radio-frequency identification*
NFC	*Near Field Communication*
EPCglobal	*Electronic Product Code global network*
COAP	*Constrained Application Protocol*
CPS	*Cyber-Physical Systems*
6LoWPAN	*IPv6 over Low power Wireless Personal Area Network*
P2P	*Peer to peer*
M2M	*Machine to Machine*
5G	*5 Generation*
MQTT	*Message Queue Telemetry Transport*
SVM	*Support Vector Machines*
WBAN	*Wireless Body Area Network*
DL	*Deep Learning*
BAN	*Body Area Networks*
ML	*Machine Learning*
CVD	*Cardiovascular Diseases*
SQA	*Signal Quality Assessment algorithm*
RL	*Reinforcement Learning*
AR	*Augment Reality*
VR	*Virtual Reality*

In this paper, a detailed survey has been presented regarding future technologies for smart healthcare and medical systems based on the IoT and the IoMT. Since smart healthcare has evolved with the advancement of various other complementary technologies, there is a need to collect works from various other fields and create a unified repository. The contribution of this paper would be:

- Review of the general architecture for IoMT, common protocols, and its applications in the medical field.
- In-depth discussion on how machine learning, edge/fog computing, and blockchain can be used to solve problems in IoMT networks.
- Analysis of the complementary technologies that would significantly benefit the IoT-healthcare system in the future.
- A literature analysis on ML, blockchain, and edge computing.

- Discussion of the open issues, opportunities, and challenges through mapping future possible applications of emerging technologies.

The organization of this paper is as follows: Section II provides a comparison with other IoMT survey applications while Section III provides an overview of IoMT, common protocol used in IoMT, and its communication protocols and applications. The current IoMT challenges are addressed in Section IV while the use of ML, edge/fog computing, and blockchain in IoMT is illustrated in Sections V, VI and VII respectively. Future works are presented in Section VII, conclusion in Section VIII, and the cited articles in Section IX.

II. Surveys in Comparison

A study of the literature and assessments of current designs led to the discovery of IoMT systems' core components and applications. The use of machine learning techniques is an essential component of smart healthcare IoT systems. IoMT relies heavily on machine learning. In this paper, we examined the use of machine learning models at the various levels and nodes of IoT healthcare systems which has not been covered in previous studies. The study by [1] presented a thorough explanation of fog computing, although it falls short of describing application-specific edge computing, and did not discuss the blockchain technology and IoMT communication. In [2], the author did not present recent technologies in ML, Edge/ fog computing and blockchain while authors in [3] failed to describe the communication protocols in IoMT and blockchain. In [4], the researcher only described the ML technologies for solving IoMT challenges while authors in [5] and [89] paid no attention to the use of blockchain communication protocols in IoMT. Researchers in [6] did not describe IoM communication and blockchain in the state-of-the-art. Hence, this study also conducted a network management review focused on IoMT communication. We also delved into the use of blockchain in IoMT systems, which is something that isn't discussed in much research. In this state-of-the-art, IoMT communication, edge/fog computing, machine learning, and blockchain technologies are discussed in this article. This research focuses mostly on the new technologies that will underpin future IoMT systems [6]. The literature under examination was as published before the literature considered in this study, and more crucially, this study focuses on emerging technologies that are changing IoT in the healthcare business. This work, to the best of our knowledge, largely comprises state-of-the-art published articles between 2017 and the time of manuscript submission. Table II lists the comparisons between the various studies.

TABLE II:COMPARISON OF STATE-OF-THE-ART FOR IOMT.

Reference	***Use case Architecture***	***IOMT Communication***	***ML***	***Edge/Fog computing***	***Blockchain***
[1]	***yes***	***No***	***No***	***yes***	***No***
[2]	***yes***	***yes***	***No***	***No***	***No***
[3]	***yes***	***No***	***yes***	***yes***	***No***
[4]	***No***	***No***	***yes***	***No***	***No***
[5]	***yes***	***Yes***	***yes***	***Yes***	***No***
[8]	***yes***	***No***	***Yes***	***yes***	***No***
[89]	***Yes***	***No***	***yes***	***yes***	***yes***
This work	***yes***	***yes***	***yes***	***yes***	***yes***

III. Internet of Medical Things

The Internet of Medical Things (IoMT) is a group of medical equipment and apps that use online computer networks with link to healthcare IT systems. M2M communication, which is the foundation of IoMT, is enabled by medical equipment connected to Wi-Fi. IoMT devices connect to cloud systems like Amazon Web Services, which store and analyse recorded data. Remote patient monitoring for people with chronic or long-term illnesses, tracking patient prescription orders, and the location of patients admitted to hospitals, are all instances of IoMT, as are patients' wearable mHealth technologies that may convey information to providers [10]. Medical tools which can be changed to or implemented as IoMT technologies include infusion pumps that link to analytics dashboards and medical beds outfitted with sensors that assess patients' vitals [10]. Because so many consumer devices are equipped with NFC and RFID tags, which enable the devices to communicate data with IT systems, now, there are more conceivable uses of IoMT than ever. Medical equipment and supplies can also be fitted with RFID tags so that hospital workers can keep track of the quantity they have on hand. Telemedicine is the technique of employing IoMT equipment to remotely monitor hospitals. This type of care eliminates the need for patients to visit a hospital or a doctor's office every time they have a medical issue or a change in their health status.

Some of the advantages of IoMT include the following:

- Patients benefit from improved treatment options that include better healthcare gadgets and medications at a lower cost. Patients will save money in the long run as a result of this.
- It provides superior treatment outcomes.
- It ensures a higher level of trust in doctors because IoMT technologies enhance the capacities of doctors and researchers.
- Errors are reduced to a greater extent.
- Medicine intake can be tracked and managed.
- In an IoMT network, it is simple to maintain the use of medical equipment.
- It provides improved disease control.

A. IOMT Architecture

Many academics have researched the architecture of the Internet of Things and proposed some architectures that can be used for the IoT, with the EPCglobal architecture, web of things architecture, sensor network-based architecture, autonomous architecture, and Machine-to-Machine (M2M) architecture, being the most common. The M2M architecture is the most extensively utilised architecture in the field of the internet of things, covering certain relevant contents of EPCglobal and WSN. The IoMT is the medical field's concentrated manifestation of IoT technology. The application layer, network layer, and perception layer are all part of the general three-tier architecture of Internet of Things applications [8].

Perception Layer: The IoMT's emphasis and difficulty are determined by the perception layer. The data access sublayer and the data acquisition sublayer are the two main sublayers. To complete the identification and perception of nodes in IoMT, and to collect data about things and people, the sublayer of data collection uses various types of medical perception equipment and signal acquisition equipment. It employs signal gathering techniques such as general packet radio service technology [10], [11], Radio Frequency Identification (RFID), image recognition, graphic coding, and a variety of sensors, including physical signal sensors. Everything and everyone in the network are transmitted into easy-to-identify Cyber-Physical Systems (CPS) nodes using physiological signal sensors, chemical sensors, and DNA sensors. In the Internet of Things, there are three types of nodes: passive CPS, active CPS, and Internet CPS [13]. According to various objects and demands, corresponding identification is required in the IoMT. The data access sublayer connects the data collected by the data acquisition sublayer to the network layer using short-distance data transmission technologies like Bluetooth, Wi-Fi, ZigBee, etc. The major access methods should be chosen based on the IoMT's current environment and the needs of different objects [14]. (See Fig. 1)

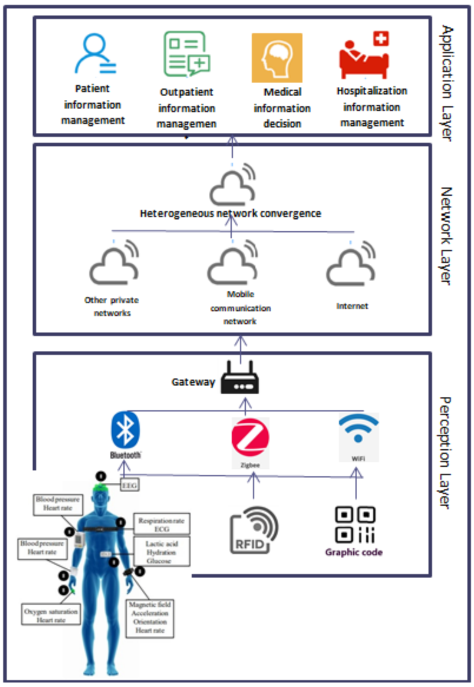

Fig. 1. IoMT Architecture [8].

Network layer: The network layer has two sublayers-the service layer and the network transmission layer. The network transmission layer is the internet of medical things backbone network that is analogous to a person's nerve center and brain. The network layer uses the Internet, the mobile communication network, and other specific networks to transfer the data information obtained by the perception layer in a real-time, reliable, accurate, and barrier-free way [15]. Rather than completely replacing the original network, the IoMT's objective is to investigate the integration technology of heterogeneous networks suited for hospitals. The service layer is responsible for integrating heterogeneous networks, as well as multiple data types, descriptions, data warehouses, and other data. Simultaneously, it develops a support service system based on this, which gives an open interface for different services in the application layer, allowing third parties to construct appropriate applications for use by medical professionals and other relevant employees [16].

Application layer: Health data decision-making applications and medical information applications are the two levels of the application layer. Medical data management applications include material management and medical equipment, patient data management, inpatient treatment data management, outpatient data management, and so on [17]. Patient data analysis, disease data analysis, pharmaceutical data analysis, diagnosis, and therapy data analysis are all examples of medical data decision-making applications [18].

B. IoMT Communication

The IoMT communication protocols allow near-patient health devices to communicate with other health-related information technology systems. Sensors and/or actuators might be used in IoMT devices to track and treat patients in real time. In the first scenario, sensors at the perception layer may collect data from patients utilising IoT communication technologies [19]. After this information has been converted into a format suited for a specific medical application, network layer communication protocols may transfer it to information technology systems. This data might lead to real-time patient care. In the second scenario, actuators attached to patients might help with real-time medical care provision. In order to change health treatment procedures, smart medical devices may process information received from apparently reliable communication channels (e.g., modify the dosage to be injected) [20].

TABLE III: DESCRIPTION OF IOMT PROTOCOLS

Layers	*IoT Protocols*	*Description*
Perception layer	*RFID*	*Radio Frequency Identification (RFID) is a wireless object identification technique that communicates over extremely short distances using radio frequency signals. In RFID communications, there are two basic components: RFID reader (a reading*

		device) and RF tag (a radio transponder device).
	Infrared	***Infrared light is used for short-range communication in the Infrared Data Association (IrDAplanned)'s infrared technology. Wireless infrared communication protocols that work up to a few meters distance with focused, targeted infrared beams are guided by IrDA.***
	NFC	***The Near Field Communication (NFC) standard allows devices to communicate across short distances (in the range of few centimeters at most).***
	Bluetooth/BLE	***Bluetooth is a widely used wireless connectivity protocol based on IEEE 802.15.1. It operates in the 2.4 GHz spectrum and is suited for low-cost and low-power devices. Bluetooth can enable star topology Personal Area Networks, which consume less power, take less time to set up, and have an infinite number of nodes.***
	Z-Wave	***Zensys created Z-wave, a low-power wireless MAC protocol. It supports two categories of devices: slave and controlling devices, and it may be used to construct up mesh topology networks*** [21]***. A Z-Wave network may have up to 232 nodes and use point-to-point communications to span distances of up to 32 meters.***
Network layer	***Wi-Fi***	***Wi-Fi (Wireless Fidelity) is a medium-range (more than 100 m) protocol based on the IEEE 802.11 standard family. Wi-Fi is extensively used for portable devices and local area networking, allowing numerous devices to connect to the Internet.***
	ZigBee	***ZigBee is a low-power, low-speed, and low-cost wireless communication technology that complies with IEEE 802.15.4. It has a connectivity range of more than 100 meters and a data rate of 40 to 250 kbps.***
	6LoWPAN	***LoWPAN is a wireless protocol developed by the Internet working group of the Internet Engineering Task Force (IETF) for allowing internet of things devices to join IP networks. It has a restricted packet size, low bandwidth, and variable address length. Its IPv6 version is 6LoWPAN.***
	LoRaWAN	***Semtech created LoRa (Long Range) as a physical layer protocol to facilitate low-power and wide-area networks. It broadcasts on license-free frequencies that vary by region (e.g., 915 MHz in North America, Australia and 923 MHz in Asia, and 868 MHz in Europe)***
Application Layer	***COAP***	***COAP is the Constrained Application Protocol. a web transfer protocol designed for internet of thing nodes that have restricted memory and processing capacity. It's designed for usage in lossy and power-constrained networks.***
	MQTT	***IBM created Message Queue Telemetry Transport (MQTT) with the primary objective of supporting lightweight M2M communications. It's an asynchronous publish/subscribe messaging protocol that runs on top of the TCP stack and allows programs and users to communicate over networks.***
	HTTP	***At the application layer of IoMT, plain HTTP is utilized in various circumstances. In*** [22]***, a basic IoMT scenario in which the cloud and the clinician communicate over HTTP was presented.***
	HL7	***HL7 is a collection of standards that allow electronic health information to be exchanged, integrated, shared, and retrieved amongst different health institutions, allowing for the creation of flexible and effective procedures. The HL7 standard ensures that data transmitted between health-care systems is transparent.***

In Table III, we present the medical-specific internet of thing communication protocols (referred to as internet of medical things protocols for short) based on the layered IoT architecture of [21], which includes the application, network, and perception layers.

C. IoMT Applications

By adding sensors, signal converters, and communication modems to existing medical equipment, they may be converted into IoMT devices that can perceive real-time data for patient monitoring. IoMT devices can connect with medical specialists in remote places, and comes in a variety of formats, including smart wearable devices, home-use medical equipment, mobile healthcare applications, and point-of-care kits [23]. They have also been utilised for illness prevention, fitness promotion, and remote intervention in emergency cases, and in managing regular health status. The following are some examples of IoMT end-user applications [24]:

1. Chronic Disease Management: IoMT-enabled devices are promising in the management of chronic morbid disease states like hypertension, diabetes, and heart failure [25]. This device is utilised to monitor internal body characteristics like blood pressure, weight, random blood sugar levels, and electrolyte concentrations. The real-time critical data collected by these devices is processed at a higher level and used to make treatment and dose adjustments in the future, as well as forecast illness progression [26]. Also, centralised data collection can help researchers learn more about how certain diseases are spreading in a certain area.

2. Remote Assisted Living (Telehealth): The physician's office keeps track of data from network devices in a central location. Compiling and analysing patient specific data enables healthcare automation that compares new data to previous records and determines how to best manage the patient in the future [27]. This machine-assisted intelligence assists service providers in monitoring, transferring routing, and field administration responsibilities to IoMT machines, reducing the cost of adopting follow-up services, and maximising infrastructure usage. Furthermore, remote monitoring has resulted in a decrease in member drop-out rates and an increase in the productivity of healthcare resources [28]. The BodyGuardian Remote Monitoring System is a commercialised cardiac monitoring system that secures the patient's identification information and observation data. Furthermore, encryption technologies are employed

to transfer and store crucial data, ensuring the solution's security.

3. Remote Intervention: In the event of an emergency, clinicians can use real-time data from sensors to prescribe medications and assess reaction. Such prompt measures provide high-tech medical help while lowering inpatient costs [29].

4. Wellness and Preventive Care (Lifestyle Assessment): With monitoring systems for physical activity, diet, and quality of life, IoMT-enabled devices have made health supervision easier [30], [31]. Iimplantable chips, wearable gadgets, and embedded systems in biomedical devices are examples of innovative technologies that track continuous data on patient activities and related essential changes. Smart devices with advanced sensors, convertors, and firmware permit the users to assess and correlate numerous vital events with local health problems [32]. In additional, these devices' remote networking capabilities enable professional support in emergency situations at any remote location.

5. Improved Drug Management: RFID tags based on the IoMT are used to monitor medicine availability issues and supply costs. RFID and medicine supply chain management recommendations have been proposed by the FDA. The addition of labels to medication packaging, for example, allows producers to ensure supply chain quality [33], [34]. Another option is the incorporation of these technologies into medications; for instance, WuXi Pharma Tech and TruTag Technologies have created edible internet of thing "smart" tablets that help monitor drug dosages and pharmacodynamics in patients. Such solutions may be able to assist pharmaceutical corporations in reducing risks and losses in the supply chain and administration [35].

IV. IoMT Challenges

Any developer working on the IoMT system will consider the influence of numerous elements to achieve balance; hence, several issues should be considered in order to develop a better IoMT environment.

A. Mobility:

Mobility is a key problem in internet of things-based systems. Because the sensors are attached to the user's body, network performance degrades immediately the user walks away from them. The services should be accessible regardless of the user's mobility.

The implementation of IPv6 in BANs has shown to be beneficial in ensuring network service availability. To reduce changeover times from one communication standard to another, the designs for IPv6-based systems must be improved [36].

However, there are challenges with coverage and localization. Additionally, because nodes are always changing, there are concerns with calibrating the network. This could be provisions for resilience to work with the network's dynamic nature that necessitates reprogramming. All these issues have spawned a slew of new research areas [37]. Enhanced compatibility for an ever-increasing range of devices is a game-changer for IoMT in the 5G scenario. Furthermore, developments in CRs will aid in mobility support [38].

It has been proposed that the human body should be included in the network in a unique way. Greater human integration in the network may be used to improve the scalability of internet of medical things while also addressing mobility issues.

B. Security and Privacy

With the deployment of smart IoT-based healthcare systems in everyone's life, it must be ensured that it has all the features to protect and secure the confidential and critical information of the patient. Not only this, but it must also ensure data integrity, freshness, as well as legal and authorized access to the patient's information and data so that patient or user satisfaction is achieved. As per the researchers, several security and privacy attacks can possibly occur at any communication protocol layer. In [45], security attacks and threats like authentication, confidentiality, access control, privacy, policy enforcement as well as the trust of IoT-based systems have been analyzed and a comparison has been made among the security techniques and algorithms, for instance, "data encryption standards", "advanced encryption standard", "rivest-Shamir-Adleman", have been compared to address the possible security threats and challenges. If the medical and health data of patients fall into the wrong hands, the patient's treatment mechanism can be affected adversely. In [46], the author has presented the framework of a secure system to develop the "two-fold access control mechanism" which is considered to be self-adaptive not only for normal situations but for emergency conditions. Additionally, Blockchain has significantly contributed to system privacy and security by delivering transparent and clear mechanisms of storing data and leveraging smart measures to protect the services [39], [40]. In this technique of Blockchain, every user or patient can hide his/her data or information from other individuals; it is all in the patient's or user's hand who to allow to see and check their reports. Furthermore, the patient can restrict the amount of data to be shown to others [41]. Within the Blockchain technology, at whatever test or point exchange, for instance, medication is given to the patient, different components can approve the test, treatment cost, or medication cost in the context of some specific infections. The physicians, examiners, or specialists can no longer exploit patients by requesting needless tests, taking huge medicine costs, or even gaining extra medical costs.

C. Interoperability & Scalability:

Challenges of interoperability within IoT-enabled healthcare system are supposed to be a big threat with its wider adaptation. Semantic interoperability within the IoT-based healthcare sector is a mandatory condition of the Big data approaches for supporting decision making procedures [48]. It is significantly becoming necessary for the manufacturer of any recently developed technology startup, system or device to describe their protocol, architecture, and data formats that cannot be adapted in an healthcare environment until or unless they are substantially re-developed to interoperate with IoT-based platforms within hospitals [42].

D. Real-Time Operations

The information gathered by the sensors is analyzed to provide information about the medical state of the user. The amount of data that are collected through the sensing process is significant, necessitating the deployment of specialized processing methods to extract meaningful information [43]. The present algorithms, on the other hand, is incapable of digesting all the information supplied by the sensors. Hence, there is a need for an algorithm that can extract all the important data in real time to provide alerts and trends. The DL algorithms improve data processing performance, allowing for real-time alerts and disease detection [44]. However, retrieving all the good data contained in a dataset is the key problem recognized in the processing methods. As a result, effective data processing algorithms are required which can discover various features in a dataset and integrate redundant features in real time.

E. Low Power Operation

The user's requirements and demands have always been in the direction of having multiple tasks like data collection, pre-processing of data, and data transmission in real-time; all these contribute to high power consumption by devices. Similarly, the charging requirement of a device can come out to be a burden for many users, especially the elder ones [45], [46]. To tackle this problem, researchers have found a solution to put the gadget on power-efficient mode or sleep mode at the needless duration of monitoring or highly sophisticated techniques to minimize the power consumption of IoT-based healthcare devices. In [47], the "real-time quasi-random signal (QRS)" detector and "ECG compression framework" have been presented for energy reserved IoT-enabled medical wearable gadgets. The compression process is considered to be lossless and has been integrated with the proposed structure that uses the ECG signal first subsidiary known as "variable-length encoder". Pressure design assists the IoT-enabled clinical devices to consume extremely low power and restricts the data that must be sent, to lower the power consumption for remote transmitter-based devices.

F. Low latency

Dealing with the huge and heterogenous data volume may hinder or block access to the data at any time until a consistent data and information availability is provided. For this, the consequences may be fatal considering various patients and situations. The healthcare system must be proficient enough that if the critical situation of a patient occurs, like lower BP or quick change in heart rate, the IoT-enabled healthcare system must alarm the caretaker or doctor immediately.

V. MACHINE LEARNING IN IOMT

Machine Learning (ML) is a term that refers to intelligent approaches for optimising performance criteria by learning from instance data or prior experience. More specifically, machine learning algorithms use mathematical techniques to create behavioural models from large datasets of data. Learning without being explicitly programmed is also possible with machine learning. These models are then utilised to make future predictions based on the newly entered data. Information theory, artificial intelligence, optimization theory, and cognitive science are just a few of the science and engineering fields that have influenced machine learning [47].

Machine learning algorithms may be divided into four categories: (1) supervised, unsupervised, semi-supervised, and reinforcement learning algorithms. Supervised Learning: When specified targets are defined to be reached from a set of inputs, supervised learning is used. The data is first labeled, and then trained with labeled data in this sort of learning (with inputs and good outputs) [48]. It allows automatic finding of rules from accessible datasets and construct different classes, then predicts whether items (individuals, things, and criteria) belong to a specific class. (2) Unsupervised Learning: this algorithm occurs when the environment just delivers inputs rather than desired outcomes. It may analyze the similarity within unlabeled data and divide the data into distinct groups without requiring labeled data [47]. (3) Semi supervised Learning: In the first two types, either all the observations in the dataset have no labels or all the observations have labels; this algorithm is somewhere in the middle. In many practical instances, the cost of labeling is relatively significant because it necessitates the use of qualified human experts [49]. Consequently, when labels are missing in the majority of observations but present in a few, semi-supervised methods are the best option for model construction. (4) Reinforcement Learning (RL): There are no predefined outcomes, and the agent learns by interacting with the environment and receiving input. It performs certain actions and makes judgments based on the compensation it has received. Human and animal learning behaviors have influenced it tremendously. Such characteristics make it an appealing technique in highly dynamic robotics applications where the system learns to do specific tasks without explicit programming [51], [52]. It's also critical to choose the proper reward function since the overall reward accumulated determines whether the agent succeeds or fails [53]. RL approaches are commonly used in the following circumstances:

- When there is a lack of historical data and previous instances for model training.

- The exact right and wrong values for the particular case are unknown a priori.
- The overall aim is known, and the environment may be detected to maximize both short- and long-term benefits.

In the lack of established healthcare services, machine learning can aid in remote and real-time diagnosis of illnesses. Patients' rehabilitation following trauma or treatment processes is aided by assistive systems [54]. AAL is made possible by monitoring systems for the immobile and elderly patients. The use of internet of medical thing in the treatment and diagnosis of CVDs, on the other hand, appears to be a very feasible strategy.

A signal quality-aware method for ML-based CVD detection was presented in [55]. The suggested technique uses a machine learning system based on SQA (Signal Quality Assessment algorithm) to assess signal quality. The outcome of this analysis determines whether the signal will be processed for further analysis. The data is discarded if the signal quality is poor, but I the quality is good, it is forwarded for storage and processing. This machine learning based solution improves the energy efficiencies of the system by eliminating noise-infested and less-quality information recorded and transmitted, hence conserving resources [56]. This also aids the user's mobility and flexibility of movement without jeopardizing the system's accuracy as the technology is tested in different scenarios. Stroke is one of the big prevalent CVDs that often results in limb paralysis. As a result, internet of thing was proposed for use in the rehabilitation of limbs following a stroke by [57]; the goal was to develop an armband with sensor for detecting surface EMG signals (sEMGS). Machine learning based on CCE algorithm and principal component analysis (PCA) was used to process the data acquired by these variables [58]. The system can recognize gestures of surface electromyography signals with a 97 percent accuracy rate. The findings are confirmed by real-time operation of a 3D printed robotic hand powered by processed sEMG signals [59].

A new method for handling healthcare data in an IoT setting using machine learning for diabetic patients was proposed by [60]. The suggested system's integration of machine learning, cloud computing, internet of thing, and big data aids caregivers in offering individualized treatment to diabetes patients depending on medical information gathering over time.

The researcher in [61] provided a framework for classifying recorded medical indicators from an internet of things environment using machine learning based classifiers to estimate the prevalence of a health conditions for combating diseases proactively. The classifiers examine patients’ data and compare them to previous data to see if the vital parameters' threshold have been exceeded; a warning or response is sent in the event of a breach. The system's performance, on the other hand, is determined by the classifiers' capacity to appropriately categorize data; this is reliant on the quality of the labeled data fed to the classifier during training.

An unsupervised learning approach known as Generative Adversarial Network (GAN) that enhances the quality of labeled data for improved categorization was proposed in [25]. The GAN is an unsupervised learning technique used to create false data in order to balance out datasets and ensure that every kind of data is spread evenly. This information is utilized to improve the performance of conventional classifiers like SVM and KNN. As a result, the entire procedure might be classified as semi-supervised [62]. The outcome of the tests on datasets for brain strokes verified the approach's effectiveness in assisting physicians in making informed decisions regarding patient care [63]. The use of machine learning in the decision-making process for caregivers can thus be extended in real-time.

Security and privacy are two major challenges related with the installation of IoMT networks. When patient files are created, and information is sent to the cloud for working, this problem becomes even more problematic. It becomes critical that data be safeguarded against all types of breaches. Data manipulation can have serious consequences for consumers, and in rare situations, it can be lethal [64]. While training an algorithm, any alteration of labeled data can introduce biases. As a result, efforts to secure the network in each level are required. The application of machine learning to improve the security of the IoMT system is a valuable tool. A new method or proposed was proposed in [25], which uses DL to protect users' privacy in an AAL environment. The suggested approach encodes and decodes data using LSTM. The data access permission determines how the data is encoded and decoded. The relevant permission holder can attach the information if the appropriately matched decoder is available with permission. The LSTM can distinguish between different data kinds and, as a result, can grant access to people based on their authorization levels. The performance of the IoMT network can be skewed by malicious data tampering or sensor functioning in less-than-ideal settings [65].

The overall performance of IoMT can be improved by machine learning methods. The battery life of sensors (which is a significant parameter) can be improved in IoMT using ML [66]. In most cases, the sensors provide all the raw information to the processing unit, thereby wasting power. The suggested approach uses SVM (Support Vector Machine) optimized embedded machine learning to preprocess and classify information onboard. The data showed that the battery lifetime was increased from 13 days to 997 days. Therefore, autonomous operation and maintenance of IoMT systems is one of their long-term objectives. Therefore, it has not yet been possible to employ ML, and more precisely RL, for autonomous operation. The legend in Table IV reflects this.

TABLE IV: SUMMARY OF THE MACHINE LEARNING APPLIED IN IOMT

Ref.	*Challenge*	*Proposed Work*	*Implementation Tools*	*Findings*	*Drawbacks*
[21]	***Real time, Mobility, Low Power Operation***	***On the Internet of Things, an ECG classification system that is aware of signal quality is being developed.***	***Matlab***	***Improve accuracy battery life of IoT, better mobility***	***security***
[59]	***Real time***	***EMG data is used in a stroke rehabilitation system to recognize gestures on prosthetic devices.***	***CCEAs Tools***	***For diabetic patients, a machine learning and cloud-based solution has been tested.***	***Scalability and Interoperability***
[60]	***Real-time***	***ML-based diabetes management system***	***SQL***	***reduced costs of treatment significantly***	***Interoperability, security***
[61]	***Real-time***	***ML algorithms are used to classify the input data and transfer the disorder to the wearable.***	***Proof-of-concept***	***The data is used to create an alert.***	***Scalability and Interoperability***
[67]	***Real-time***	***ML-based decision support and GAN-based data labeling***	***Benchmarks tools***	***A high-accuracy stroke decision system with semi-supervised learning for labeling the training data***	***Security and Interoperability***
[68]	***Privacy***	***using LSTM Encoder Decoder for increasing privacy***	***Implementation tools not mentioned***	***Permission-based data access in the context of Assisted Ambient Living***	***Low power and latency***
[66]	***Low power***	***ML is being used to extend the battery life of sensors.***	***SPHERE***	***The SVM data classifier distinguishes between necessary and superfluous transmission data, increasing the sensor's life from 13 to 997 days.***	***Security, scalability***

VI. EDGE/FOG COMPUTING IN IOMT

The amount of information created by sensors and subsequently sent across the network is growing at previously unmatched speeds. This has necessitated bringing computing capabilities to the network's edge to reduce the need for sending information to the cloud computing for processing. Aside from that, IoMT system's quality of services requirements necessitates a guaranteed latency and data rate. Similarly, low latency and strong data integrity are also required for real-time input-driven feedback systems [69]. A paradigm called edge computing is being extensively used to address important concerns such as energy consumption, latency, scalability, and bandwidth usage. The incorporation of cloud technology already has helped to alleviate the scalability issues that plague IoT devices. Because extensively distributed IoT devices create a huge amount of data every second, network resources are likely to become overburdened. To solve these issues, edge computing has been proposed for a quicker reaction time as well as more efficient bandwidth and power use [70], [71].

CISCO created the fog technology in 2012 for bringing cloud computing capability to the network itself. It has also been combined with the internet of thing to improve security, scalability, ease deployment, and autonomously maintain the IoT network's optimal performance [72]. Unlike cloud technologies that is completely centralized, fog computing allows the system to offer cloud services in network level for computing capability dispersed locally at the network level. Cloudlets, which may be thought of as extensions of cloud servers, make up the fog network. Mobile nodes like cellphones, gateways, and high-capacity sensors, can be used to deploy fog nodes. The sensor nodes are generally only a single hop away of them [73]. Virtualization functions are provided by Network Function Virtualization and Software defined Networks and can be implemented by fog nodes [74]. The terms "fog” and "edge" are often used interchangeably, however, they are not interchangeable. Fog computing, often known as fogging, is a type of architecture which uses cloudlets part of the architecture to accomplish a variety of tasks. The edge computing of the network, such as an access point or gateway, is involved in executing a particular network optimization works in edge [75]. In contrast to fog computing, edge is a hardware concept. The implementation of this paradigm is shown in Table V to emphasize the distinctions between cloud, edge, and fog computing in IoMT [76], [77].

IoMT takes advantage of the benefits offered by these technologies. Fog computing and Edge computing applications in IoMT can be classified into: (1) to increase reaction time and reduce latency. (2) To cut down on electricity usage. (3) To improve the security of sent information. (4) To make the most of bandwidth and network traffic. (5) To improve the IOMT system's overall quality of services.

TABLE V: COMPARISIN BETWEEN CLOUD, EDGE AND FOG COMPUTING [76], [77]

Parameters	***Cloud***	***Edge***	***Fog***
Location of data processing	***Located at different geographical locations***	***Located at gateways***	***Located at LAN***
Processing of data	***Far from the end users***	***Close in distance to end user***	***At the end users***
Computing capabilities	***Only if there is a small virtual cloud in between,***	***Data must travel a shorter distance from the edge***	***Data must go the maximum distance possible***

	is there a minimum distance.	*device to the cloud than fog.*	*from the fog device to the cloud.*
Architecture	*Centralized storage*	*Distributed storage*	*Distributed storage*
Response time	*Takes minutes to hours for transmission time*	*Takes seconds to minutes for transmission time*	*Takes from milliseconds to seconds for transmission time*
Communication	*Highest communication cost*	*Higher communication cost*	*Cost-effective communication*
Latency	*End-to-end latency still exists.*	*End-to-end latency is an unsolved issue.*	*End-to-end latency has been resolved.*
Mobility	*The use of explicit mobility is not recommended.*	*The use of explicit mobility is recommended.*	*The use of explicit mobility is recommended.*

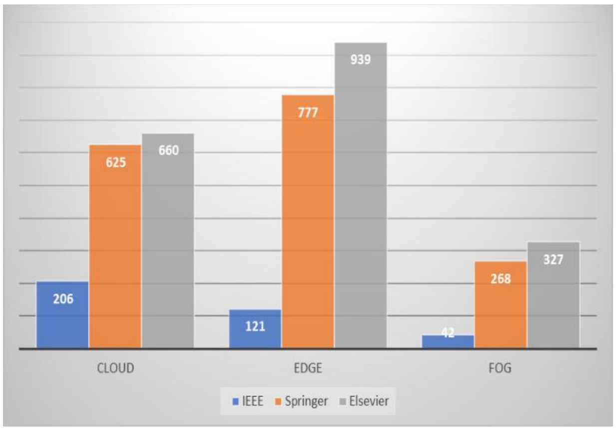

Fig. 2. The total number of papers published in solid journals.

Fig. 2 A review of the existing literature between the year 2020 to 2022 showed that few works on the Internet of Medical Things have focused on the fog technology; therefore, more studies can be focused on this technology in future.

Many writers have used a variety of ways to apply the fog/edge paradigm in the IoMT field. This section discusses the most recent advances in this field.

The authors in [78] reported the outcomes of two case studies that suggested a revolutionary design dubbed Body Edge. A hardware gateway and a software client are the two major components of the proposed system. The client element interfaces with multi-radio technology to provide dependable communication, while the gateway guarantees easy communication in cloud servers. The reaction time satisfies the specifications for IoMT applications, according to the experiments. The results were obtained in a laboratory setting and for athletes. The results demonstrate that the edge-based architecture's response time is half that of the cloud computing depending on the system.

The researchers in [79] presented a multimodal hybrid system for monitoring industrial workers' vital signs and their environment to assure their safety in the workplace. The system examines the compatibility of Lora and BLE (Bluetooth Low Energy) networks [80]. The edge nodes installed at the internet of things gateway fulfill the function of alert creation from sensors information since the information is preprocessed there. In addition to viewing and transferring information to the cloud server, the edge node serves as a user interface. The processing at the IoT gateway decreased the response time significantly.

A multi-tiered architecture based on fog computing for real-time patient monitoring was proposed by [81]. The system improves the capabilities of associated infrastructure and deployed sensors by allowing for cross-platform compatibility. The authors showed that using hybrid compression to compress ECG data can save up to 200 nW of energy.

In [82], the authors compressed the observed data using Compressive Sensing (CS). The suggested approach improves energy efficiency by approximating duplicated data that makes up most biomedical data. Compressive sensing is installed at the proposed system's edge node. With a 40 percent approximation, the results show that 59 percent of energy savings may be accomplished. Due to computational costs, the energy efficiency decreases as more data is approximated.

An edge-internet of medical thing computing architecture that reduced delay and increased bandwidth efficiency was presented by [83]. It was made up of two parts: edge computing unit components that compress and filter real-time video data, as well as cloud computing infrastructure components that securely deliver health data to doctors.

The authors in [84] created an IoT system based IPv6 that uses fog nodes to analyze important data locally for risk assessment in patients. Fog nodes are used to minimize delay and enhance risk assessments accuracy. The disease detection systems use cascaded deep learning to assess chronic diseases, such as hypertension, diabetes, and chronic heart disease with high levels of accuracy. The classification can be implemented with the help of the fog. Furthermore, the latency measurements are well within the expected range. The fog computing can assist save energy by restricting long-distance broadcasts and utilizing a temporal threshold method to choose neighbors [85]. Fog computing may reduce system traffic by pre-processing original information and only sending non-redundant information to the cloud technology servers. By using edge computing in fitness monitoring systems, the reaction time was considerably lowered.

The authors in [86] aimed to enhance the quality of the signal of ECG information obtained from a unique smart fabric. The signal quality is severely harmed by motion artifacts. At the fog node, the acquired information is processed to extract the appropriate information from the ECG signal. Although the current installation lacks a diagnosing agenda, it does demonstrate the extraction of relevant information. The collected results show that four electrodes had a high SNR. Moreover, in a tabular format, Table VI shows the results from the reviewed literature.

TABLE VI: SUMMARY OF EDGE/ FOG COMPUTING IN IOMT

Ref.	Challenge	Proposed Work	Implementation Tools	Findings	Drawbacks
[78]	*Latency processing time*	*BodyEdge is an Healthcare-IoT architecture that reduces network traffic and reaction time.*	*BE-MBC module*	*For two cases, there was a reduction in response time and data transmission.*	*Mobility, interoperability and security*
[79]	*Latency*	*For health and environmental monitoring, a multimodal hybrid system is used.*	*Raspbian, an open-source system*	*Decreased delay and a data monitoring interface*	*Security*
[81]	*Low power*	*H-IoT framework with many layers*	*LABVIEW simulation*	*Using a hybrid compression technique, 200 nW of energy may be saved.*	*Scalability and Interoperability, and security*
[82]	*Low power*	*Data compression method based on Compressed Sensing*	*Matlab*	*Energy savings of 59 percent for a 40 percent approximation*	*Scalability, security*
[40]	*Latency*	*Smart healthcare monitoring platform real-time video consultation*	*C#*	*Develop the edge-IoMT computing architecture for H-IoT.*	*Security and Scalability*
[84]	*Latency*	*A fog-assisted H-IoT framework based on IPv6*	*Implementation tools not mentioned*	*Good classification accuracy and decrees in latency*	*Security*
[86]	*Latency low power*	*Signal quality optimization in the H-IoT*	*Implementation tools not mentioned*	*SNR at the fog node has improved.*	*Scalability and Interoperability*

VII. Blockchain in IoMT

Blockchain is considered one of the most important technical trends of the future. Blockchain has always been associated with bitcoin, although it also has applications in a variety of sectors. The word "blockchain"[87] refers to a distributed and totally decentralised P2P storage of data, which is meant to store data in a chain of immutable chunks of memory. A P2P currency transmission system was first defined in 2008 when a white paper by an anonymous organisation or person named Satoshi Nakamoto was published, and later became what was recognized as Bitcoin in 2009 [88]. Every block in the block-chain is simply a collection of data that is cryptographically signed with a private key and used as an input for producing a unique hash. This hash is specific to the data block and change as the data in the block changes. This hash is used to keep track of the block's origin or chain [89]. The block is dispersed to all users across the network. The validity of blocks is confirmed by solving a difficult mathematical problem known as a proof-of-work. Miners are a group of blockchain users that strive to gain PoW to verify a block on the chains in exchange for a payment. This method renders the blockchain visible, safe, and impervious to illegal modifications [90].

Integrity, security, and privacy are all required for IoMT systems, but the blockchain is built on decentralization, anonymity, and integrity [91], [92]. By incorporating blockchains with IoT systems, the use cases and performance of internet of things systems can be improved. Blockchains are assisting in the implementation of services in healthcare, smart cities, and smart grids. Nevertheless, security, scalability, storage, and consensus remain significant challenges. The storage and access management of gathered health information is the major application area of blockchain in healthcare. However, blockchain's promise in the IoMT paradigm has yet to be realised [93].

The existing studies on blockchain and the internet of medical things will be discussed in this section.

A new method was proposed in [48] using an authorised blockchain based on architecture. This method was designed to protect and monitor remote patients. Ethereum was used to execute smart contracts for analysing data and sending alerts to healthcare providers and patients. Practical Byzantine Fault Tolerance (PBFT) was proposed instead of PoW consensus.

A new system that continually monitors the health of patients was designed in [48]. For privacy protection, the architecture of the system was backed by a blockchain. A customized blockchain was used in the remote monitoring system, which was administered by a suggested PCA. The Patient-Centric Agent classifies the stored information according to its criticality, and responsible for selecting miners, and, in some circumstances, filling in for miners when none is available. The PCA is also responsible for security by maintaining the authentication keys in the RPM blockchain.

Cloud-based IoMT devices for monitoring the development of a neurological disorder was created by [94]. IoMT data is stored and processed using cloud computing. To protect exchange, the deployed Ethereum relied on blockchain network and enabling healthcare users to share data. Users can access cloud data under the control of the smart contracts.

The smart contracts are implemented by an architecture based on a private Ethereum to manage the requests of the users and devices, and access control relies on a group of attributes containing the credentials, scope, and role [50]. For information storage, the Interplanetary File System (IPFS) was used. The device technical information and patient health records are stored by using IPFS. The smart contract implements the consensus mechanism. A proof of medical stack (PoMS) was proposed by the author instead of a proof of stack to secure smart contracts against malicious actions. The proof of medical stack permits stakeholders to an enormous quantity of medical information provided as tokens to a block's validation and creation [95].

A four-layer format called MedShare that employs smart contracts to manage data access on the blockchain, was created in [96]. To prove the validity of the suggested approach, it was tested via experiments.

The authors in [97] proposed a system based on a private blockchain for medical data management. The data access permission is managed by Ethereum smart contracts between parties such as doctors, patients, research organizations, hospitals, and other stakeholders. The smart contract includes medical records smart representations containing data integrity, record ownership metadata and permissions. An external server stores the medical record data and to ensure data integrity, the blockchain keeps the record cryptographic hash.

A new blockchain method for IoMT that included the benefits of smart contracts was implemented in [54]. The system looked at the several dimensions that smart contracts and decentralization may bring to IoMT. The IoMT devices are placed in strategic locations to gather data relevant to the application's requirements. These IoMT devices are also pre-programmed to analyze and send the data they collect. The system's efficiency is proven in contrast to other comparable approaches in terms of performance measures such as average latency, average energy efficiency, and average packet delivery ratio. The system, as per results, recorded a lower level of service quality and didn't work efficiently.

The rising need for healthcare equipment and wearable technologies, as well as the problems of storing and preserving patient information, were highlighted in [98]. Blockchain provides a considerably more secure and optimal means of retaining these records. The wearable gadgets are connected to a cloud database or network, which stores all the user's data, but because such large volumes of data are saved in this manner, information is saved in batches in a Merkle tree, making data processing more efficient. Table VII provides a table-based summary of blockchain's uses in the IoT.

TABLE VII: BLOCKCHAIN SUPPORTED IOMT

Ref.	*Challenge*	*Proposed Work*	*Implementation Tools*	*Findings*	*Drawbacks*
[99]	**Security and Privacy**	**Blockchain-enabled continuous monitoring architecture**	**Java 8 Development Kit 64 bit and Netbeans IDE 8.1 as editor**	**Privacy-preserving PCA agents that chooses miners depending on the data's criticality.**	**Scalability**
[100]	**Security and Privacy**	**A new fine-grain authorization system for controlling access to IoMT devices and related medical data**	**Implementation tools not mentioned**	**Ensure access granularity, as well as high integrity and traceability assurances**	**Scalability and latency**
[96]	**Data privacy, and latency**	**Smart contracts are used in a four-layer MedShare framework.**	**JMeter**	**Validation of smart contracts as a means of granting data access**	**Scalability**
[101]	**Latency, low power**	**Blockchain method for IoMT that included the benefits of smart contracts**	**MATLAB**	**Performance measures such as average energy efficiency, average latency, and average packet delivery ratio, the system's efficiency is proven in contrast to other comparable approaches.**	**Covered a lower level of service quality and didn't really work efficiently**
[98]	**Security**	**Maintaining electronic health record using blockchain**	**Implementation tools not mentioned**	**More responsibility with user**	**Scalability issue and limited health data sharing**

VIII. FUTURE WORK

In this part, we show the key areas that require involvement and contributions from various research and regulatory groups to improve the overall IoMT performance.

A. Future IoMT Applications

IoMT applications are being more widely used in the commercial sector. There are several commercial options available for tracking a person's health condition; however, there is still a lot of room for IoMT systems to become main healthcare facilities and hospitals to become secondary care units. Here are a few examples of future IoMT applications:

B. Strokes and Epileptic Seizures Prediction in Real-Time

Diagnosis of neurological diseases like Alzheimer's, epilepsy, and Parkinson's (PD) is considered one of the main application of IoT-enabled healthcare systems. The monitoring of patients is done for brain electrical activity known as "electroencephalogram (EEG)". Along with this, a gait pattern is observed to diagnose the issues. EEG is taken as a standard tool to detect neurological disorders [56]. The IoMT technology within the healthcare system consistently observes the movements of the body, its temperature, and also its sounds to detect the occurrence of epileptic seizures [57]. In [58], a framework was provided for the prediction of the presence of seizure using a combination of classification and feature extraction techniques. A classification algorithm was proposed based on the patient’s features to improve the algorithm’s accuracy. The same method was applied for detecting tremors and gait patterns for PD analysis. In [59], the epilepsy detection framework was proposed using EEG that captures the sensor-based headband linked to the intermediary gadget that acts as a gateway and edge node within the IoT-enabled framework. The acquired EEG data is then processed at the gateway, after which the alerts are produced and sent to caregivers. The arbitrator transfers the data to the cloud to store it for in-depth analysis and also for precision diagnosis by the physicians. Big data and "convolutional neural network (CNN)" were proposed by [60], for the prediction of the presence of seizure through analysis of pre-ictal EEG. The cloud computing convolution and pre-processing at the network level can predict seizures, and can generate the stimulus signal for suppressing seizures [60].

C. Real-Time Brain Tumor Detection:

Traditional approaches to detect brain tumours are biopsy and human diagnosis of MR images or CT scans. In the former approach, a pathologist has to take a little piece of tissue from the human body and examine it under the microscope to investigate if there is any tumour growth. Even though this approach explains everything, however, it comes out to be more painful for patients. In the case of surgery, doctors or physicians have to be familiar with the exact position where it is located, thus, a CT scan or MRI based examination becomes mandatory. The main advantage of using MR imaging is that it does not involve radiation and is thus considered safe for human health [61].

Rehabilitative therapies based on AR/AV: Technology and medicine have progressed significantly, and augmented reality and virtual reality development services are playing an increasingly important role in the creation of healthcare mobile applications. By the year 2025, the healthcare-related AR and VR industries are expected to be worth $5.1 billion. While the future is still a long way off, the value of AR/VR in the healthcare area is already evident in a variety of settings. AR/VR has been shown to benefit all four major areas of healthcare: treatment, training, diagnostics, and rehabilitation. In comparison to standard therapy, the experiences of rehabilitative therapies based on augmented reality and virtual reality could have a considerable influence. Fog/edge computing enables resource-intensive graphics processing to be completed quickly. Furthermore, because IoT devices lack this processing capability, fog/edge systems are necessary for these kinds of operations. This application could be used in a consumer environment by utilising tactile internet.

Health monitoring and treatment management using a smart contract-based service subscription: Smart contracts can be used by the IoMT system to automate and control the healthcare services that nodes that can be trusted sign up for. The smart contract's terms and conditions govern the services that the user has subscribed to, and if any of the terms and conditions are violated, remedial steps can be taken automatically. Each node in the blockchain subscribes to a service per smart contract; as a result, users can utilise a smart contract-based connected service agreement to access services like treatment management and health monitoring. In the consumer market, it could deliver safe and accurate health services.

D. Open Issues

Several academics have worked on the design and implementation of different IoT-based medical care models, as well as the technological and architectural issues that come with them. There are still numerous problems and unresolved questions that must be properly addressed. Based on the research in the previous sections, the following problems have been brought up as reasons why IoMT systems can't be used on a large scale.

Many wireless communications technologies, including Wi-Fi, BLE, and ZigBee, have lately been utilised in the healthcare industry to access multiple medical equipment and sensor types. These wireless sensor and wearable devices must be used to protect against eavesdropping, Sybil assaults, plunger hole assaults, and sleep loss attacks. Data sets containing personal facts, family histories, and electronic medical records can also be guarded against hackers and malicious devices to maintain security and privacy.

Complexity and Memory Usage: Integration of healthcare system with IoT is itself a complex ecosystem. This complexity significantly impacts the availability and performance of the overall system. The complexity in IoMT system occurs because of the incorporation and association of several devices together with the multiple point, for instance, mobile applications, endpoint devices, or cloud platforms. In this context, a large amount of data is generated from different points on one single central hub, and for which high memory space is required, the availability of which, sometime, is not achieved. Therefore, memory issues remain a major problem that impact the whole IoMT system [103].

Cost for Resource Usage: The cost of deploying the IoT-based healthcare system is not cost-efficient yet. Its resources are rising daily, and it is dominating the healthcare industry. IoT-based technological advancements and progressions have yet to establish themselves sufficiently to offset the rising cost of healthcare. With the development of IoT in healthcare, the affordability of advanced healthcare is still out of reach. Even in developed countries, low-income people or individuals cannot afford this facility [100].

Autonomous Network Management and Security: In the IoMT, one of the aims of artificial intelligence is to achieve absolute network management autonomy. RP based on Reinforcement Learning algorithms can create traffic management solutions that are both reliable and intelligent. In a distributed random-access context, the adoption of lightweight reinforcement learning algorithms can also help with channel selection. An intelligent intrusion detection system (IDS) powered by machine learning can assist in preventing security breaches while also learning network behaviour and mitigating future threats on its own. SDN plays a crucial role in establishing autonomous network management. Using learning algorithms to control the virtualization of network devices and services could lead to an IoMT that runs itself.

Overfitting of Training Data: While processing is done locally, devices that employ wireless body sensors typically gather data from the same group of users, resulting in data redundancy. When this kind of data is used to train or update deep learning algorithms, they often end up being too good or too bad.

Privacy Issues: In [101], a "noise-aware biometric quantization framework (NA-IOMBA)" was introduced; this system can generate reliable, unique, and high entropy keys, consumes less time to enroll, and cost-effective for various examinations. The "reinforcement learning-based offloading algorithms" for IoT-based healthcare devices proposed by [102] acquired the prime policy through trial-and-error irrespective of being aware of privacy leakage, edge computing, as well as energy computing.

Key Distribution: In a blockchain, a cryptographic key secures a node's identity. Threats such as grey hole and selective forwarding attacks should be avoided while distributing public keys. No hostile node should be able to eavesdrop the control traffic. There's also the possibility of a Sybil attack that permits hostile nodes to assume a fake identity. As a result, a secure identification method can guarantee that a node's identity is retained. For optimal performance, technologies that can assure safe key distribution without incurring additional costs are necessary. Furthermore, time restrictions must be observed since the existing efforts exhibit end-to-end debugging.

Scalability: In large-scale networks, most of the existing techniques are ineffective, and because the IoT was designed for large-scale adoption, the present techniques suffer from problems such as long delays and increasing packet losses during packet transit. Maintaining a high packet delivery ratio and low delay throughout the whole network is essential for large-scale IoT implementation. Edge computing and Software Defined Networks (SDNs) are two methods based on distributed network controllers that can help solve this problem.

Computational Overhead: IoT sensor nodes are power and energy limited. The existing approaches, on the other hand, have a high computational cost, which necessitates the use of both computing and energy resources. Hence, there is a need for low-computing-power techniques. Because the nodes may share the computational burden with the edge devices, edge computing can play a significant role in reducing overhead limitations. Low computing needs improve energy efficiency as well.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, methodology, investigation, writing—original draft, Naeem Ali Askar; Conceptualization, investigation, supervision, review and editing, Adib Habbal; Analysis, visualization, writing—review and editing, Alaa Hamid Mohammed; review and editing, funding acquisition Mohd Samsu Sajat; review and editing and conceptualization Ziyodulla Yusupov; review and editing Dilshod Kodirov. All authors have read and agreed to the published version of the manuscript.

IX. Conclusion

This paper has provided a detailed and in-depth survey analysis of IoT-based healthcare systems and their significance in our daily lives. Even though the IoT-based healthcare system has several benefits and has eased the lives of not only patients but also healthy people, it has some issues as well. These issues are power consumption, energy, privacy and security, resource management, high data rate, low latency, etc. To resolve these challenges, various emerging technologies have been developed by researchers at present, such as technologies include machine learning (ML), blockchain technology, and edge and fog computing. All these technologies are in high demand in recent times for integration with IoT-enabled healthcare devices to provide better healthcare facilities and services to patients and other users, and to overcome the challenges mentioned in Section IV. Machine learning has significantly helped with the exploitation of various healthcare systems. Furthermore, fog and edge computing not only minimise the cost of communication but also provides low latency. Blockchain gives its users a much better way to protect their sensitive and confidential information and data. In this survey paper, a comprehensive elaboration of the IoMT based healthcare system has been conducted based on recent modern technologies. In this research, all the emerging technologies have been discussed from the perspective of being incorporated within the IoMT-enabled healthcare system. After that, applications have been highlighted related to these smart healthcare mechanisms. This paper also describes the future trends and applications for a better understanding of how IoMT can enhance the healthcare industry now and in future.

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