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Review Article

The internet of medical things in healthcare management: a review

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Abstract: The widespread adoption of Internet of Things (IoT) technologies across various domains has given rise to the Internet of Medical Things (IoMT), which has significantly enhanced the accuracy and capabilities of electronic devices in producing reliable results applicable to the healthcare industry. To leverage the potential of IoMT in healthcare, a series of interconnected events must take place, starting with edge devices collecting data, followed by data aggregation, processing, and informed decision-making based on data analysis. This review article stems from a collaborative and innovative project conducted by participants in the digital economy, organized by the Department of Software Engineering at Tsinghua University in 2021. The project focused on implementing technologies in various fields, with specific teams dedicated to healthcare. During this project, several gaps were identified, and solutions centered around the IoT were proposed. In this comprehensive review, we extensively investigated IoMT services and applications and emphasized how these applications can be optimally implemented to unlock their potentials. Our survey encompassed over 300 research papers, that examined the implementation of IoMT in domains such as Pharmacy Management and Health Insurance Management. Additionally, we analyzed the key enablers and barriers to the successful implementation of IoMT in recent times. To provide a practical perspective, we presented a feasible case study that applied deep learning to IoMT, considering the security concerns associated with its implementation. Furthermore, we identified future research directions and potential areas of improvement based on the gaps identified from the reviewed literatures. By undertaking this review, we aim to contribute to a deeper understanding of IoMT services and applications, shedding light on their optimal utilization within the healthcare industry. Ultimately, our goal is to facilitate advancements in IoMT implementation and to pave the way for enhanced healthcare delivery and improved patient outcomes.

Keywords: Applications, Healthcare devices, Internet of Medical Things (IoMT), Management, Security, Wearables

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1. Introduction

The IoT (Internet of Things) refers to the concept that hovers over a set of connected things that is not restricted to the class of anyone and anything but extends to anytime, as well as any service, and any place without excluding any network [1]. This concept – IoT therefore, is considered a system comprising wireless digital devices that are in most cases interrelated and/or connected with the capacity to collect data as well as send data in addition to data storage over a network. In some other cases, wired devices can be included in the system as the need arises but are dominated by wireless devices. This set of activities carried out by IoT does not need interaction involving human-to-human or human-to-computer [2]. The role played by IoT in healthcare is so vital [3] that it is almost difficult to overlook and underuse. The IoT has the potential to streamline and boost healthcare delivery to proactively make a prediction of health issues, as well as, detected by diagnosis, managed by treatment, and to monitor patients not only in the hospital but also out of the hospital. The Internet of Medical Things (IoMT) is considered the integration of IoT with devices that are medically enabled to assist in improving the comfort of patients, bringing cost-effective solutions in the medical field, assist in bringing quick response to health-related issues as well as bringing more personalized healthcare delivery [4]. Recently, it is becoming increasingly important to have a good understanding of how customary and advanced IoT technologies are able to aid health systems not only in delivering and dispatching safe care but also in delivering effective ones [2]. As there is an influx of devices joined to the internet by various connectivities than ever known before now; this is expected to continue to rapidly increase and grow on the global level, with greater than 23 billion devices connected to the internet and will be projected in 2025. This projected number is about 3 times the amount of devices connected 4 years adrift of 2025 [5], IoMT is to leverage this increase and maximize its usefulness. In addition to that, the need for change in the healthcare system became imminent, especially with the retort to the 2020 public health call to the unprecedented COVID-19 pandemic which almost brought a shutdown to the global customary health service delivery modes. This triggered the efforts to minimize or eliminate if possible the drawbacks to the implementation of technology-supported health delivery which spotlight the prospect and possibility to reframe traditional models into virtual and distance modalities of care [6]. Additionally, many countries have made success in implementing technology-supported services that will help to maintain healthcare practices without bridging the norm of social distancing [7]. Global leaders and professionals in the healthcare sector continue to research and consider approaches with the aptitude and capacity of providing better access and ingress to technology-supported health services as a reaction to (and in consideration of) the COVID-19 crisis. It is therefore rising as an indispensable matter to grasp how emerging paradigms in IoT technologies can aid the healthcare systems for care delivery. These deliveries of secure and effective care are either complementarily or alternatively during times of emergency, crisis, disaster, or epidemics in the health sector [8]. IoMT is an infrastructure that we can term smart that enables the operation of smart health services. The gathering of health data by IoMT sensors, oftentimes triggers their being communicated in addition to their storage, making both data analytics as well as smart or apt health care possible. This generally will bring improvement in the identification of risk factors, diagnoses of diseases, and treatment of the diagnosed disease, not excluding remote monitoring which works together to empower people to self-manage.

So, if so connected, IoMT can generally be considered as any device with the capability of getting data that are related to health from individuals, including computing devices, smart bands, digital medications, wearables, phones, embeddable surgical devices, or other lightweight devices, with the capacity of measuring health data in addition to being connectable to the internet [9-10] or simply a blend of IoT with medical devices. This IoMT can therefore be considered the future of the medical field since it has the potential to provide professional healthcare delivery successfully over the internet. The IoMT also promises to offer both faster healthcare delivery as well as more cost-effective health delivery as it keeps evolving. It can be applied majorly in caring for elderly patients where it can provide constant tracking capacity of their health conditions and another pronounced impact on people who live alone as well as their family members who may be living far away. It can also enable physicians or health workers to track the health of their patients better and more effectively, tracking adherence to treatment plans as well as a probable need for immediate attention. The health worker can benefit from the IoMT also in utilizing the gathered data to pinpoint the best approach to patient treatment. The IoMT technology has enormous applications for hospitals, aside from being used for observing patients' health. IoMT devices stubbed with sensors are effective for spotting equipment like wheelchairs, nebulizers, and defibrillators in real-time including oxygen pumps. The analysis of the deployment of staff at certain designated locations in real-time is also possible with IoMT. One major concern deep in every society is the spread of infections, especially among patients in hospitals, it is, therefore, possible to use hygiene monitoring devices that are IoMT-enabled to aid in keeping patients off infections. IoMT devices have found usefulness in the area of asset management such as pharmacy inventory control, as well as environmental monitoring, for example, checking the temperature of the refrigerator, as well as humidity and general temperature control. It has also been suggested that IoMT technology is very useful for insurance companies. Health insurers are provided uncountable opportunities with IoMT-linked intelligent devices. They can anchor on data got through IoMT surveillance devices for both their underwriting as well as claims. These IoMT devices will help insurers to minimize or eliminate fraudulent claims and can give room for the validation of claims through the data got by these IMoT devices. The implementation of IoMT is not without several challenges which include but are not limited to the capture of enormous data containing sensitive information. This especially has triggered concerns on data security and privacy.

To this end, this review has been carried out to identify gaps in the existing literature and research. By analyzing and synthesizing multiple studies, reviews are known to uncover areas that have not been adequately explored or those that require further investigation. This helps guide future research efforts and promotes the development of new ideas, methodologies, and technologies in IoMT. Secondly, with the rapid evolution in the field of IoT which has a wide range of technologies, applications, and research areas, this article aims at providing a comprehensive and organized summary of existing knowledge, research findings, and advancements in IoMT. In the end, researchers, practitioners, and policymakers can stay updated on the state-of-the-art in IoMT, identify trends, and understand the broader landscape of the field. Since policy-makers, industry leaders, and decision-makers often rely on review articles to gain a comprehensive understanding of the opportunities, challenges, and implications of various fields and decisions. This article can also help to inform strategic decisions, shape policies, and guide investments in IoMT technologies and applications. It also aims at providing insights into the societal impact, ethical considerations, and regulatory aspects of IoT deployment. To achieve the goals, the methods that have been used are the systematic method of review where conclusions are drawn from the findings from the reviewed papers, and the integrative method of review which was integrated into the aforementioned method for a much better understanding of the subject matter.

The article is organized into the following sections to provide a comprehensive understanding of the topic. The introduction in section 1 provides an overview of the article and highlights the importance of the Internet of Things (IoT) in transforming the healthcare system. Background of IoT in healthcare in the second section offers a brief description of the background of IoT and its impact on the healthcare industry. It highlights the potential benefits and challenges associated with implementing IoT in healthcare. Section 3 – Technologies for Healthcare Management focuses on the various technologies that are employed for managing healthcare using the Internet of Medical Things (IoMT). It explores the range of services and applications enabled by these technologies. In section 4, the role of Smartphones in Healthcare delves into the role of smartphones in leveraging IoT for healthcare delivery. It discusses the categorization of smartphones based on their functionalities and capabilities in the healthcare context. Expanding IoT for enhanced healthcare which introduces the concept of expanding the IoT ecosystem to improve healthcare delivery was highlighted in the latter part of section 4. It explores the potential of integrating IoT with other emerging technologies and platforms to enhance patient care and outcomes. Enablers and Barriers in healthcare IoT discussed in section 5, covers aspects such as interoperability, privacy and security, regulatory challenges, and infrastructure requirements. In section 6, the Conclusion and Future Work was done which summarizes the key findings and insights from the article. It emphasizes the potential of IoT in revolutionizing healthcare and highlights areas for future research and development.

2. Background

IoT which was first proposed by Ashton [11] and Brock [12] as recorded by [13] has been applied in many fields like transportation, building, agriculture, environment, and others. This IoT sprang from the Auto-ID Center at the MIT which was founded by Kelvin Aston, David Brock, Daniel Engels, Sanjay Sarma, and Sunny Siu. The terminology 'Auto-ID' is regarded as any type of technology for the purpose of identification of many forms of application, with advantages in the range of error reduction, and improvement of efficiency, in addition to automation. The fitting and suitable Electronic Product Code (EPC) network launched in 2003 by the Auto-ID center at its executive symposium [13] was not considered a negligible contribution to the IoT from which the IoMT was birthed. With the EPC, tracking of objects when they are moved from place to place is made possible. The announcement of the EPC network makes one imagine the big-time potency of the IoT paradigm as a global commercial means, where there will be a network of microchips for the formation of IoT [13] which is foundational for IoMT. When RFID was successfully developed, it indicated that IoT would leave the laboratory and pioneer a new IT era not only in academia but also in the industry [14]. The report of 2002, by the NSF published on convergent technology [15] as mentioned in [13], was focused on incorporating nanotechnology into ICT to significantly improve people's quality of life as well as the productivity of nations. In 2005 when the ITU gave their first report [16] as mentioned in [13], IoT was suggested to be merged or amalgamated with technologies available in the identifications of objects, embedded systems, sensors, wireless networks, and nanotechnologies in order to connect things in the world, to achieve tagging of things, their sensing, and control over the internet [14], [17-18]. This has led to the development of IoT-based enterprise systems for various applications such as healthcare systems [19], industrial environment [20], and public transportation [17] with major interest geared towards developing countries as well. For instance, an IoT national research center was set up in 2009, and the former Premier of China gave a national speech that supports the promotion of research and development of IoT as reported by [21-22]. This became a trigger for the application of IoT and more than 90 cities from then in China had developed applicable plans that were strategic in the development of smart cities. In addition to that, several big companies that are nationally recognized especially Telecom companies, like China Mobile, China Unicom, and China Telecom, have associated their enterprises with the realization of the proposed smart cities.

In healthcare management, some of the key influencers include Electronic Medical Records (EMR), Electronic Health Records (EHR), and Personal Health Records (PHR) which are forms of digital health records. While they share similarities, they differ in scope and purpose. These electronic record systems offer several benefits which include improved data accessibility and availability to authorized healthcare providers, leading to better-informed decision-making. Enhanced communication and collaboration among healthcare professionals involved in a patient's care. Efficient record-keeping, reducing paper-based documentation and associated errors. Facilitated clinical research, population health management, and public health surveillance through aggregated and de-identified data.

While EMR covers the systems used by healthcare providers within a specific organization or practice to document and store patient health information electronically. They contain patient medical histories, diagnoses, treatments, medications, laboratory results, and other relevant clinical data. They streamline workflows, improve data accuracy and facilitate better coordination of care within a healthcare setting. The EHR systems although similar to EMRs, offer a broader scope and are designed to share patient information across different healthcare organizations and providers. EHRs can integrate data from various sources, including EMRs, hospitals, clinics, pharmacies, and laboratories, creating a comprehensive digital health record for a patient. They support interoperability, enabling the secure exchange of patient data between healthcare providers, improving care coordination, and reducing duplicated tests or procedures. This gives a good base for the IoMT to thrive in this area in comparison to the aforementioned EMR. On the other hand, PHRs are patient-controlled health records that individuals manage and maintain themselves. They allow patients to store and access their health information, including medical history, allergies, medications, immunizations, and test results. They can be in various formats, such as standalone applications, web-based portals, or mobile apps. Patients can grant healthcare providers the access to their PHRs to enhance communication, and empower individuals to actively participate in their own healthcare. The implementation and use of these systems varies across healthcare organizations, regions, and countries, and is expected to comply with privacy and security regulations to protect patient information.

In healthcare management, there are various standards and regulations that govern the implementation and use of electronic health records and healthcare information systems. These standards aim to ensure interoperability, data security, privacy, and the effective exchange of health information. Compliance with these standards and regulations ensures the security and interoperable exchange of health information, protecting patient privacy and promoting efficient healthcare delivery. Different countries and regions may have additional standards and regulations specific to their healthcare systems. Some of the well-known standards include Health Level Seven International (HL7) – a global authority that develops standards for the exchange, integration, sharing, and retrieval of electronic health information. Integrating the Healthcare Enterprise (IHE) – an initiative that promotes the interoperability of healthcare systems and facilitates the seamless exchange of health information. IHE develops technical frameworks and profiles that specify how different standards can be implemented together to address specific cases and improve interoperability.

Others standards include Continuity of Care Document (CCD) and Continuity of Care Record (CCR), Health Information Exchange (HIE) Standards, Health Insurance Portability and Accountability Act (HIPAA), General Data Protection Regulation (GDPR), and many more according to the requirements of regions and countries. However, most of these standards are in full implementation in the developed countries.

2.1 Redefining healthcare with IoT

The Internet of Medical Things (IoMT) is a subset of the broader Internet of Things (IoT) concept. At its core, IoMT refers to a system that connects various medical devices and objects to the internet, enabling them to collect, transmit, store, and receive information [23]. Referenced as “Smart Healthcare” by [24] it has been researched extensively with numerous applications, some recent reviews overviewed the different services and applications of IoMT in healthcare (eg, eHealth, ambient assisted living, mobile health [mHealth], wearable devices and smartphones, semantic devices, and community-based health care) [9], [25]. The IoMT is primarily a connected infrastructure of software applications, medical devices, and health systems as well as services.

There are many challenges that seek to be addressed in the field of medicine, one prevalent in many societies is that how to provide adequate healthcare to the aging population in a more cost-effective way. The healthcare, nursing, and assisted living sectors are widely recognized as expensive forms of care. However, enabling elderly individuals to reside in their homes for as long as possible presents an opportunity to reduce costs and enhance quality of life. This is an area where IoT technology can play a key role as a facilitator, and significant progress is already being made in that regard. Numerous companies are currently developing components of the solution, such as wearable devices that monitor vital signs, environmental sensors, and tracking of movement and activity. These developments represent a valuable application of the IoMT. These areas require a focus on sensing, communication, and generating appropriate responses, which were previously viewed as isolated solutions. But with this paradigm being researched, development has continued in these areas. However, the central area for upgrade is in the incorporation of every sensing and monitoring into integrated systems alongside intelligence to make sure that those living at home are not abandoned in that place. Since there is an escalation of healthcare-specific IoT products, it gives room for immense opportunities. And the enormous data engendered by these linked devices holds the potential of transforming the healthcare system.

IoMT is reforming healthcare by guaranteeing superior care, improved outcomes of treatment, and cost reduction for patients, in addition to improved procedures and workflows, enhanced achievement, and a better patient experience with healthcare providers [26-31]. In order to redefine healthcare with IoT, an understanding of the architecture of IoT is important. IoT comprises a four-step architecture staged in a process shown in Figure 1. The entire stages are linked in such a way that data is processed following their obtainment at one phase whose yield goes into the next phase.

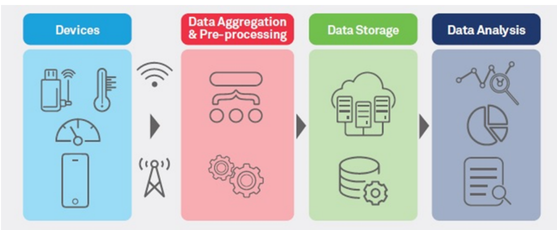

Figure 1: The four stages of IoT solutions

Step 1: This phase comprises the deployment or stationing of devices that are interconnected and include monitors, detectors, sensors, actuators, camera systems, etc. These devices accumulate the needed data.

Step 2: In this phase, the data collected in the first step is aggregated and converted to digital form for processing since data accumulated from sensors and other devices is in the unprocessed and analog form.

Step 3: After the data is modified and aggregated in step 2, it is pre-processed, then standardized in this step before it is moved to the cloud or data center.

Step 4: Finally in step 4, the data is analyzed and managed at the needed level. Advanced analytics, is applied to the data, bringing actionable business insights for good decision-making.

The above sketch is the flow of data in the IoT system, but the expanded architecture is shown below in Figure 2 with five layers.

Perception Layer (Sensing systems that collect data): IoT is built on the basis of technologies that enable perception and identification and are very core to the architecture. The sensors here have the ability to perceive alterations in an environment and may include, RFID, cameras, medical sensors, infrared sensors, smart device sensors, and GPS. These sensors permit perception via object, geographic, and location recognition, and can transform this into digital signals, which is preferred for network channeling [32-34]. Sensor technologies permit real-time monitoring of treatments and also facilitate the gathering of a good number of physiological vitals about a patient for diagnoses in addition to high-quality care fast-tracking. Multitudes of instances of prospective lifesaving IoMT sensor devices are available, nevertheless, not all of them have passed the required clinical test or have been proved to be clinically effective or safe thus they are at the trial stage.

Network Layer (Data communication and storage): This level comprises not only wired but also wireless networks, with the ability to pass on and preserve processed information of the first layer (perception) locally or at a designated centralized location. In IoT, communication between the component devices can take place over low, medium, as well as high frequencies, the latter being the more prominent. They are categorized into short-range communication technologies, like Bluetooth, RFID, low-power Wi-Fi, wireless sensor networks, Zigbee, and the Global System for Mobile Communications (GSM) [32]. However, high-frequency 4G and 5G networks have given better communication prospects making the IoMT easily available and 6G will do more with the expectation that they become the major driver of IoMT growth and applications. This has the prospect to provide a dependable connection for thousands of devices simultaneously [35].

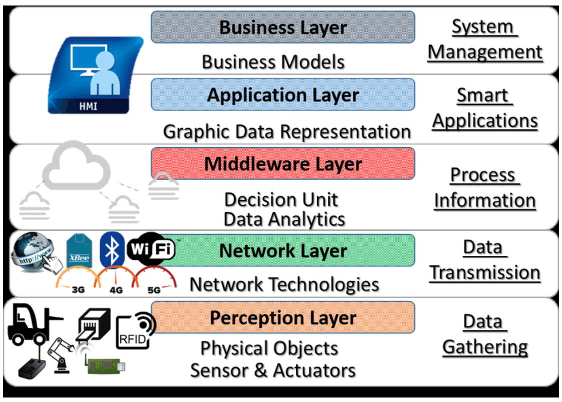

Figure 2: The architecture of IoT

Middleware Layer: This layer has some newfangled features such as storage, processing, computation, analysis, action-taking capabilities, and many other similar features. The tasks handled by this layer are categorized into the data accumulation stage and the data abstraction stage. It stores all the sets of data based on the device's address and name while giving the right data to that device. It also takes decisions based on calculations or analysis done on the data obtained from sensors. In some other five-layered architecture, it is termed the processing layer [36-38].

Application Layer: This layer interprets and works at applying data therefore it shoulders delivery to the user application-specific services. One of the voyages with the most auspicious medical applications provided by the IoMT is AI. Its exertion have escalated, covering image analysis, drug activity design, text recognition, and prediction of gene mutation expression [39]. By leveraging EMR data such as medical history, imaging, laboratory results, physical examination reports, and medications, AI can analyze and interpret this information to inform potential diagnoses, treatment decisions, or other relevant possibilities.

Business Layer: It is known that the success of any device depends not only on the technologies used in it but on the manner it is being delivered to its consumers as well. This layer is saddled with the task of handling how the technology is delivered to the consumers of the device. It involves making flowcharts, diagrams, graphs, analysis of results, how the device can be improved, etc. It is the business logic of the model, the information generated from the preceding layers is given value in this layer as they are used for problem-solving in order to achieve the business goals.

The architecture of IoT is the basic for IoMT [40] used in healthcare delivery, but it essentially consists of 3 basic layers carved out from the 5 layers of the general IoT architecture: (1) the perception layer, (2) the network layer, and (3) the application layer. The other layers act as subs in these major identified layers. Although there is no single consensus on architecture for IoMT as well as IoT, which is agreed upon universally, different architectures have been proposed by different researchers with various viewpoints from the researchers [26], [28], [36], [41-44].

2.2 IoT Standards and Frameworks

There are many emerging IoMT standards seen also in IoT generally, they and their brief description are:

- 6LoWPAN an open standard defined by the Internet Engineering Task Force (IETF) permits the communication of any low-power radio to the internet, including Bluetooth Low Energy (BLE), 804.15.4, and Z-Wave (for home automation) [45-49].
- ZigBee is a wireless network commonly used in industrial environments that operates on low power and low data rates, following the IEEE's 802.15.4 standard. Dotdot, created by the ZigBee Alliance, is a universal language for IoT, including IoMT, which facilitates secure communication between smart devices on any network by ensuring they can understand each other well [49-57].
- LiteOS a Unix-like OS for wireless sensor networks has good support for wearables, intelligent manufacturing applications, smartphones, and smart homes including another sub-system of IoT called the IoV. The OS has the capacity to serve as a smart device development platform as well [58-63].
- OneM2M is a service layer for machine-to-machine communication that can be integrated into both software and hardware to connect devices. Established as a global standardization body, its aim is to develop standardized protocols that can be reused to facilitate communication between IoT applications in different verticals [64-73].
- DDS was developed by OMG and is an IoT standard for real-time, scalable, and high-performance M2M communication [74].
- To achieve asynchronous messaging through wire, AMQP was developed as an open-source published standard. This enables encrypted and interoperable messaging between applications and organizations. Although it was initially used for client-server messaging, it is now utilized for IoMT device management [88-101].
- CoAP: This protocol is designed by the IETF to specify how low-power and compute-constrained devices can operate in the IoMT [82] [89-95].
- LoRaWAN is a protocol for WANs designed to support huge networks, such as smart cities, with millions of low-power devices [109-120].

With the above standards and frameworks, the state-of-the-art of IoT has a much simpler technology that helps in enabling it to perform its tasks successfully. This technology is quite basic for all aspects of the IoT incorporating all the frameworks and standards as shown in Figure 3.

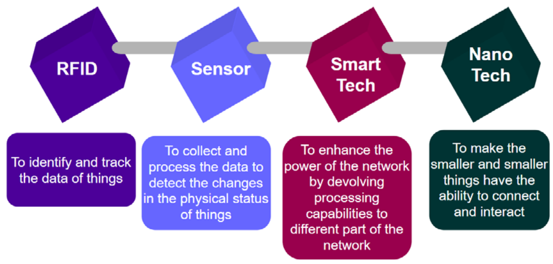

Figure 3: Enabling technology of IoT

Other subsidiaries of the IoT then include other technologies that will ensure that it performs optimally. For example, the Internet of web things [108], [109], or the Web of Things as it is also called can have the addition of some other technologies within this one to achieve its implementation. The details of the technologies on the internet of medical things are described in the following section.

3. IoMT healthcare technologies

Apart from the general enables shown in Figure 3 above, there are many enabling technologies for IoT-based healthcare solutions that are included on the basis of need, and therefore it is difficult to prepare a clear-cut list for that. With this regard, the discussion turns attention to several core technologies with the prospect of revolutionizing IoMT very useful in healthcare services.

Cloud computing: The integration of cloud computing with IoMT technology has the potential to provide access to shared resources globally, enabling services to be delivered on demand through the network and performing operations to meet diverse requirements.

Grid computing: To address the limited computing capability of medical sensor nodes, grid computing can be integrated into the global health network. Cluster computing, which is the foundation of cloud computing, can provide the necessary backbone for IoMT making grid computing an essential component of IoMT.

Big data: Large volumes of critical health data obtained from a variety of medical sensors can be categorized as big data, and this data can be leveraged to enhance the effectiveness of relevant health diagnosis and monitoring methods and stages.

Networks: The physical infrastructure of the healthcare network based on IoT includes various networks, ranging from those intended for short-range communications such as WPANs, WBANs, WLANs, 6LoWPANs, and WSNs to long-range communications, like any type of cellular network. Furthermore, the use of technologies such as UWB, BLE, NFC, and RFID can assist in the development of low-power medical sensor devices and communication protocols.

Ambient intelligence: The utilization of ambient intelligence is essential in healthcare networks since the end-users are humans, such as patients or health-conscious individuals. Ambient intelligence can continuously learn human behavior and take necessary actions triggered by identified events. Integrating autonomous control and HCI technologies into ambient intelligence can additionally improve the potential of IoT-supported healthcare services.

Augmented reality: Augmented reality is a significant aspect of healthcare engineering within the IoT. It has practical applications in areas such as surgery and remote monitoring.

Wearables: Adopting wearable medical devices as landmarks can aid in patient engagement and improve population health through three key advantages: connected information, healthcare communities with specific goals, and the application of gamification.

The implementation of the technologies functions in a concerted manner in the following way. The data that has been communicated is stored locally (usually decentralized) or sent to the cloud server (centralized). Cloud computing can offer numerous advantages in supporting the provision of healthcare services, including its ability to be widely available, adaptable, and capable of expanding to accommodate the collection, retention, and transmission of data between devices linked to the cloud [110]. Cloud use is futurized to support data-intensive EMRs, medical IoT devices, patient portals, and big data analytics gaining decision support systems and therapeutic strategies [9]. As an increasing number of cloud-based applications are being used in the healthcare industry, it is essential to have evidence supporting their effectiveness and safety. Additionally, there is a need to address security concerns related to health data, as well as ensure the reliability and transparency of data accessed by third parties. Additionally, it has been proposed that centralized cloud storage will become challenging in the future for users, with challenges in the region of excessive data accumulation together with latency as a result of the distance between IoMT devices and data centers.

It has been ascertained that decentralized data processing in addition to networking approaches will enhance the scalability of IoMT. Edge cloud is although a newer cloud computing concept that permits IoMT sensors including network gateways not only to process data but also to analyze data themselves that is to say, at the edge and in a decentralized manner, bringing reduction to the amount of data needed to be communicated and also managed at a centralized location [32], [111]. In the same fashion or in a similar way, blockchain storage makes use of a decentralized method of data storage, creating blocks that are independent and containing individual information sets, forming a dependent link in a block that is collective. This in turn creates a network that can be regulated by patients in lieu of a third party [112]. According to [113], some notable platforms are already engineering blockchain technology for medical practice; that notwithstanding, research on edge cloud and blockchains in the area of healthcare is still virgin and is an important area for future research.

3.1 IoMT services and applications

IoMT applications refer to specific software programs or solutions designed to perform specific tasks or functions within the healthcare domain. These applications leverage the data collected from medical devices and utilize it to provide various functionalities, such as remote patient monitoring, health tracking, diagnostics, treatment planning, and patient management. IoMT applications are built to address specific healthcare needs and are typically tailored to specific user groups, such as patients, healthcare providers, or researchers. IoMT services, on the other hand, encompass the broader infrastructure and support systems that enable the functioning of IoMT applications. These services can include data storage, data processing and analytics, cloud computing, connectivity solutions, security protocols, interoperability standards, and communication networks. IoMT services provide the underlying framework and resources required to facilitate the seamless operation and integration of

IoMT applications. They ensure the secure and efficient transmission, storage, and analysis of medical data generated by IoMT devices.

The IoMT has various applications, including managing chronic diseases, caring for pediatric and elderly patients, and private health and fitness management. To facilitate understanding, this review divides the discussion into two aspects: services and applications. Applications are further divided into two groups: single-condition and clustered condition. Single-condition applications focus on a particular disease or infirmity, while clustered-condition applications deal with multiple conditions together as a whole. The categorization is shown in Figure 4 below. It is important to note that this classification structure is not exhaustive and is based on the available healthcare solutions using the IoMT. Additional services with distinct features and many applications covering not only single but also clustered-condition solutions can be included. This section provides an overview of each of the services and applications.

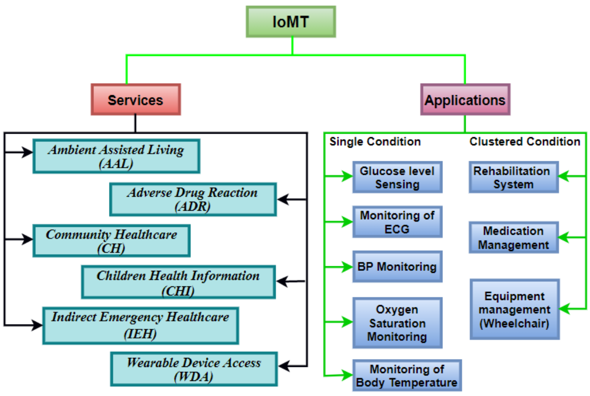

Figure 4: IoMT Applications and services

3.1.1 IoMT services

The IoMT has the potential of enabling a variety of services that are healthcare-based in which every service makes available a set of solutions in the health sector. It is worth noting that in the context of healthcare, there is no generally accepted definition of services referred to as IoMT services, however, on some occasions, a service may be difficult to be objectively separated from a certain application or solution. This review makes the assumption that service is in the generic sense and naturally with high potential to be the essential component for a solution set or a set of applications. Furthermore, it is worthy of note that the generic services, as well as the protocols needed for IoMT frameworks, may as well need some little adjustments for their proper functioning in healthcare or IoMT scenarios. These may constitute notification services, cross-connectivity protocols to serve non-homogenous devices, internet services, resource-sharing services, and link protocols for the connectivity that is major. The other thing that can be added to the list includes a secure, fast, easy, and low-power discovery of both devices and services. However, the details of such generalized IoMT services are not covered in this review but are just mentioned.

Ambient Assisted Living (AAL): Generally speaking, neither in the plan of smart homes nor a standard IoT-based medical service is fatedly proposed to exclusively offer specialized services to seniors or elderly individuals, thus, a separate IoT service is obligatory. An IoMT platform empowered by AI that can help in addressing the healthcare of incapacitated individuals and the aged is called what is referred to as AAL. The AAL plans or purpose to extend the free life of elderly people in their abode in a manner that is more convenient and safer. Solutions provided by AAL services make available strong confidence to the elderly people by ensuring better autonomy in addition to providing them with a sort of human-servant-like help in case of any challenge. Many studies have discussed the use of AAL on the basis of IoT and IoMT [114-121]. A modular architecture for the purpose of automation, control, security, and communication is proposed for IoT-based AAL by Shahamabadi, et al [122]. This architecture is a framework exclusively designed for the provision of healthcare services to the elderly as well as incapacitated individuals. As some basic technology for the implementation of this architecture is needed, some of them are 6LoWPAN employed for active communications, and RFID, as well as NFC, for the purpose of passive communications. This architecture since its inception has received several expansions through the incorporation of algorithms that are on the basis of medical knowledge to achieve the detection of the problems faced by the elderly. The other issues related to how the central AAL paradigm can be realized over the IoMT have been analyzed by some authors including [115], [123-126], and it has been said from findings that an amalgamation of KIT smart objects with closed-loop healthcare services can promote AAL. Then the infrastructure that was obtained can be employed in IoMT to permit communication between stakeholders like the elderly, physicians, caregivers, as well as family members of the elderly and incapacitated individuals. These endeavors have prompted researchers towards developing protocols that can enable KIT smart objects and closed-loop healthcare services to function through the IoMT [127].

Adverse Drug Reaction (ADR): This may happen after a single dose of a drug is taken or when it is administered for a prolonged time or as a result of a mixture of two or more drugs since it is concerned with injury resulting from the consumption of medication or some medications [128]. For the fact that ADR is essentially generic, in other words, not specific to the medication for a specific ailment or disease, the need to distinctively design some common issues that are technical and their solutions found and called ADR services arose. This prompted the proposal of an IoT-based ADR in [129] which is categorized as an IoMT service. Here the sensor at the patient's end or terminal identifies the medication in the form of drugs by means of a device that is barcode/NFC-enabled or the EPC global services then, using the pharmaceutical information system that is highly intelligent, the obtained information is organized to sense if the drug has any compatibility with its proposed allergy profile as well as electronic health record. One of the prominent development is the iMedPack as a constituent of the iMedBox to handle the ADR as reported by [130] use of RFID and technologies known as CDM.

Community Healthcare (CH): The monitoring and management in the community healthcare perspective come along with the concept and aim of establishing a network that envelops a stipulated area around a community, usually a local one. This may be seen as an IoMT-based network covering a hospital in a municipality, a residential area, or a rural community [131-134]. If similar networks are concatenated in the right manner, there will be a realization of a network that is structured cooperative. In this respect, a specialized service is inevitably needed for the purpose of attaining collective requirements in the form of a package and CH can embody it. An IoMT platform that is cooperative for rural healthcare monitoring was proposed [135] and has shown to be very energy-efficient. Here it is required and expected that there will be an incorporation of a distinct authentication and authorization mechanism into the network since it is a cooperative one. A similar proposal called community medical network was made by You et al [136] with a description of its architecture and implementation. Multiple WBANs are integrated into this network to materialize CH. The community medical network is structured to be viewed and function as a “virtual hospital." A service platform called resident health information service which is based on a four-layer structure called a functional framework has received consideration for implementation in CH, alongside a technique for the purpose of data sharing between medical facilities, in addition to the service platform for getting health records and having access to remote medical advice [137].

Children Health Information (CHI): It is quite crucial to raise appropriate awareness concerning the health of children and ensure that the general public in addition to children themselves have adequate and correct knowledge and information on the requirements of children with a behavioral, emotional, or mental health challenge and those of their family members. This intuitively triggered the development of a specialized IoMT called CHI by researchers to address this need effectively. With respect to that, an interactive totem is often stationed in a pediatric ward to the end of giving services that are CHI-based with the sole aim of not only educating, and amusing children, but also empowering hospitalized children [138], alongside an IoMT service that has the capacity to encourage children to imbibe good habits of eating with the aid of their teachers and parents who are usually present with them at the hospital [139-142].

Wearable Device Access (WDA): Many sensors that are nonintrusive have been developed for application in various medical fields, particularly for healthcare services that are WSN-based [143-145]. These sensors are prospective enough to give similar services through the IoMT. Alternatively, wearable devices can be developed with a set of characteristics that are desirable and appropriate for the IoMT architecture and applicability. Therefore, the inculcation of the sensors mentioned before into wearable products meant for health purposes is perceptible. However, the nature of wearable products which is characterized by heterogeneity and medical sensors unveils numerous challenges for those in the field of research as well as developers who are working toward the mentioned integration. Therefore, to achieve it, a dedicated service known as WDA is needed. Incorporating wearables into IoT applications that use WSNs results in a prototype system that can be utilized in numerous healthcare applications via different mobile computing devices, such as medical sensors, smartphones, smartwatches, and communication technologies that support healthcare services [146-148].

Indirect Emergency Healthcare (IEH): Numerous emergencies involving healthcare issues are known, including transport (aviation, vehicle, and train) accidents, adverse weather conditions, fire, and earthen site collapse, among others. In issues of this type, a dedicated service known as IEH can offer loads of solutions like information availability, post-accident action, alter notification, as well as record-keeping. IoMT can be employed with respect to this area to help in enhancing the duties of emergency workers [148-153].

3.1.2 IoMT healthcare applications

Apart from the IoMT services mentioned above, applications that are IoMT-based deserve to be studied closely checking how fitting they will be to the IoMT. It is noticeable that services are the drivers for the development of applications, while applications are used directly by users as well as patients. Services, therefore, can be said to be developer-centric, while applications can be seen as user-centric. Besides the applications discussed in this section, various wearables, gadgets, and other devices that are currently obtainable in the market are discussed. These products can be considered IoMT innovations that can pilot various solutions to healthcare problems. The next things to address are various applications that are IoMT-based, including single- and clustered-condition applications.

Glucose Level Sensing: The monitoring of the blood glucose and recording helps to decipher the pattern taken for the changes experienced or seen in the blood glucose of an individual which consequently helps meal planning, activities, and times of medication [154-156].

In line with that, Istepanian et al [157] proposed an IoMT configuration method that can achieve real-time noninvasive glucose sensing. The method they described uses sensors from patients linked via IPv6 connectivity to connect to the appropriate healthcare providers. To serve as a transmission device, appropriate models one of which was referred to as the utility model in [1] were employed to achieve a successful transmission of gathered somatic data of blood glucose based on IoMT networks. This device comprises a collector of the blood glucose, a phone (mobile) or a computer, and a processor that works in the background. Similar technology or the technology in a slightly modified manner was used by [158-163] to achieve glucose level sensing. With this device and those that function in a similar way, emergency situations resulting from diabetes will be reduced and life prolonged.

Electrocardiogram Monitoring: The task of monitoring the electrical activity of the heart as collected and recorded by electrocardiography popularly called the ECG, comprises the assessment or estimation of the simple heart rate and the ascertainment of the basic rhythm together with the diagnosis of myocardial ischemia, multifaceted arrhythmias, and prolonged QT intervals [164]. The incorporation of the IoMT into the monitoring of ECG has the likelihood of providing maximum information and can be utilized to its fullness [165]. The IoMT-based ECG monitoring system in its basic form includes a wireless acquisition transmitter that is portable and a wireless receiving processor. The system is to integrate a technique that is search automated for the purpose of detecting abnormal data so that the cardiac function can be noticed in real-time. At the application layer of the IoMT network for ECG monitoring there exists an algorithm that is said to be comprehensive detection for ECG signals. Some authors who researched and reported ECG monitoring using IoT include [130], [136], [166-170].

Blood Pressure Monitoring: The strategy of how a KIT BP meter in combination with a KIT mobile phone that is NFC-enabled is used for the purpose of monitoring BP anchored on the IoMT paradigm was stated in [123], [171]. A motivating case in which BP has to be controlled remotely as a matter of compulsion and on regular basis is presented by displaying the communications structure found between a health post and the health center [172]. In another work, the issue regarding how the Withings BP device works is dependent on the connection it has to a mobile computing device preferably Apple as stated in [19]. In [173] a device for the collection of BP data as well as its transmission over an IoMT network was proposed, this proposed device comprises a BP apparatus body that has a communication module among other general components of an IoMT device. In some other pieces of literature, a terminal for carry-on BP monitoring is location-intelligent or some have a similar function based on the IoMT was proposed in [174-176].

Oxygen Saturation Monitoring: For the purpose of monitoring the saturation of blood oxygen in a nonstop and noninvasive manner, pulse oximetry is quite suitable. Therefore, for application in technology-driven medical healthcare systems and scenarios, combining the IoMT with pulse oximetry is beneficial. The inherent prospects of the IoMT-oximetry combination were discussed in the light of CoAP-based healthcare services in the survey of Khattak et al [177-178]. The device known as a wearable pulse oximeter Wrist OX2 has its function shown in Jara et al [179] for example and it comes with Bluetooth-enabled connectivity and is based on a health device profile that works with Bluetooth while the sensor of the device links directly to a platform called the Monere. This engineered the proposal of an IoMT-optimized low-power and at the same time low-cost pulse oximeter designed for monitoring patients remotely [180-181]. Over an IoMT or IoT network generally, this device has the capacity to be employed for the continuous monitoring of the health of patients. A wearable pulse oximeter that can monitor and record health data using the WSN with adaptation to the IoMT network is also feasible, as is a system of integrated pulse oximeter for application in telemedicine [182-184].

Rehabilitation System: Physical medicine and rehabilitation are crucial areas of medicine that focus on enhancing and recovering the functional capacity and overall quality of life for individuals with physical disabilities or impairments [185-189]. The potential in IoMT to improve the rehabilitation systems focuses on addressing the challenges that concern such people as the aging population in addition to the notable shortage of health professionals in the field [190-194]. A design of an ontology-based automation method for smart rehabilitation systems is IoMT-based, and also demonstrates that the IoMT has the capacity to be an effective platform for the purpose of integrating all relevant resources to provide real-time information interactions [190], [195]. IoMT technologies offer promising infrastructure for remote consultation in comprehensive rehabilitation. A range of IoMT-based rehabilitation systems are already available, such as an integrated application system for prisons, training systems for hemiplegic patient rehabilitation, a smart city medical rehabilitation system, and even a language-training system designed for children with autism [196-197].

Medication Management: Noncompliance with medication poses a severe hazard to public health and wastes a lot of money all around the world. The IoMT offers some intriguing solutions to this problem [198-200]. In [197] a proposal of an intelligent method of packaging medicine boxes for the purpose of managing IoMT-based medication was made. This method of packaging utilizes materials that are able to delaminate and are controlled through wireless communication to achieve controlled sealing. Additionally, [201] presented an eHealth service architecture that is based on RFID tags for a medication to control the proposed system over the network of IoT. This ubiquitous medication control system implemented as a prototype is intended specifically to make provision for AAL solutions.

Wheelchair Management: Several resources in various forms [202-206] have been invested in developing smart wheelchairs that are fully automated to serve the disabled. Although enormous resources have been invested here, the corresponding output is still below expectations, yet the IoMT has all it takes to advance the pace of the work done in this direction. A system in healthcare for the users of wheelchairs whose basis is on IoMT technology is supposed to be designed with WBANs with the integration of various sensors tailored to IoMT requirements for functionalities. A medical system considering P2P and IoMT technology has found implementations where they make provision for wheelchair vibration control in addition to the ability to detect the state of the user of the wheelchair. The connected wheelchair developed by Intel's IoT section is a notable example of IoMT-based wheelchair development [207]. This breakthrough demonstrates that ordinary "things" can eventually grow into data-driven networked machines. This device has the ability to monitor the vitals as it is called of the person sitting in the wheelchair in addition to the collection of data on the surroundings of the user. With these, the device, therefore, is enabled to allow for a rating of the accessibility of a location or site.

4. Healthcare solutions using smartphones

The emergence of smart devices other than smartphones possessing smartphone-controlled sensors in recent years, emphasizes the emergence of smartphones as potential and trusted drivers of the IoMT and IoT in general [208]. In various forms, not only hardware products but also software products are designed to ensure that smartphones have versatile capabilities for implementation in healthcare scenarios. The healthcare apps in smartphones can be apps for patients and general healthcare apps, as well as those focused on medical education, information search, training, and others (generally known as auxiliary apps), were reviewed in [209] by Mosa et al. However, there are other platforms with the capability of serving similar purposes but are not mobile apps. The apps that have the potential of being used as IoMT is classified into diagnostic apps which can be used to access both diagnostic information as well as treatment information, drug reference apps are designed to provide the names of drugs, the associated dosages based on body weights, their indications, and other identifying features including the relative cost. Literature search apps are designed to accelerate the search for related biomedical literature from databases to get adequate and appropriate medical information. While medical education apps primarily deal focus on training, tutorials, various demonstrations of surgery, medical books, and others. The other apps that can be referred to as calculator apps come alongside many useful and needed medical formulas and equations for the calculation of various parameters of interest (such as BMI). Clinical communication apps are designed to make communication between clinicians within a hospital much easier and better by simplification of communication [210-217]. In addition to phone-based apps, cloud-based algorithms for image analysis can be used on smartphones to achieve non-contact measurements and this may be very useful for healthcare applications. Smartphones of these contemporary times have the ability to effectively carry out both the diagnosis and/or monitoring of the following: asthma detection, a pulmonary disease especially the chronic obstructive ones, coughing, cystic fibrosis, respiratory tract ailments especially those with symptoms that are nose-related, the heart rate, allergic rhinitis, BP, oxygen saturation of the blood, and melanoma in addition to the analysis of wounds in patients with advanced diabetes[180], [183-184], [218-223]. Apart from its capability to be ubiquitously deployed and its availability for users, the other great advantage possessed by the use of smartphone healthcare apps is that it provides solutions that are more affordable since they are considered low-cost solutions. Despite that, certain notable challenges are yet to be addressed which are in the region of power consumption, computational complexity, and noisy environments in the surroundings of smartphones. Some mobile applications that are popular in healthcare and their operability are shown in Table 1 below.

A number of other portable medical devices can be seen although with no clear-cut show of their integration into the networks of IoMT. While with the advances in research, it will only be a matter of time before these devices become enabled with IoMT functions. Also, it is worth noting that the increase in the number of healthcare devices, applications, and cases has not met the ever-growing demand for IoMT-based services in the global sense of it and opens doors for further research. That notwithstanding, some of the areas in healthcare where integration of IoMT seems imminent have been identified as follows detection of hemoglobin, skin infection, peak expiratory flow, cancer treatment, abnormal cellular growth, eye disorder, and remote surgery [224-230].

Table 1: The list of popular healthcare applications and their operability

Infirmity or health condition	Sensor(s) used, the operation of the sensor, and the IoMT roles/connection
Diabetes	Non-invasive Opto-physiological sensor, the output of the sensor is fused to a TelosB mote that transforms the signal from analog to digital; IPV6 and 6LoWPAN permit the wireless sensor devices for all IP-based nodes.
Analysis of wounds for patients with advanced diabetes	A camera (smartphone), decompression, and segmentation of image; the smartphone's SoC is where the app runs to drive the IoMT.
Monitoring of the heart rate	The sensor comprises capacitive electrodes that are crafted on a printed circuit board; a digital chain connected to a wireless transmitter is digitized above the electrode where it is transmitted; BLE and Wi-Fi connect devices via a gateway.
Body temperature monitoring	A body temperature sensor that can be worn; temperature measurement on the skin; WBAN connects devices via a gateway.
BP monitoring	A BP sensor that can be worn; oscillometric and automatic inflation plus measurement; WBAN connects devices via a gateway.
Rehabilitation system	Sensors of wide range use in the form of wearable and/or smart home sensors; cooperation, coordination, corporation, event detection/tracking, reporting, as well as giving feedback to the system; a heterogeneous wireless network that is interactive allows devices with sensors to have many access points.
Medication management	The delamination objects take the form of sensors, and they are combined with a set of wireless sensors that detect touch, humidity, and carbon(iv)oxide. These wearable sensors record vital signs and enable diagnosis and prognosis. Additionally, the system includes GPS, database access, web access, RFIDs, wireless links, and multimedia transmission.
Wheelchair management	The sensor is WBAN like accelerometers, ECG, and pressure; nodes for signal processing, realizing abnormality, communicating with sink nodes wirelessly, and perceiving surroundings; devices and data center layers with non-homogenous connectivity.
Oxygen saturation monitoring	Nonin's wrist pulse oximeter is equipped with intelligent pulse-by-pulse filtering technology and can be integrated into various clinical environments to provide ubiquitous monitoring capabilities.
Eye disorder and skin infection	Cameras of smartphone; pattern matching with a standard library of images or visual inspection; the app assisted by the cloud platform runs on the smartphone's SoC (System on Chip) to the IoMT.
Asthma, chronic obstructive pulmonary disease, and cystic fibrosis	The audio system of smartphones; estimates the rate of airflow rate outputs flow per time, volume per time, and flow per volume graphs; the apps run the SoC of smartphones to drive the IoMT.
Cough Detection	The audio system of smartphones; the analysis of recorded spectrograms and the classification of random forest ML; the apps run the SoC of smartphones to drive the IoMT.
Allergic rhinitis and nose related symptoms	The audio system of smartphones; speech recognition and support vector machine classifier; the apps run the SoC of smartphones to drive the IoMT.
Melanoma detection	This process involves using the camera of a smartphone to detect suspicious patterns on the skin, which are then matched with a library of images of cancerous skin. The applications utilize the SoC of smartphones to power the Internet of Medical Things (IoMT).
Remote surgery	The surgical robot systems incorporate augmented reality sensors, robot arms, a master controller, and a feedback sensory system. These components work together to provide telepresence, real-time data connectivity, and an information management system. The feedback system helps ensure that the user receives appropriate feedback while using the robot system.

In addition to the above-mentioned applications that are used for IoMT, the design and program of many apps of great importance that are in use today have been ongoing. Although some of them need the cooperation of other technologies and have the need for a good OS to operate, some of the smartphone apps that are used in general healthcare are as follows.

Some apps known as Health assistant which tracks the major paramters of the body that are biomarkers such as glucose, temperature, blood pressure and others. Some are designed to search for pediatricians by location and request their service for quick response. Some are designed to keep track of the walking, running and cycling activities of the user while some are designed to count the steps of the user like Noom walk and Pedometer which also checks the calories utilized. For the use by females, period calendar assists the user to achieve or prevent pregnancy by tracking the best periods, cycles, and ovulation dates.

Heart-related apps include cardiomobile that monitors cardiac rehabilitation remotely on a real-time basis, including heart rate monitor and runtastic heart rate. ElektorCardioscope app displays ECG data through a wireless terminal while Cardiax Mobile ECG is designed to serve as a complementary app for Cardiax Windows' full-scale, 12-channel PC ECG system. Instant heart rate app is made to measure the heart rate utilizing the camera of the smartphone to sense the variation in the fingertip's color, which corresponds to pulse.

Blood Pressure (BP) watch is a device that collects, tracks, analyzes, and shares BP data. A similar app - Finger blood pressure prank measures the BP from fingerprint. From the fingerprint, the body temperature can also be ascertained by using the Finger Print Thermometer app. For the tracking of blood glucose as well as the prognosis of the medical disorder, on track diabetes app is developed. To aid the appropriate use of pills and medicines, Medisafe Meds and Pills Reminder app and Dosecast medication reminder app were developed to remind users of the medicine times with the latter having extra capacity to track the inventory and maintains a log for drug management.

There are also other apps in different categories include iOximeter for calculating the pulse rate, eCAALYX designed monitor chronic conditions, uHear and Test your hearing apps were made for getting hearing data as well as the assessment of the hearing. While sleep aid app helps to manage sleep apnea, real noise 3 app is designed to help users stay focused even in a noisy environment. Apps categorized as eye care plus tests and monitors vision. Some of these apps are already in use while others are still in the pilot stage of development and/or testing.

4.1 Categories of the devices

In another attempt to categorize these devices into the where and how their functionalities are required, the following was birthed; On-Body, In-Home, Community, In-Clinic, and In-Hospital Segments

4.1.1 On-body segment

Abroad categorization of on-body wearables is possible, including consumer health devices and medical-grade devices.

Consumer health wearables encompass all devices that are consumer-grade employed for personal fitness or wellness, like activity trackers, bands, smart garments, wristbands, and sports watches. A good number of the devices in this category are not regulated by any health authorities, however, some of them have experts' endorsement for particular health applications on the basis of informal clinical validation together with consumer studies. Companies operating in this space include Misfit (Fossil group), Samsung Medical, Withings, and Fitbit [231-235].

Clinical-grade wearables refer to wearables that are certified and approved for use by regulatory or health-related authorities, such as the FDA. These wearables are comprised of regulated devices and supporting platforms that meet specific standards and regulations. A good number of these devices are used according to experts' advice or a physician's prescription. Some examples include Active Protective's smart belt, which detects falls and deploys hip protection for elderly wearers; Halo Neuroscience's Halo Sport headset, which is worn during workouts and physical training to stimulate brain areas responsible for muscle memory, endurance, and strength; and Neurometrix's Quell, a wearable neuromodulation device that provides relief from chronic pain by targeting sensory nerves [236-240].

4.1.2 In-home segment

The in-home segment comprises RPM, PERS, and telehealth virtual visits.

A PERS incorporates wearable devices and/or relay units alongside a live medical call center service to enhance self-reliance for individuals or seniors who are homebound or have limited mobility. This makes it possible for users to communicate and receive emergency medical care [241-243].

RPM encompasses all devices and sensors in the home with monitoring capacity which can be used for the management of chronic diseases [244-245]. It requires continuous monitoring of parameters physiologically, most importantly to support the care of patients in their homes on a long-term basis in an effort to make disease progression slow [246-250]. In addition to that, it helps to achieve acute monitoring in the homes, for continuous observation of patients who have been discharged in order to accelerate recovery and avoid re-hospitalization and management of medication, to reminder about the mediation to the users as well as information about the dose in order to improve adherence and outcomes [251-

253].

Telehealth virtual visits include consultations that are reachable virtually with the capacity to help patients manage their conditions, get prescriptions, and obtain recommended care plans [254-258]. Examples of this may include consultations on video and symptom evaluation or lesions via video observation and digital tests.

4.1.3 Community segment

In this segment, there are five components which are mobility, emergency response intelligence, Kiosks, point of care devices, and logistics.

Mobility services are designed to permit passenger vehicles to track health parameters in transit [259].

Emergency response intelligence is constituted to help first responders, hospital emergency departments, as well as paramedics, and care providers [260-262].

Kiosks are components with physical structures, usually with computer touchscreen displays, with the ability to dispense products or provide services like connectivity to the care providers [263-264].

Point-of-care devices are classes of medical devices that a care provider uses outside of the home or outside well-known healthcare settings, like at a medical camp [265-267].

Logistics refers to the transportation and delivery of healthcare products and services, including medical supplies, pharmaceuticals, medical equipment, and devices, as well as other necessary items for healthcare providers [268-271]. IoMT applications in logistics include temperature, humidity, shock, and tilt sensors in pharmaceutical shipments, end-to-end solutions with RFID and barcode tracking for personalized medicine delivery to cancer patients, and drones that enable faster last-mile delivery.

The IoMT ecosystem expansion is surely paving the way for some new technologies too, like kiosks that enable connectivity to care providers. These kiosks function to allow clinicians not only to monitor but also to treat patients remotely. This has been regarded as an ever-growing requirement for patients who reside in rural communities as they have difficulty recruiting and retaining medical specialists. The location and condition of patients will be the least worry since the evolution of the IoMT ecosystem will grow increasingly impactful. And the targeted beneficiaries are those who live in the most remote locations far from better access to care, as medical devices connected continue to find their access into the hands of clinicians and patients alike.

4.1.4 In-clinic segment

This segment encompasses IoMT devices that are mainly used for administrative or clinical functions (either in the clinic, at the point of care, or in the telehealth model). The point-of-care devices mentioned in this segment differ from those in the community segment in this regard: other than the care provider using a device directly and physically, he or she can be stationed remotely while a device is used by trained staff [272-274]. Examples are Rijuven’s Clinic in a Bag – a cloud-based examination platform used by clinicians to check patients at any point of care; ThinkLabs’ digital stethoscope; as well as Tytocare’s comprehensive telehealth patient examination device for the heart, ears, lungs and throat, skin, and abdomen, which also has the ability to measure temperature.

4.1.5 In-hospital segment

The segment can be divided into two categories: IoMT-enabled devices and a broader range of solutions related to various management areas:

Asset management: This does not only monitor but also tracks high-value capital equipment as well as mobile assets, like wheelchairs and infusion pumps, throughout the facility [275-276].

Personnel management: This measures both the efficiency and productivity of members of staff [277-278].

Patient flow management: This works at improving facility operations by helping to avoid bottlenecks while enhancing patient experience. For instance, monitoring the arrival times of patients from an operating room through post-care to a wardroom [279-280].

Inventory management: This tries to streamline ordering, storage, as well as the use of hospital supplies, pharmaceuticals, consumables, and medical devices in order to reduce the costs of inventory and improve the efficiency of members of staff [281-284].

Environment (e.g., temperature and humidity) and energy monitoring: This oversees the use of electricity ensuring optimal conditions both in the in-patient areas as well as storage rooms.

The devices that fall under the category of innovative devices include Zoll's wearable defibrillator, which continuously monitors patients who are at risk of ventricular fibrillation or tachycardia; Stanley Healthcare's hand hygiene compliance system, which uses an occupancy sensor and a real-time location receiver to track employees' identity while using the dispenser and employs analytical methods to determine if employees are following hygiene protocols; and the Boston Children's Hospital's GPS-based app called MyWay, which guides visitors to their desired destination taking the fastest and safest route possible.

4.2 Expanding the functions and scope of IoMT to provide smart healthcare

Smart healthcare services leverage the advancements in ITs, such as IoMT, cloud computing, AI, big data analytics, and deep machine learning, to transform the traditional healthcare delivery to be a more efficient, convenient, and more personalized system [285-288]. The advancements in information and computer technologies have enabled the creation of healthcare solutions with enhanced predictive abilities, both within and outside hospital settings. The application of virtual models has made it possible to shift hospital-based care to patients' homes by utilizing sensors and devices that enable remote monitoring and assessment of patients, thereby bridging the gap between hospital and home care through cloud-based access [25]. Governments and policymakers worldwide have temporarily removed implementation and remuneration barriers in response to the 2020 public health efforts to control the spread of COVID-19. This has enabled healthcare professionals to use virtual models of care to provide necessary medical attention to patients [6]. The IoMT has the potential to enhance the efficiency and quality of the entire service delivery system, encompassing the management of hospitals, medical asset management, monitoring of staff workflow, and optimization of medical resources in response to patient flow [289-290].

In recent times the need for the implementation of a web-based medical service became very important. In the conception of the web-based medical service, patients will be able to access various health-related aids without going to the hospital physically. For this type of system, patients will create an account and agree to the policies of the platform, and input their information, especially their health history and health status. This will be kept in the cloud and in case of any health challenge of the client, the data can be accessed easily and treatment can be administered to the patient immediately. The platform is conceived to work as a recommendation system in which when a patient logs into the platform and inputs the symptoms of the ailment he or she is having, the system responds by linking the patient with an appropriate physician who will help the patient. With the symptoms, it will be easy to link the patient with the appropriate physician. The system is also supposed to have affiliation with several hospitals, medical laboratory centers as well as pharmacy shops. They will be recommended to the patients depending on their location for a physical examination if need be, for diagnosis and drug purchase as the need arises. The affiliation will be extended to counselors, it will help to make the medical field a united entity which will enhance proper treatment and better health delivery services. The platform is made smart by training a deep learning model deployable on the cloud with various symptoms of diseases including medical images for the medical practitioners who will also use the platform.

Because of the large amount of data that is conceived and generated by the implementation of this system with the IoMT devices, the edge computing paradigm will be incorporated into it to enhance the effectiveness of the system and data management.

4.3 How IoMT can improve health service delivery

The potential benefits of IoMT include enhanced precision in diagnosis, reduced errors, and decreased healthcare costs [291]. Integrating IoMT with smartphone apps enables individuals to share their health information with healthcare professionals, leading to improved monitoring of medical conditions and prevention of chronic illnesses. This not only reduces the need for in-person medical visits, but also saves money. Another good consequence of IoMT on drug management has been described as the creation of "smart tablets" with microscopic sensors that, if taken, can communicate data to linked devices. Smart pill capabilities have been focused on assessing drug treatment effectiveness to improve clinical outcomes by several digital medicine businesses, such as Proteus Discover. Others, like HQ's CorTemp, are utilizing the pills to monitor their patients' internal health, wirelessly communicating data like core temperature - metrics that can be essential in life-or-death situations.

4.3.1 Primary health care becoming more accessible

As stated in [292] and [293] the burden of disease caused by modifiable risk factors has increased significantly, emphasizing the need to prioritize disease prevention in this decade. The use of IoMT in healthcare has the potential to enhance population health and shift the healthcare system to a hybrid model of primary, secondary, and tertiary care, allowing for more effective utilization of existing staff. A majority of self-management related to lifestyle, even among high healthcare users, takes place outside of hospitals and clinical settings. Therefore, transforming healthcare delivery in this manner is essential to enhance self-management for individuals with chronic illnesses [294-295]. A substantial public demand exists for easily accessible health information. In a 2015 US survey, 58 percent (931/1604) of smartphone users said they have downloaded a health-related app to help them manage their lifestyle. AI has also accelerated the availability of point-of-care health information, such as chatbots (also known as AI physicians) that can provide lifestyle and medical advice. Woebot, Your.Md, Babylon, and HealthTap are examples of well-known AI bots that allow patients to enter their symptoms and receive immediate advice [296]. However, more than half of the top-rated apps make unapproved medical claims [297], and there is no official procedure for licensing applications or informing consumer choice [298], so there is still a lot of work to be done to fully grasp the potential of chatbots to enhance health. As a result, a trustworthy digital health evidence base is critical [299]. The availability of evidence-based digital resources, devices, and mobile apps to healthcare professionals can enable the use of digital prescriptions, which can in turn promote the wider adoption of IoT in healthcare and facilitate a shift towards disease prevention in the general population.

We are of the opinion that IoMT provides the chance to link and perhaps learn from non-health IoMT Technology and /or general IoT technology in order to track everyday activities, provide information assistance, and encourage behavior adjustments. Furthermore, IoT and data linking offer tremendous promise for transparent, evidence-based decision-making, which has the ability to modify illness trends and improve citizen well-being at a large scale. The combination of urban infrastructures, IoT technology, and cloud computing enables the collection and analysis of a massive amount of human and nonhuman data. According to [300], such data can be valuable for population-level surveillance of diseases and accidents, risk factors, and environmental conditions. Obtaining this information through the traditional human-reported disease surveillance system is challenging, but IoMT can provide a solution. This type of data could be particularly beneficial for pandemic response efforts [301]. For instance, Taiwan leverages big data analytics to analyze electronic data, such as GPS, closed-circuit video monitoring, and credit card payments, as well as personal mobile data, to effectively trace, communicate with, and isolate potential contacts during the global COVID-19 pandemic in the community [302]. IoT and data linkage have the potential to enable decision-makers to make evidence-based decisions that promote healthy environments, safe transportation systems, high-quality public services, and smart health care and emergency response systems [300][303-304].

4.3.2 Secondary and tertiary health care that is proactive, continuous, and coordinated

An IoT-based healthcare system enables total healthcare systems to transition from a reactive, intermittent, and uncoordinated model of service delivery to a proactive, continuous, and coordinated approach [305]. Such an approach is advantageous since it allows patients and healthcare providers to receive high-quality care in a less invasive and appealing manner. This shift in the healthcare landscape is also appealing to policymakers because it has the potential to greatly improve the healthcare system's efficiency (and thus reduce resource use) [306], as well as provide the healthcare system with the flexibility to shift its models of care and delivery of services as needed on an individual or population-wide basis.

5. Enablers and barriers to address for Iot-based healthcare

5.1 Enablers

Policy Support: The support of policies is one of the crucial factors that can facilitate the implementation of IoMT in healthcare. Many countries have already established policies for eHealth, which refers to the use of software and web-based programs to provide healthcare services. Moreover, some countries like China, India, Japan, the Philippines, and the United States, to name a few, have also developed relevant policies for the implementation and investment in IoMT. In addition, other countries are currently in the process of developing and investing in IoT infrastructure, which is likely to have a comprehensive impact on the implementation of IoMT in healthcare [1], [307].

Technology that is Accessible and Easy to Use: Because of the pervasiveness of technology, consumers and healthcare providers now have more access to digital materials than ever before [308]. However, health systems must be conscious of the disparities that may arise as a result of the widespread adoption of IoMT, such as persons who may not be able to buy or access technology hardware or dependable internet services due to geographic location or financial hardship. Similarly, if people don't think the technology is user-friendly, have bad connections, or don't think the effort was built with them in mind (both patients and health professionals), they are more likely to be frustrated and hesitant to utilize it as stated by [309] and [310] distinctly.

5.2 Barriers

Guidelines Focused on Cybersecurity for Strong and Durable Adoption in the Market: Cyber threats pose a significant hindrance to the widespread adoption of IoT, including IoMT [311]. Ensuring the privacy of patients is crucial to prevent unauthorized tracking and identification. As the level of autonomy and intelligence in IoT devices increases, protecting identities and privacy becomes more challenging.

Confidence and Acceptability: There is a disconnect between public knowledge and comprehension of data security in cloud-based health records. This is concerning since it is the single greatest societal danger to the adoption of IoMT. The principle of IoMT is well understood by society; however, what is less well understood by people is the actual benefit that IoMT provides to them directly in terms of healthcare [312-313]. The possibility of broken confidentiality may never go away; but, consumers' perceived benefits must overcome these worries and make them comfortably interact with IoT-supported health infrastructure [311]. Similarly, health care providers' trust and acceptance of IoMT are critical. Physicians' acceptance of technology-supported programs is influenced by various factors, such as the technology's properties (e.g., accuracy, compatibility with existing systems, and ease of use), as well as their individual attitudes and knowledge. External factors, such as patient and health professional interaction, and organization readiness, including training and reimbursement, also play a role in determining the acceptance of such programs [314].

Data Storage, Control, and Ownership

To advance IoT-based healthcare, it is necessary to have transparency and enforced regulations regarding the storage and ownership of centralized cloud data. There should be clear rules in place about who can access and control the data. For instance, does the data host have complete control over the data, or whether it can be deleted upon a user's request? There are also concerns about sharing data across states or even globally, and the need for federal regulation to ensure the privacy, security, and confidentiality of data storage. However, international hosts and suppliers may not be subject to these regulations, making it necessary to establish transparent guidelines and strategic planning to implement effective IoT-based healthcare policies and care models.

Interoperability and Standardization Protocols

The lack of interoperability and standardization of IoMT and healthcare systems pose a significant threat to the widespread adoption of IoMT for healthcare. The absence of a consensus among the industry and manufacturers on wireless communication protocols and standards for machine-to-machine (M2M) communication jeopardizes the development of IoT in the healthcare industry [315]. Without a standardized and interoperable system, the implementation of IoMT in healthcare will be greatly impeded, and it is unlikely to be researched internationally [224]. In the Internet of Things, semantic interoperability is necessary for big data approaches to enable effective decision-making processes. However, each technological startup, device, or system maker has its own architecture, protocols, and data formats, which are incompatible with the healthcare industry unless they are substantially overhauled or converted to work with hospital IoMT platforms [224]. This leads to vertical silos [316], necessitating the creation of additional features to ensure interoperability between different systems. The future and full potential of IoT-enabled healthcare depend on addressing interoperability, and some frameworks already exist [317]. Achieving interoperability across IoT platforms can provide a safer, more accessible, productive, and satisfactory experience for both clinicians and patients.

Privacy and Security: In general, IoT could open the door to hackers and the improper collection of personal data. This is not restricted to only the IoT but also to IoMT. IoT-based applications are susceptible to cyber attacks due to two main reasons. Firstly, most of their communications are wireless, which makes them vulnerable to eavesdropping. Secondly, many IoT components are energy-limited, which makes it impossible for them to implement sophisticated security measures on their own [318]. The National Institute of Standards and Technology has developed a security guide and recommendations for IoT devices that highlight the need for data security. However, it is uncertain whether this guideline can be or will be applied to IoT health devices. All these are also serious considerations in IoMT. IoT-based healthcare solutions have similar security needs to regular communications settings. As a result, in order to provide secure services, the following security considerations must be prioritized.

i. Confidentiality: to guarantee that only authorized users can access medical information, it is necessary to ensure its inaccessibility for unauthorized individuals. Furthermore, confidential messages must be resistant to revealing their content to eavesdroppers.

ii. Integrity: The goal is to prevent any unauthorized modifications to medical data during transmission. Additionally, the security of stored data and content should not be compromised.

iii. Authentication: To enable secure communication between IoMT devices, it is necessary to establish a mechanism that ensures the identity of the communicating peer.

iv. Availability: To ensure that authorized parties have access to IoT healthcare services (whether they are local or global/cloud services) even during a denial-of-service attack, it is important to focus on the survivability of these services.

v. Non-Repudiation: Non-repudiation refers to the inability of a node to deny having sent a previously transmitted message.

vi. Authorization: To ensure the security of network services or resources, it is important to ensure that only authorized nodes have access to them.

vii. Resiliency and Fault Tolerance: To ensure the security of the network, device, and information, the security scheme must remain effective even if some interconnected health devices are compromised. Moreover, the security scheme should be able to provide the necessary security services despite the presence of faults such as software glitches, device compromises, and device failures.

New challenges are presented by IoT that traditional security techniques cannot ensure. Therefore, novel countermeasures are required to address these challenges. Some of the challenges that need to be addressed to secure IoT healthcare services include as follows:

i. Computational Limitations: Low-speed processors are built into IoMT devices. In such gadgets, the CPU is not very powerful in terms of speed. Furthermore, these gadgets aren't built to execute computationally intensive tasks. In other words, they merely serve as a sensor or actuator. As a result, finding a security solution that consumes the least amount of resources while maximizing security performance is a difficult issue.

ii. Memory Constraints: The majority of IoMT devices have limited onboard memory. An embedded OS, system software and an application binary are used to activate such devices. As a result, their memory may be insufficient to carry out complex security processes.

iii. Energy Constraints: IoMT networks commonly employ small health devices with low battery power, such as body temperature and blood pressure sensors. These devices conserve energy by switching to a power-saving mode when no sensor readings need to be reported and by operating at a low CPU speed when there is no important processing to be done. Due to the energy constraint characteristic of these devices, developing a security solution that is mindful of energy consumption is a difficult task.

iv. Mobility: Healthcare devices are often mobile in nature and connected to the internet through IoT service providers. For instance, wearable devices such as body temperature sensors or heart monitors are connected to the internet to notify caregivers of the user's health status. These wearables are connected to different networks depending on the user's location, such as home or office. However, these networks have varying security configurations and settings.

v. Scalability: Designing a highly scalable security scheme that meets security requirements while accommodating the increasing number of IoMT devices being connected to the global information network is a challenging task. Moreover, as healthcare devices are mobile and may be connected to different networks with different security configurations and settings, developing a mobility-compliant security algorithm is an additional challenge.

vi. Communications Media: Health devices are typically connected to local and global networks through various wireless links, including Zigbee, Z-Wave, Bluetooth, Bluetooth Low Energy, WiFi, GSM, WiMax, and 4G/5G. The wireless channel characteristics of these networks make traditional wired security schemes unsuitable, and finding a comprehensive security protocol that can treat both wired and wireless channel characteristics equally is challenging.

vii. The Multiplicity of Devices: Health devices used in an IoMT network come in a variety of forms, from high-performance personal computers to basic RFID tags, and differ in terms of their processing power, energy consumption, memory capacity, and software features. Consequently, creating a security system that can accommodate even the most rudimentary devices is a challenging task.

viii. A Dynamic Network Topology: A health device can join an IoMT network at any moment and from any location. It can also graciously (with suitable exit notification) or disgracefully abandon a network (abruptly). The dynamic characteristics of medical devices in terms of their temporal and spatial admission result in a dynamic network topology. As a result, coming up with a security model for this type of dynamic network structure is tough.

ix. Multi-Protocol Network: A health device may utilize different network protocols to communicate with other devices within the local network and IoMT service providers over the IP network. This creates a challenge for security experts to develop an effective security solution that can cater to multi-protocol communications.

x. Dynamic Security Updates: Updating security protocols is crucial to prevent potential vulnerabilities in IoMT health devices. Therefore, it is necessary to install updated security patches. However, developing a mechanism for the dynamic installation of security patches is a challenging task.

Implementing appropriate security measures is essential for the success of IoMT. By enabling real-time health monitoring and access to patients' health data, IoMT has opened new avenues for patient care. This data is highly valuable for healthcare stakeholders as it can help them improve patient health and experiences, increase revenue, and streamline operations. In today's interconnected world, being able to leverage this digital power will be a key differentiator.

An Attack Taxonomy

The IoMT field is constantly growing with the addition of new devices and services, which creates an opportunity for attackers to develop various security threats that can compromise both current and future IoMT networks and devices. These threats are in different forms and can be challenging to predict. This report categorizes existing and potential threats based on three main properties: compromising information, host properties, and network-specific properties.

Information-Based Attacks: The manipulation and analysis of stored or transmitted health data will lead to inaccurate information, thereby compromising its integrity. These attacks include interruption, interception, modification, fabrication, and replay. Interruption attacks can cause network or healthcare service unavailability, while interception attacks threaten data confidentiality. Modification attacks tamper with health data to create confusion, and fabrication attacks inject false information to mislead the IoMT network's innocent entities. Replay attacks reuse existing messages to threaten message freshness.

Host-Based Attacks: Attacks based on host properties can take three forms, namely user compromise, hardware compromise, and software compromise. User compromise attacks involve the theft or cheating of user health devices and networks, which can reveal sensitive information such as passwords and cryptographic keys. Hardware compromise attacks involve physical tampering with devices to extract program codes, keys, and data, and reprogramming the devices with malicious code. Software compromise attacks exploit software vulnerabilities and glitch to cause IoMT devices to malfunction or become dysfunctional.

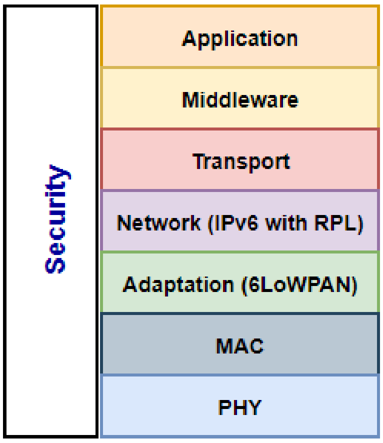

Figure 5: Network model of secure IoMT in layers

Network-Based Attacks: Network-based attacks can be classified as protocol-specific or layer-specific. Protocol-specific attacks involve deviating from standard protocols and behaving maliciously, which will threaten service availability, message privacy, integrity, and authenticity. Layer-specific attacks may occur at different levels of the network stack and will affect network functionality, device responsibility, and healthcare service availability.

Network Protocol Stack Attack: The protocol stack designed by the IoT working group of IETF includes different layers, each with its own vulnerabilities that attackers can exploit. Figure 5 illustrates these vulnerabilities. To enhance the security, longevity, and connectivity of IoMT networks in diverse environmental conditions, it is essential to ensure security and to implement measures at every layer of the protocol stack.

6. Conclusions

Various research work has made substantial inputs to the Internet of Medical Things (IoMT) technology and how it can enhance the healthcare system. This review article reviewed literature that involves devices and applications with the capacity of use in the IoMT. These devices and applications are dependent on the internet for interaction as required by machines as well as for data transmission and storage. A wide variety of clinical use and management application has been identified for these IoMT-enabled devices and applications, thus transforming the healthcare industry and with great potential of bringing much more transformation. Although there are many advantages it provides for the healthcare industry, it is faced with tremendous challenges, especially that of security and privacy which is followed by confidentiality and acceptance. Since it is not outrightly taking medical practitioners out of the way but is intended to enhance their performance and give better results it will help in lowering the cost of delivery of healthcare services. Some areas that can be considered the future direction include:

In the use of sensors especially in the form of wearables, they have variations in their functionality based on the skin color of the users, this is a strong bottleneck that needs to be addressed by developing sensors that can break the barrier of skin color. This is in addition to the power supply needed for the wearables that contain these sensors. If the wearables are to be used by the elderly people, recharging them routinely may be burdensome to the elderly, and if used in remote villages where most of these elderly people live, where power is not constant, especially in most developing countries, recharging may be challenging. Wearables that have a low-power consumption capacity can be developed or those that solar-powered can be researched and be used to solve this challenge. The issues of security of data and their privacy are what can be improved upon since the IoMT function only through the collection of data and their transmission over the internet, and the safety of the users is a serious concern. There is a high possibility of collecting data that are too personal and inappropriate as well as unauthorized tracking. The wide variety of IoMT available working over the internet makes eavesdropping very cheap and simple and because the IoMT is simple, complex encryption cannot be implemented in them, this is in line with the fact that they have very low computing capacity. This opens the door to research in the management of security and privacy of IoMT.

There is a need for improvement and standardization of the technologies used in the IoMT in addition to the network type and service quality. The review is expected to be helpful for the management of IoMT and its technologies.

Future work

The IoMT is a rapidly evolving field as it can be deciphered from this article and for its adequate and proper development as well as the impact on the healthcare industry the areas of interest for future work may include enhanced data security and privacy, integration of AI into the system, interoperability and standardization, edge computing and real-time analytics, and integration with Electronic Health Records. Remote Patient Monitoring and Telehealth, Cost-effectiveness, and Scalability, as well as Ethical and Regulatory Considerations, may be considered an important aspect of future work as IoMT continues to expand.

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Ethical approval

Not applicable.

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Competing interests

No competing interest.

Authors' contributions

C.E conceived the idea, laid out the format and wrote expanding the functions and scope of the IoMT smart devices part. M.E., G.N., and M.H. did the background studies and the healthcare solution using smartphones. T.E. and A. A. worked on the Technologies related to the IoMT as well as the enablers and barriers. C.D. and C. O. worked on the IoMT application and services. Z. Q. supervised the entire work. All authors read and reviewed the manuscript.

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Abbreviations used and their full meanings

6LoWPAN	IPv6 over Low-Power Wireless Personal Area Networks
AMQP	Advanced Message Queuing Protocol
AAL	Ambient Assisted Living
ADR	Adverse Drug Reaction
BLE	Bluetooth Low Energy
CoAP	Constrained Application Protocol
CDM	Controlled Delamination Material
ITIF	Information Technology and Innovation Foundation
UWB	Ultra-wideband
ECG	Electrocardiogram
HCI	Human-Computer Interaction
EMR	Electronic Medical Records
KIT	Keep In touch
NFC	Near-field Communication
RFID	Radio Frequency Identification
WBAN	Wireless Body Area Network
GSM	Global System for Mobile Communications
IETF	Internet Engineering Task Force
BLE	Bluetooth Low Energy
WSN	Wireless Sensor Network
WLAN	Wireless Local Area Network
BMI	Body Mass Index
PC	Personal Computer
RPM	Remote Patient Monitoring
PERS	Personal Emergency Response Systems
ICT	Information and communication technology
ITU	International Telecommunications Union
MIT	Massachusetts Institute of Technology
EPC	Electronic Product Code
NSF	National Science Foundation
NIST	National Institute of Standard and Technology
LPWAN	Low Power Wide Area Network
IEEE	Institute of Electrical and Electronics Engineers
GPS	Global Positioning System
DDS	Data Distribution Service
OMG	Object Management Group

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