Survey of the Current State of the Internet of Medical Things

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***Abstract*—The Internet of Medical Things embodies a network of multi-sensor devices that exchange data between a patient and their doctor for the purpose of providing a higher quality and more flexible healthcare service. As technologies have developed in the larger scope of IoT, so too have they developed in the IoMT. New algorithms and protocols are being developed that allow sensor nodes to become smaller, cheaper, and safer while providing better quality of care to patients. The implementation of these new technologies has resulted in a more cost-effective system that allows for remote monitoring of patients, which helps to reduce healthcare cost. Hallmarks of IoMT include robust security and reliable data collection and transfer. With these features comes significant challenges, including decentralized encryption and interoperability with EHRs and different hospital systems. These challenges will have to be overcome in order for IoMT devices to reach the consumer level and empower everyday people with the data and insights previously only available to industrial medical devices and products. While analyzing the new technologies and their shortcomings, we will discuss where the industry is heading and how challenges should be addressed.**

***Index Terms*—Internet of Medical Things, healthcare, IoMT Security, Remote Monitoring, Emergent IoT Technology, IoMT Challenges**

I. Introduction

The world is more connected than ever due to an array of smart devices that form a network of both physical and virtual things for the purpose of interoperable communication schemes, media, and standards, which has been termed the Internet of Things. These devices serve specific functionalities such as performing sensing, data processing, networking, and communicating with other devices. When these devices are geared towards application-specific tasks in the domain of healthcare, we call these devices the Internet of Medical Things. The devices that fall under this category of IoT have been implemented in the healthcare domain to allow for continuously tracking a patient's health vitals, improving the health record system by establishing smartphone access to medical records, and upgrading traditional medical equipment/amenities to improve the quality of life for the patient. Overall, the implementation of IoMT devices attempts to provide a more cost-effective healthcare system, while simultaneously enhancing the quality of service it can administer. This paper surveys the current state-of-the-art designs and devices of IoMT with a closer look into several areas of focus. First, we discuss the emergent technologies that have arisen from IoMT and how they may be applied to improve other areas of IoT devices. Next, a general overview of IoMT applications is explored to give an understanding of the specific tasks some of these devices are designed for. The security requirements and challenges that IoMT still face are laid out in detail in the proceeding paragraphs. Lastly, we explore some of the novel state-of-the-art devices that could shape the future of IoMT such as expanding the domain into an area of Implantable Internet of Medical Things for healthcare applications.

II. IoMT Emergent Technologies

When the Internet of Things is looked at in the scope of medical devices, several unique challenges become apparent. To address the challenges new and novel technologies have been, and continue to be, developed. In this section we look at what technologies have been developed for the area of medical devices and how they might be applied to other areas of IoT.

The first immediate problem one sees when engineering IoT devices for the Wireless Body Area Networks (WBAN) is that the wireless channel around the human body is not an ideal medium for radio frequency wave transmission [1]. Since the human body is such a lossy medium there is much attenuation in the transmission from any nodes in or on one's body. Authors in [1] attempt to overcome this problem by using ultra wideband (UWB) technologies to transmit high data over a short range. This approach seems to have promising results when analyzing the received data, however it depends on a specific configuration of an antenna and has a higher efficiency when the antenna is 16mm away from the simulated human body. This of course, would have poor results for implanted devices or devices that must placed directly on the skin.

Another severe complication with WBANs is the highly dynamic nature. Humans are highly mobile and dynamic, which makes the probability of a successful transmission to be very minimal when transmissions are performed randomly. Moin *et al.* attempt to create an algorithm that performs more efficient transmissions in [2]. The proposed algorithm leverages the data collected in [3] that discusses that while humans are highly dynamic, much of the motion is periodic in nature. This periodicity can be leveraged to transmit when the RSSI (received signal strength indicator) will be at its peak during transmission. For example, imagine a transmitting node on a person's left wrist and the receiving node in the right pants pocket. While walking, the left arm will swing and will measure the RSSI throughout the swinging motion. Once that peak is recorded and a full period has been conducted, the proposed algorithm can then attempt to transmit at that same position in the next period as a way to predict the most efficient transmission. The most energy consumption occurs during the transmission phase, which is why this algorithm attempts to transmit only when it is most efficient. The authors of [2] continue to propose another adaptive transmission algorithm that takes the readings of EMG sensors to detect and predict movements to better understand where the sensors will be when being transmitted.

More work was done in analyzing and constructing a new MAC protocol that would provide a more efficient and less lossy protocol for WBAN [4]. The proposed BANMAC (Body Area Network MAC) protocol is designed around the IEEE 802.15.4 MAC protocol stack and is designed to be a collision-free MAC protocol. As opposed to other protocols, like CSMA/CA commonly used with IEEE 802.15.4, the data transmissions are flexibly scheduled and do not provide random channel access. The authors of this paper verified their algorithm by comparing experimental results against that of the IEEE 802.15.4 protocol and found that BANMAC performs consistently better. They found the packet loss ratio to be nearly zero for all experimental configurations except for when the Tx power was set in such a way that the coordinator began losing the RSSI time-series transmissions from nodes. This affected their algorithms by altering the Opportune Transmission Window (OTW) predictions. This paper is used to outline that work is being done to improve the MAC protocols used in WBAN. In fact, this is one area where much work is done. For example, in [5] a different protocol, referred to as HACMAC, is proposed which leverages a link quality-aware MAC protocol to adapt the access mechanism during varying activities based on link-quality. General deep learning principles are also being applied to WBANs to increase the efficiency of transmission, as done in [6]. Liu *et al.* have developed a communication framework named DeepBAN which uses a temporal convolution network (TCN) based deep learning approach to lower response time and increase system energy efficiency by 15%.

Furthermore, work has been done on the scope of Implantable Internet of Medical Things devices or IIoMT. IIoMT is under the scope of IoMT as the devices being implanted subcutaneously are medical devices such as muscle stimulators or pacemakers. While much of this work is still experimental, the ground work is being laid and IIoMT devices could be entering the market sooner rather than later. For example, the authors in [7] have laid the groundwork in implantable devices that follow FDA regulations by using ultrasound-based waves for recharging and communication. As one might assume, a large issue with IIoMT is energy consumption and keeping the device running. By using ultrasound-based recharging the device is much closer to being within the FDA requirements and will recharge the device in anywhere from 10 minutes to 2 hours. The proposed scheme would be to have the patient wear a transducer overnight that would then charge the implanted device. The other large step addressed in this paper is the size of the implanted device. The proposed device, of course being a prototype, has a smaller 2D footprint than a penny but consists of a few layers for the transducer, FPGA, and other components. This small form factor makes implanting subcutaneously much easier than other experimental work done to date. While the authors note that this is simply a blueprint for future work, it is a promising step to seeing IoT devices as implantable medical devices.

Much work is being done to progress the field of internet of medical things. As the technologies develop, the applications for the technology become much more diverse.

III. IoMT Applications

The permutations of IoT technology have created advancements in the healthcare and medical device domain that has revolutionized the conventional system and improved the quality of life for the patients it seeks to help. The three areas this paper will spotlight for the contributing applications of IoMT are Smart Hospitals, Telehealth services, and Remote Monitoring applications of patients. The Smart Hospital differs from a traditional healthcare infrastructure by utilizing IoT technology to upgrade its infrastructure and equipment by including an electronic health record system, artificial intelligence-based algorithms for patient diagnosis, IoMT enhanced medical devices, and smart ambulances that can notify hospitals ahead of arrival for treatment of patients. [8]. Telehealth contributes to boosting the patient-clinician relationship via web-based interfaces for remote appointments and virtual access to medical records, or test results, while also providing alternative options for patients who are incapable of getting themselves to the hospital, as with elderly or handicapped patients. Lastly, the innovations towards Remote Monitoring of patients across different IoT-based technologies allows for more accurate and up-to-date diagnostics for doctors and clinicians to treat their patients. The proceeding paragraphs survey these three main areas of IoMT applications and provide an insight to how these technologies have enhanced the healthcare domain for a better experience for the patient.

A. *Smart Hospitals*

A Smart Hospital can be defined as a hospital that optimizes its management systems, medical equipment, and infrastructure through state-of-the-art interconnected technology to administer a more advanced healthcare service to those in need of medical assistance. The first area that is usually improved to upgrade a traditional hospital to a smart hospital starts with developing smartphone-based applications for appointment registrations, access to test results, and mobile-based inquiries through online database servers to showcase electronic health records [10].

The traditional methods for management of health records included a paper system [8], and the first electronic health

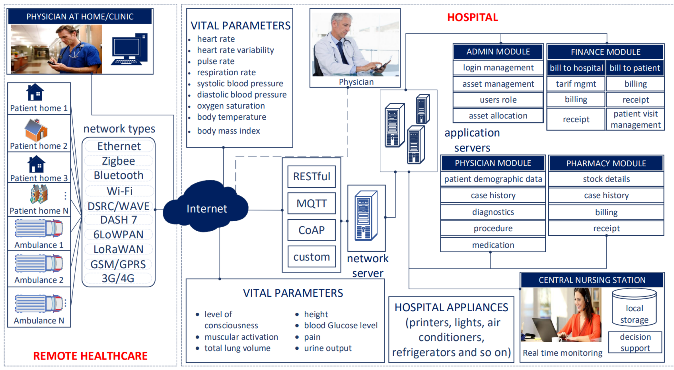

Fig. 1. Overview of IoMT for Smart Hospital [10]

records date back to the 1960s [11]. However, the convenience of smartphone-based applications has modernized the healthcare medical records management system, allowing for remote access to healthcare records and all the patients' sensitive information in the palm of their hands. This online database of patient information can then be accessed by a patients' doctor or clinicians for uploading or examination of health checks and test results. For example, patient information obtained from wearable medical devices that capture real-time signals from vitals like blood sugar levels, electrocardiogram, and blood pressure are uploaded to the patients' medical information platform for a more accurate diagnosis by their doctors [12]. The use of RFID technology has been adapted to the field of IoMT by implanting RFID tags on expensive and crucial medical technology for tracking and locating the equipment during emergency procedures [13]. Hospitals tend to experience unproper inventory management, which results in unnecessary overstocking of equipment. RFID technology has been used as a means for tracking medical supplies and solving this inventory issue [10]. IoMT has also been able to provide applications of healthcare services to regions of the world that are not properly equipped with medical devices, such as hospitals in most developing countries [10], which has about 75% of their radiologists in urban areas. In [14] a low-cost portable ultrasound system for point-of-care applications was built using a single Field Programmable Gate Array (FPGA). The system is capable of transferring MRI images, using its external memory, to other systems and provides real-time imaging at about 30 frames per second. The system operates on a battery and can last for about 2 hours, which is optimal for the portable requirement. Another instance of an IoT-based FPGA system for the application of portable ultrasound imaging was realized in [15], where a computer-aided diagnosis helped detect abnormalities in patients' kidneys. In recent years, tech company General Electric has made a partnership with New York Hospitals and has installed IoT-based sensors on hospital beds, which will be used to indicate to the hospital staff whether a bed is free or occupied by a patient [16]. Over the height of the COVID-19 pandemic, the availability of hospital beds became a serious issue [17], and this IoMT-based solution could provide a more accurate assessment for the inventory of occupied beds for patients if the technology become available to more healthcare facilities. Hospitals can upgrade their mobile and emergency healthcare services with proposed systems towards a novel Smart Ambulance. A system has been proposed in [18] that uses biosensors to check the vitals of the patient being rushed to the hospital and relays the patients' health data to the hospital via a Google Cloud App Engine. The hospital can then start to anticipate the arrival of the patient with information on their condition and can move forward with a treatment solution, prior to them being delivered to emergency room. To take this a step further, another system proposal would then be able to update the traffic pattern the ambulance is taking by proposing the fasted route to the hospital [19]. IoT can ultimately give the conventional hospital system cutting-edge solutions towards providing rapid and reliable healthcare services that benefits its patients.

B. Telehealth

The applications of IoMT have expanded the conventional hospital patient-doctor relationship by allowing healthcare services to be utilized remotely from the comfort of the patients' home which satisfies the demand for increased accessibility of care outside of hospitals. The term Telehealth can be described as a healthcare scheme which allows a patient of any age to keep track of their own vital health data, via remote monitoring, to take better control of their own well-being [8]. These services seek to help those who are incapable of getting themselves to the hospital, or doctor's office, by offering a remote solution that improves the patient-doctor relationship and saves the patient money from commuting back and forth for doctors' visits. This type of healthcare solution benefits elderly patients, who are remotely monitored by wearable and environmental sensors, with the clinicians in the hospital or home nurses having access to real-time data records of the patients [8]. Conventional remote monitoring systems include bulky hardware that are deemed uncomfortable to the patient to wear due to size of modules and battery recharging. Thus, the revolution of IoMT aims to resolves these issues by developing compact, low-power sensor devices and lightweight communication networks [8]. In [20] a proposed system called Ambient Assisted Living (AAL-IoTSys) monitors the patients' heart rate and location within their home, environmental parameters such as temperature, humidity, and C02 through a variety of different protocols and technologies. The heart rate and location information are processed by a NodeMCU ESP8266, which operates wirelessly using a Wi-Fi interface 802.11b/g/n, temperature and humidity are collected using a MEMS STM32 that uses the 802.15.4 and 6LoWPAN protocols, and C02 data is collected by an Arduino microcontroller utilizing the Zigbee wireless protocol [20]. All these devices are then connected to a Smart IoT Gateway, which is designed using a Raspberry Pi 2, with a communication module that establishes and maintains the connections between the different WSN protocols. The processing unit of the Smart IoT Gateway evaluates the measurements of sensor data and if an event is detected, i.e., heart rate below 60 bpm, temperature above 30o C, or C02 levels above 1500 PPM, the caretakers or doctors would be alerted through the internet to a web-based application [20]. In other telehealth systems, elderly patients who struggle with mobility, or who are confined to a wheelchair, are remotely monitored using wearable sensors such as gyroscopes, accelerometers, and breathing rate sensors, for the detection of the patients' movement in their homes [10]. The sensor data is processed by a microcontroller unit that sends information wirelessly to a central server that records the data to a web-based application for the doctors or nurses to obtain real-time movements of the patient. In the case of an unexpected fall or emergency, the healthcare professionals would be alerted to assist the injured patient and respond immediately. These telehealth databases have also been augmented their clinical decision making by implementing advanced technology such as Artificial Intelligence-based algorithms into their cloud servers [8]. An AI-based Virtual Assistant created from sophisticated Deep Learning algorithms has been used to keep doctors up to date with new information regarding different medical articles, journals, and clinical practices in [8]. Using this technology in combination with IoMT devices, doctors can provide more accurate and modern medical solutions while the patient receives a more accessible healthcare service in present day.

C. Remote Monitoring

As mentioned in the previous section, IoMT enabled a more accessible version of healthcare services, by providing real-time remote monitoring of patients using different technologies and wireless communication protocols. These remote monitoring applications vary from sensors that collect biometric information of the patient to real-time data logging of prescription medication ingestion. The main contributing factor that IoMT has provided to the domain of healthcare, through utilization of different data acquisition sensors and network protocols, is a more accurate model of the patients' health information that improves the overall quality of the healthcare services.

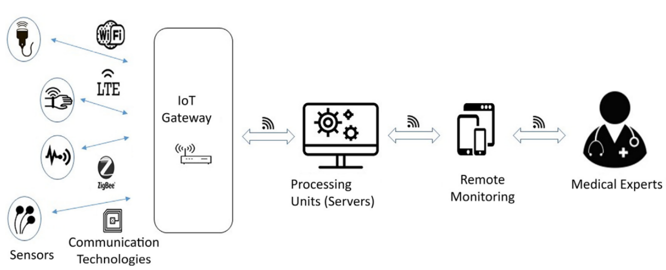

Fig. 2. Overview of Remote Monitoring Systems [8]

Some of the most utilized areas of remote monitoring include heart monitoring, diabetic monitoring, digestive/diet monitoring, and medication monitoring. The following paragraphs give an overview of some of the state-of-the-art IoMT applications of remote monitoring.

The monitoring of a patients' heart is done using common techniques for heart conditions such as heart sound auscultation, heart rate variability, and electrocardiography [8]. The data acquisition of these parameters has been achieved from wireless body sensors and commercially off-the-shelf ECG monitoring systems for heart patients, which provides signal processing and digitizing of vital signs [10]. Monitoring of the heart is considered the most important vital parameter because the information extracted can reveal stress and illnesses that are hidden, like arrhythmia [10]. In [22] a low-cost 3D printed stethoscope was designed for inexperienced users to perform heart monitoring remotely from their homes and have the capabilities for connectivity to a smartphone for which the user can run various tests using a mobile app that sends data to their doctor for diagnosis. In recent years, these remote heart monitoring systems have implemented more complex processing algorithms by implementing machine-learning models that extract features from the P, T, and QRS complexes of the heart's electrical signal. They also diagnose abnormalities from the heart as part of a decision-support system for remote monitoring [23]. In addition to diagnosing chronic diseases, heart attacks, and strokes, there have been new efforts to utilize IoMT devices with machine-learning algorithms for the prevention and detection of the COVID-19 virus [24]. The system is designed using a Raspberry Pi as the central processing unit with multiple wearable physiological sensors that capture heartbeat, blood pressure, and temperature information. The Raspberry Pi uses OpenCV for the computer vision-based algorithms and connects to a cloud network that contains the machine learning model for predicting the presence of COVID-19. The cloud network offers access to healthcare professionals for them to analyze the processed data with which they can suggest next steps to the patient through the touchscreen display of the system [24].

Diabetic monitoring has also been upgraded through IoT-based solutions that allow a patient to record their glucose levels remotely and transmit these glucose readings to their doctor through smartphone-based applications. It's reported that over 400 million people worldwide have diabetes [25], which has created a need for an IoT-based solution that is low-cost and enables remote monitoring of the patient. It also enables those with this disease to be able to keep track of their glucose levels throughout the day. A system named DiaLoop was developed [25] that uses a blood glucose sensor to measure the patients' blood sugar levels, which are then transmitted to their smartphone via Bluetooth. Within the mobile application, the measured glucose levels are then compared to a local database of measurement ranges. This database is connected to a cloud that the supervising physicians can monitor from a web-based application. The mobile app will notify the patient if their glucose levels are sufficient or they will be an alerted of their insufficient glucose levels. Then, the physician will be notified through the cloud server [25]. A new state-of-the-art wearable called iGLU 2.0 has been presented in [26] which uses a novel near infrared (NIR) spectroscopy for serum glucose monitoring and validates data using a deep neural network and polynomial regression model for glucose level prediction. The system is designed using NIR LEDs, Infrared detectors, Infrared photo diodes, and an Arduino microcontroller to perform data acquisition from these sensors. Currently, the serum glucose can only be measured through a laboratory setup, which has presented a demand for an accurate and low-cost solution to monitoring blood glucose levels like the iGLU 2.0.

In a similar application to diabetic monitoring, the Internet of Medical Things has also reached the domain of nutritional monitoring for caloric intake for those who have nutritional imbalances or food allergies. Wearables and other monitoring systems have been designed in the past decade to help elderly patients maintain a healthy diet by focusing on their input calories and monitoring the number of calories they burn [27]. However, these systems can also be targeted infants and children, who can develop weakened immune systems, cognitive disorders, and weakened skeletal structures because of an imbalanced diet [28]. Thus, an IoT-based system called Smart-Log, has been designed in [28], consists of a smart sensor board, microcontroller integrated with a wireless module, and smartphone application that utilizes a 5-layer deep learning model for nutritional balancing of each meal. The system works by first placing a food item on the sensor board that contains a scale. The information of the weight of the food product is processed by the microcontroller which then transmits the data to the cloud via Wi-Fi. Using the corresponding smartphone application, the nutritional information of the food that was just weighed appears in the mobile app and has the capability to log the entire nutritional content for the prepared meal. After finishing the meal, the leftover food is then reweighed on the smart sensor board to calculate the food wastage, which corresponds to unconsumed nutrients. The user's next meal can then be calculated and recommended based on nutrient deficiencies on a meal-to-meal basis [28].

The last area where IoMT has improved the domain of healthcare has been in prescription drug monitoring. Two of the most important issues regarding patient safety in prescription drug monitoring are adverse drug reactions and drug compliance. About 15% of patients suffer from serious reactions because of noncompliance to prescribed drug dosage and schedule of ingestion [8]. In some cases, patients are also prescribed more than one medication for treatment to a single ailment, known as polypharmacy, which they must manage their daily intake for. These conditions gave rise to IoT-based technologies to prevent adverse drug reactions and help those prescribed multiple medications to better manage their prescription medication. A Smart Medicine Box was designed in [29] that will audibly alert the patient when it is time to take their medicine and unlock the proper compartment containing the prescribed drugs. If the patient is not around to hear the alarm, an email will be sent over Wi-Fi using a mail transferring protocol created using IFTTT to their fixed email address to notify they missed their medication time. The smart medicine box consists of an Arduino microcontroller, which operates the alarm buzzer, LCD display screen, and servo motor that locks/unlocks the three compartments. The system also includes a NodeMCU Wi-Fi unit that reads from a temperature sensor and logs the medication time data. Information on the medication time is handled on a cloud server, with the patients' doctors having access to the timestamp information to check if the medication is being taken at the prescribed times. Another cost-effective medicine management box has been proposed in [30] that is targeted at elderly patients who suffer from memory impairment diseases like amnesia and may not have the financial resources to afford a personal doctor or caretaker. Aside from containing prescribed medications, the proposed medicine box allows the patients to also store emergency medication in a secured location. With all their prescriptions and emergency medication in one location, the patient can have access to their required prescriptions for their regularly scheduled medication, and when they have an emergency. When utilizing these smart medicine box solutions in combination with one of the various remote monitoring schemes, a patient's health can be properly monitored while giving them the luxury of remaining in their home, instead of in a hospital setting.

IV. Security and Requirements of IoMT Devices

Security is arguably one of most important factors in communication between medical devices. Numerous regulatory, legal, and organizational frameworks, like HIPPA and GDPR, require robust security to be built into every medical device that deals with sensitive information, like personally identifiable patient data. There are two main vectors of attack for obtaining information, which are during authentication and during transmission. Brito *et al.* summarize the current landscape of medical device security and attack vectors, saying "…most attacks were due to the flaws left on the authentication protocol, so authentication is the most important and critical security service [32]." Conceptually, if a bad actor is able to exploit a flaw in the authentication protocol, security during data transmission won't matter because the bad actor will become a trusted node with the appropriate permissions and security keys. This is why outside the world of IoMT, companies like Apple are locking down their ecosystems with measures to restrict outside devices or software to modify or even communicate with their 1st party hardware and software. To provide a potential solution to this authentication problem in IoMT, Quist-Aphetsi *et al.* details an encryption scheme that uses the Diffie-Hellman protocol for device authentication [33]. The Diffie-Hellman protocol consists of several steps, which use the nature of the modulus function to generate keys from prime numbers that are incredibly difficult, and pretty much impossible, to brute force by even the fastest computers today. Figure 3 shows the steps of the protocol to ensure authentication is secure between two devices.

Since the protocol was created in 1976, many iterations have been designed. In particular, a variant of the protocol used in many devices, including devices running iOS and iPadOS, is

1. Node A and node B must agree on a prime number p, and a primitive number g.
2. Node A chooses a number a, while Node B chooses a number b.
3. Node A computes the $g^a (\bmod\ p)$ and sends to Node B.
4. Node B computes the $g^b (\bmod\ p)$ and sends to Node A.
5. At this point it is possible for both nodes to compute $g^{ab} (\bmod\ p)$.

Fig. 3. Steps of the Diffie-Hellman Protocol [33]

Curve25519, which is a high speed, low resource, ultra-secure version of the protocol [34].

A common belief is that increased security can come at the cost of decreased flexibility, such as compatibility with different systems. For Medical IOT, where most devices would conceivably operate autonomously with no user input, they need to interact with different systems automatically depending on the situation. One such scenario that highlights these issues is in emergency and operational services. As Lakkis *et al.* emphasize, “In healthcare systems, we are dealing with vital information about the human body, the loss of any packet may cause a devastating impact; as a result, we need to make sure that our communication is reliable and trustworthy [35].” In addition, the authors propose a solution for emergency and operational services. It consists of devices utilizing Zigbee and 6LowPAN, which is a low power IPv6 protocol intended for devices that require long battery life. To address the compatibility issue, the authors also propose IPv6 edge routers that act as fixed sinks, providing the gateway between the sensor network and the traditional internet. A depiction of their proposal in Figure 4 is shown below.

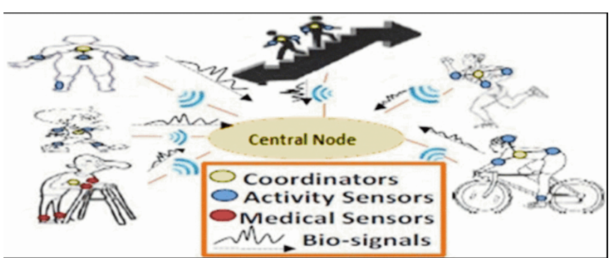

Fig. 4. Overview of Conceptual Medical IOT Sensor Structure [35]

Traditionally, medical devices that were intended for a specific task were designed to be just that. For example, a SpO2 measurement device that went on a finger did not have any functions that were extraneous to its purpose. However, with the advent of smartphones, that is no longer the case. The amount of sensors and technology packed inside a portable computing device can democratize healthcare and access to health data. Agu *et al.* describe the smartphone as a medical device, and how sensors like the microphone, camera flash, and others can be used in a medical context [36]. Some examples the authors give are using the microphone as a spirometer by measuring audio peaks and correlating them with inhalation and exhalation, using the camera flash and camera to measure heart rate, and using AI to detect melanoma from images of skin taken the with the smartphone camera. Although some of these, like HR detection, have been made obsolete with consumer devices like the Apple Watch, others, like melanoma detection with AI, can now be done on device due to improvements in machine learning computation on today’s mobile devices. Many of these smartphone sensors have accompanying applications that read sensor data and interpret results. Emerging smartphone apps may have to be FDA regulated if there is going to be a proliferation of these apps that take advantage of built-in sensors, and a significant chunk of data from those apps is obtained.

V. Barriers/Problems to IoMT Adoption

The Internet of Things has great benefits in the healthcare sector, but some major challenges need to be solved before IoT can be fully implemented in healthcare. Some key areas of concern or obstacles are

- Privacy and Security
- Standardization Protocols
- Accuracy and Risk of failure
- Cost
- Acceptability

A. *Privacy and Security*

Privacy and data security have been the main areas of concern in recent times. Internet of things in healthcare does allow for cyberattacks because of the use of wireless communication. The use of wireless communication does make eavesdropping very easy. The use of low-power modules also makes it hard to implement complex security algorithms on the system. There is also a lot of uncertainty about whether a proper guideline is being established for data security in IoT. Organizations like the National Institute of Standards and Technology has released drafts on security in IoT [37].

B. *Standardization Protocols*

Issues with the Standardization of IoT in health care systems has been one of the major reasons or threat for the wider adoption of IoT in the medical field. The development of IoT in Healthcare is always threatened by such a lack of standardization, as the industry is yet to decide on the wireless communication protocols and standardizations. The lack of such protocols, standardization, and unified systems will thoroughly delay the adoption of IoT in Healthcare and will hinder its reach in international markets [38]. Interoperability is very key in IoT as it is very common for companies to define their own data formats, architecture, and protocols. Interoperability helps with connecting such devices to healthcare environments and smooth integration in the communication process [39]. The use of many protocols creates many vertical silos [40] which in turn create a demand for the development of new features which grant interoperability between different systems. The future of IoT in healthcare heavily relies on interoperability and achieving interoperability across various IoT platforms can help the patient and clinicians in providing an accessible and safer experience [41].

C. Accuracy and Risk of failure

The risk of failure is one of the key drawbacks as a failure of the device or bugs can result in power failure which can impact the connected devices placing the healthcare operation at risk. Failure of Implanted IoT devices can result in patients' death. In addition, skipping a scheduled software update may be even more dangerous than skipping a doctor's checkup. The accuracy of measurements from sensors defines what observations are to be made and the type of diagnosis. The accuracy of an ECG from an apple watch is not the same as the one when taken at a health care facility. IoT in healthcare being a new field has issues with the accuracy of measurements from these biomedical sensors. The patient's life is at risk if the accuracy of these measurements is way off as these tiny implantable sensors are not so accurate when compared to the equipment used at a lab.

D. Cost

The Boom in Healthcare costs has rather been a worrying sign in recent years. The design and development of IoT in healthcare is rather an expensive process. The design and development of implantable sensors are much high and a promise to reduce the overall cost needs to be made. The long-term goal of any technology should be to make it more accessible to the general public and failing to do so sets everything back. Even though IoT promises to reduce the cost of sensors in the future, the cost of implementation and training the staff is quite high.

E. Acceptability

Public awareness is key in the acceptability of IoT in healthcare. Educating the general public on how data is stored safely in the cloud and societal acceptance is one of the threats to the acceptance of IoT in Healthcare. The general public is not clear on what IoT has to offer them personally from a health care perspective [42], [43]. Perceived value of IoT to consumers should outweigh the concerns associated with IoT in Healthcare. The characteristics of the technology like compatibility, accuracy, familiarity, patient and health professional interaction, and organization readiness are all factors that influence the acceptance of IoT in the Healthcare Industry [44].

VI. IoMT Future Applications

A. Future Wearable Devices

The future trends of IoMT technology will continue to expand the functionalities and capabilities in the domain of Wearable monitoring devices and introduce ultrasonic technologies that will be utilized as Implantable IoMT devices. The market value for Wearable IoT devices is projected to be 265.4 billion USD by the year 2026 [45]. The domain of Wearable IoT strive year-after-year to further miniaturize the size of devices for a more comfortable and unobtrusive design for device users. A variety of different wearable devices are shown in [45]–[47], which displays the diverse sensing applications the area of IoT is evolving into. A heart and respiratory monitoring device called Bioheart comes with a breathable chest band for wearers to track their ECG and respiratory information, along with their caloric data [47]. Toyota is also entering the IoMT space by developing a wearable IoT device targeted for blind people that will help with improving their mobility [47]. The system requires the user to wear multiple modules on their shoulders, legs, and even hands. The modules will include cameras that detect nearby objects and provide haptic feedback by warning the user through vibration alerts. One of the smallest wearable devices outlined in articles is the NFC Smart Ring, which comes embedded with multiple sensors and network connectivity to share and exchange data with other NFC devices [47]. These types of devices are further broadening the definition of how technology can be designed to track biometric information from a person's body. We should expect to see more innovations in the designs of wearables that further scale and transform the monitoring scheme for IoT devices.

B. Implantable IoMT

As discussed, The IoMT field could soon be expanded by the realization of Implantable Internet of Medical Things (IIoMT). This particular field of IoMT would involve the implantation of miniaturized networked devices inside the body of a patient that has the capabilities for healthcare professionals to continuously monitor for physiological anomalies [50]. These types of devices would allow for earlier detection and prevention of diseases [52], which would result in a more efficient healthcare service system that also reduces expenditures for the patient [53]. The discussed device called U-Verse is introduced in [7] that is aiming to become a future "blueprint" for use of ultrasonic wireless charging and communication for an implantable IoT device. This system demonstrations adequate steps toward realizing end-to-end, real-time, closed-loop, long-lasting Implantable Internet of Medical Things that don't currently exist. So, with the design and utilization of USWB communication and wireless recharging, as in a system like U-Verse, we could see this technology designed into future IIoMT systems for applications such as blood pressure and glucose sensors for chronic disease detection and implantable insulin pumps for diabetic patients.

VII. Conclusions

IoMT continues to be a very promising area of growth as new technologies are developed and the need for remote monitoring and healthcare are realized. The recent pandemic has showed the world that being able to have in-person access to health professional is not promised and IoMT may provide the missing link. IoMT may have additional benefits such as lower hospital wait times for less urgent needs and more thorough monitoring which may lead to earlier diagnosis. More development will be needed in order to overcome the barriers to wide adoption of IoMT, such as security and FDA regulations. That work is underway, however, and the world may soon see IoMT devices all around them. There are many applications for IoMT and the world is just at the start of what may be available with the Internet of Medical Things.

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