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SURVEY

Unleashing the Power of Wireless Communication in Healthcare by Empowering Patient Care and Connectivity: A Comprehensive Survey

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ABSTRACT The emergence of the wireless network as a potentially revolutionary innovation has the ability to change the field of medical diagnostics. This in-depth study aims to explore the various aspects of using the latest wireless technologies to improve the standard of care given to patients and the interactions between patients and healthcare providers. This study investigates a wide range of issues such as patient-centric communication technology, 6G based applications using smart technologies, real-time communication protocols, implementation of artificial intelligence (AI) and blockchain technology in healthcare and the use of wireless devices for remote patient monitoring. 6G wireless communication brings transformative capabilities to healthcare, offering ultra-reliable and low-latency communication (URLLC), improved network capacity, and higher data rates. These advances enable the real-time transmission of critical health data, support complex medical applications, facilitate remote consultations, surgical robotics, and AI-driven diagnostics. This study highlights the significance and implications of combining these concepts in the context of 5G and beyond, paving the way for connected healthcare, personalized medicine, and unprecedented levels of efficiency and innovation. In addition, it also investigates the obstacles and potential associated with the implementation of wireless communication in the healthcare industry. These challenges and opportunities include data security and privacy issues, as well as the need for a robust communication infrastructure. This paper demonstrates the influence that wireless communication

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has in changing healthcare care delivery, improving patient outcomes, and creating a connected healthcare ecosystem through a careful assessment of current research and case studies in terms of improving quality of services (QoS). The findings of this survey offer important perspectives and recommendations that could aid healthcare professionals, scholars, and governing bodies to efficiently harness the potential of wireless communication to transform patient care and connectivity.

INDEX TERMS Internet of Things (IoTs), Internet of Healthcare Things (IoHTs), Internet of Medical Things (IOMT), non orthogonal multiple access (NOMA), artificial intelligence (AI), blockchain, massive machine type communication (mMTC), network slicing, physical layer security (PLS), 5G and 6G wireless communication.

I. INTRODUCTION

Communication has been a key component of human society for many years. In earlier times, interpersonal contact was made mostly between individuals. However, the progress of technology has facilitated the ability of humans to interact with computers, tablets, and an extensive range of other electronic devices. In fact, researchers have successfully produced intelligent smart cameras that facilitate interaction without necessitating human involvement.

This paradigm encompasses a vast network of interconnected nodes that communicate wirelessly, including both living and nonliving entities within its surroundings. Incorporation of IoT into the medical domain assumes a crucial and innovative role in improving the quality of human-assisted living conditions. Consequently, the domain of medical technology (MT) has expanded significantly, including a wide range of industries that aim to monitor patient health status and provide real-time assistance for patient healthcare.

In the world of modern medical technologies, patients may have reduced hospitalization durations due to advances in current medical technology, which also involve less exertion and are distinguished by easier operability [1]. Patients report feeling better about their general health and living conditions. As a direct consequence of this, well-established analysis of patient data becomes possible within the framework of the digital age of medicine [2]. In addition, MTs facilitate public access to health information by gathering data in the digital infrastructure and strengthening it. This is done with the aim of helping service providers and patients obtain the information needed for further analysis. Due to the increasing number of elderly and disabled people, it is necessary for such real-time health surveillance facilities to treat patient health in a way that avoids preventable death [3]. Hence, the Internet of Healthcare Things (IoHTs) is an integrated approach of smart device networks to monitor, track, and store patient health information for continued treatment. As smart and intelligent devices offer better, faster, and cheaper customer-driven innovations in healthcare consumption.

Although cloud-based IoT devices provide the latest in healthcare care, they support the most rapidly evolving practice [4]. IoT-based healthcare devices are designed for diagnostic tests, check-up, and remote surgery over the Internet. Data input from healthcare professionals can be collected through sensors and analyzed through applications

developed for the gateway node like computers, smartphones, wearable devices, and even particular embedded devices. IoHTs can support a variety of health-related issues, including the treatment of chronic diseases, the care of younger and older patients, and the strategic planning of one's own health and fitness [5]. Therefore, IoHTs will undoubtedly be the modern intelligent rehabilitation system, helping to alleviate the problem of aging populations and lack of healthcare professionals [6]. For example, IoHT systems are attractive in this evolving situation because enabling customization of medical healthcare not only dramatically reduces costs, but also enhances results through better responsiveness, usability, and efficient use of obtained data. Likewise, the benefits of IoHTs could speed up the diagnosis process, offer excellent dependable care that reduces costs, and possibly even lessen the chance of a recurrence of the same illness. This hyperbolic development of the Internet enables live visual interactions and a significant influence on human health observation. Throughout this aspect, IoHTs provide a forum for connecting thousands of devices to a wireless network. The adoption of IoT in healthcare is a more general and significant aspect of future developments [7].

When it comes to humanitarian help, the IoT and its characteristics are crucial, especially when it comes to the integration of the IoT into IoHT-related medical treatment. IoHT equipments are more useful in providing real health-related data and are directly linked to the corresponding doctor or specialist [8] often demonstrate the specific need to cure the patient. The IoHTs offer a solution to discuss factors and prevention of disease. This can be assumed to be useful to support and improve life in the future.

The Internet of High Things, which combines high-altitude platforms (HAPs) and IoT, is a groundbreaking concept in wireless communication [9]. A comprehensive review of the relevant literature reveals a wide range of scholarly investigations exploring the possibilities, practical uses, and challenges pertaining to the integration of IoHT with wireless communication technologies. This comprehensive analysis covers the evolution of IoT and wireless communication, the establishment of HAPs, the convergence of IoT with HAPs, the advantages of IoHT, and the challenges that need resolution to fully realize its potential. HAPs have the potential to revolutionize healthcare by providing reliable and affordable connectivity to remote and underserved areas. By operating in the stratosphere, HAPs can provide a wide coverage area,

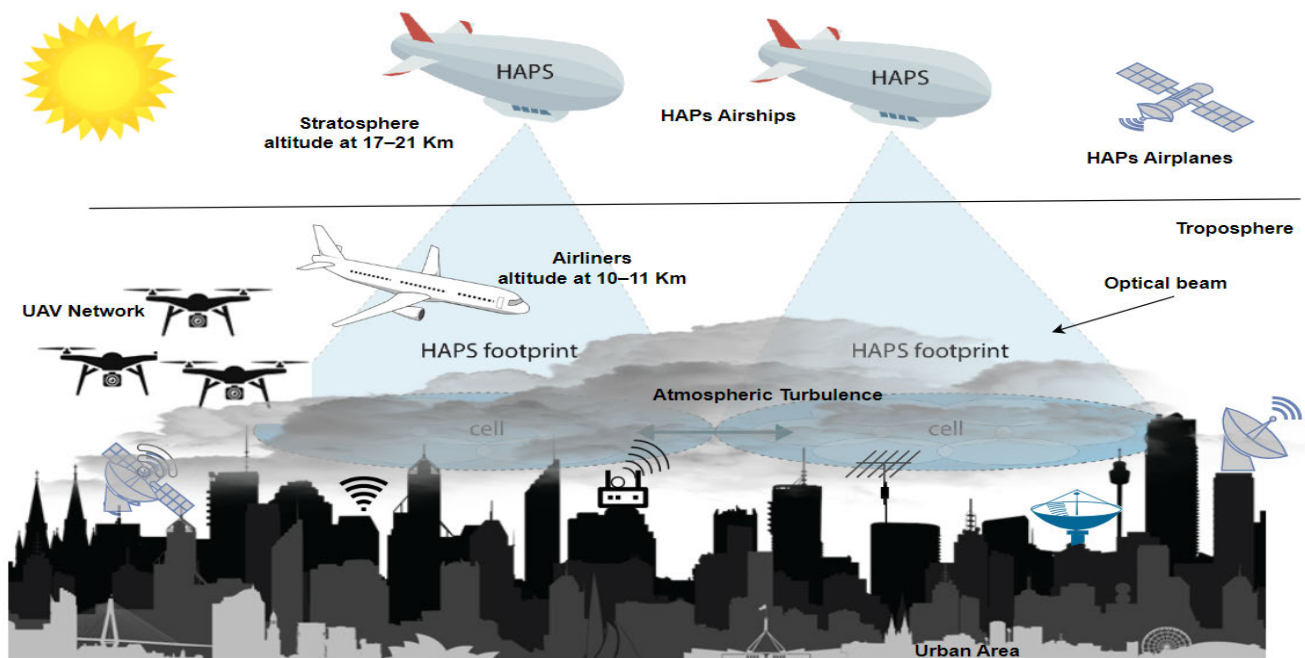


FIGURE 1. A Potential High Altitude Platform Station (HAPS) Network Vision and Framework in Wireless Communication. This figure illustrates a conceptual architecture of a HAPS network, designed to enhance wireless communication capabilities for healthcare applications. The HAPS, positioned in the stratosphere, acts as a bridge between terrestrial networks and remote areas, providing extended coverage and improved connectivity. Key components include HAPS platforms equipped with communication modules, ground stations for network management, and various healthcare devices connected to the network. This framework enables seamless data transmission, remote patient monitoring, telemedicine services, and disaster response, ultimately empowering patient care and improving healthcare outcomes.

making them ideal for reaching populations that currently lack access to basic healthcare services. HAPs can enable telemedicine services by providing the bandwidth and latency required for real-time video consultations between patients and physicians. HAPs can be used to collect and transmit real-time patient data, such as vital signs and medical device readings. HAPs can provide a critical communication link during emergencies, allowing first responders to communicate with each other and coordinate their efforts. HAPs can be used to provide health education and information to underserved communities. HAPs can be used to collect data on a wide range of health-related topics, such as disease prevalence, risk factors, and treatment outcomes. The use of HAPs in healthcare is still in its early stages, but the potential benefits are significant. As technology continues to develop, we can expect that HAPs will play an increasingly important role in improving access to quality healthcare for all.

The proliferation of IoT and wireless communication has brought about a paradigm shift in our interaction with technology, resulting in significant implications in several domains and facets of everyday existence. Considerable study has been conducted to explore the potential of the IoT and the challenges it encounters in several domains, such as smart homes, healthcare, transportation, and agriculture. Simultaneously, wireless communication technologies such as Wi-Fi, Bluetooth, and cellular networks have contributed significantly to establishing a smooth link between IoT devices and the Internet [10] by encompassing

cellular networks. Research in this domain has focused on improving wireless communication protocols, addressing security challenges, and devising energy efficient solutions to accommodate the growing proliferation of IoT devices [11], [12], [13], [14]. There has been a growing interest in platforms operating at high altitudes as potentially transformative resources that could enhance communication infrastructure. The ability to provide extensive coverage is facilitated by the use of stratospheric balloons, drones, and pseudo-satellites, which possess the capability to operate at altitudes above 20 kilometers. These technological advances serve to establish a connection between terrestrial and satellite communication systems, which reduces the existing distance between them [15].

Researchers have conducted investigations into potential applications of HAPs, focusing on surveillance, environmental monitoring, disaster response, and communication relay. To facilitate the seamless integration of HAPs into existing communication networks, several issues related to power management, flight stability, and regulatory compliance have been effectively addressed and successfully overcome [16]. The confluence of HAPs and IoT under the Internet of High Things paradigm has given rise to a complex network of communication. The network of communication described herein surpasses the limitations imposed by conventional wireless networks. The core area of study has been the advancement of communication architectures and protocols. The objective is to provide an efficient interaction between

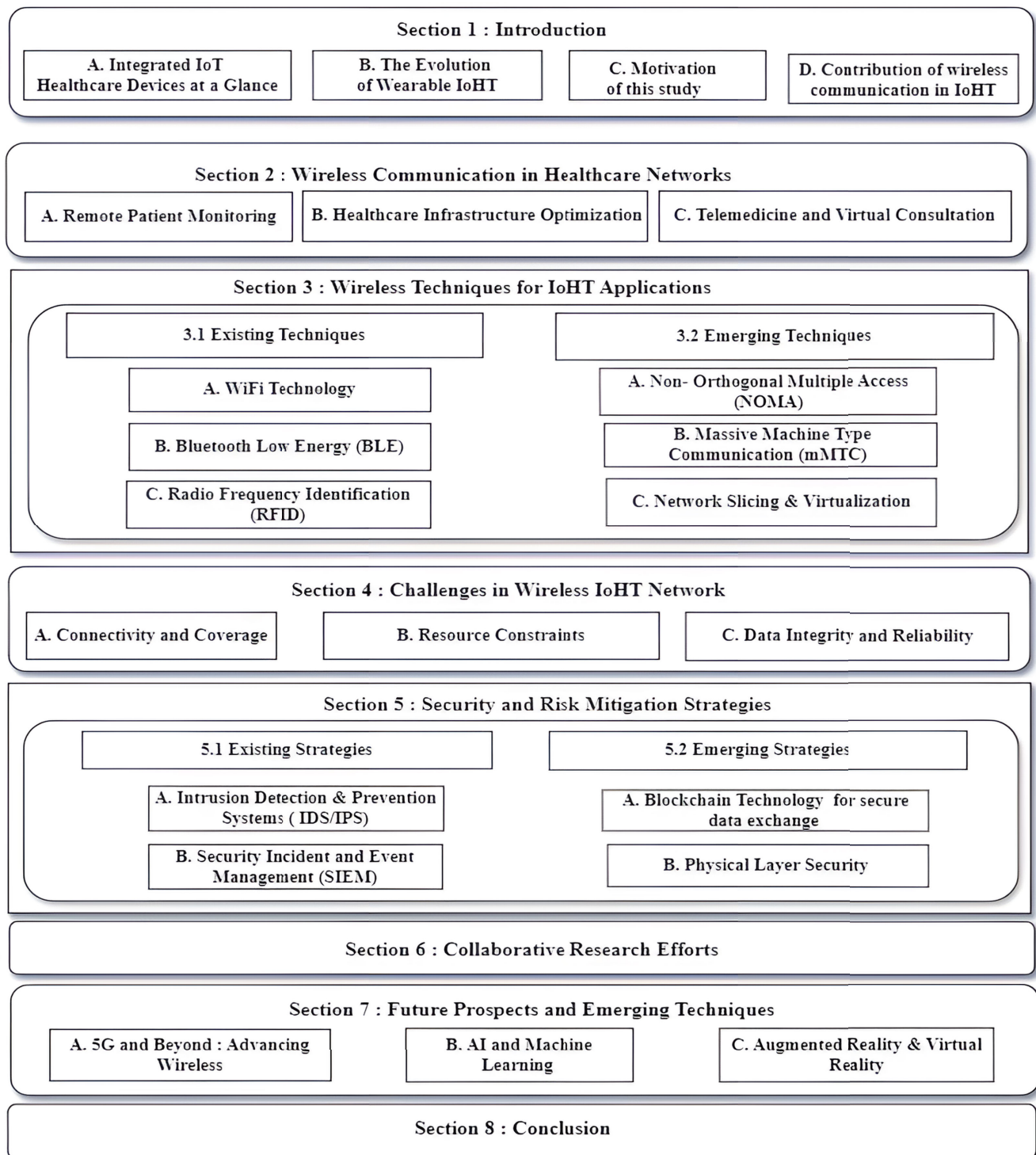


FIGURE 2. This figure outlines the organizational framework of the paper. The structure is designed to systematically investigate the intricate domain of wireless communication in the medical field. It commences with an introduction to the domain, followed by a comprehensive literature review to establish the research foundation. Subsequently, the paper delves into the core components of wireless communication in healthcare, including technologies, challenges and security and risk mitigation strategies. A detailed analysis of the existing system and its limitations sets the stage for the proposed framework. The paper concludes with a discussion of future research directions and potential implications for the healthcare industry.

the IoT devices located in the ground and the HAPs in the sky [17]. Optimization of communication performance

and assurance of continuous connection within the IoHT ecosystem are significant areas of attention. This includes

examining handover mechanisms, interference management, and resource allocation. The field of wireless communication and networking is on the verge of undergoing significant transformation due to the many advantages presented by the Internet of Hybrid Things. Due to its extensive scope, this technology has the ability to reach remote and under served regions where the traditional communication infrastructure is deficient or nonexistent [18]. The close proximity of HAPs to ground-based equipment enables low-latency communication to be facilitated. The use of this technology enables the practical implementation of real-time applications, including but not limited to augmented reality, telemedicine, and autonomous vehicles [19]. The International Organization for Humanitarian Telecommunications plays a crucial role in disaster management by facilitating relief operations and facilitating rapid response efforts through the provision of a rapid and provisional communication infrastructure in areas affected by disasters. A detailed diagram of the conceptual architecture of a HAPS network can be visualized in Fig. 1.

Hazardous air pollutants provide the capability to perform extensive environmental monitoring due to their incorporation of advanced sensor technology. This facilitates the advancement of climate research, as well as the enhancement of weather forecasting and ecological preservation [20]. HAPs that serve as aerial base stations provide a means of delivering fast internet connectivity to remote and under served regions, therefore mitigating the digital divide and fostering economic growth. In order to effectively achieve the potential of IoHT, it will be imperative to overcome many challenges. Compliance with aviation regulations and adherence to air traffic management systems are crucial factors in guaranteeing the safety and efficiency of HAPs inside the airspace. The attainment of this objective is contingent upon adherence to regulatory compliance [21]. In a wireless communication-dependent environment, the optimization of network performance necessitates the use of effective spectrum management and interference mitigation techniques [22], [23]. IoHT environments may be characterized by the features mentioned. The issue of power efficiency and endurance need attention, as it is essential to equip high-altitude platforms with power systems that possess sufficient efficiency to sustain prolonged operations [24]. Stringent data security and privacy controls are crucial in ensuring the protection of sensitive information transmitted across the Internet of Human Things network. In order to maintain uninterrupted communication during infrastructure transitions, it is essential to provide interoperability and efficient handoff mechanisms that seamlessly integrate with the existing communication infrastructure [25]. The Internet of High Throughput, is specifically designed to provide enhanced geographical coverage, minimal delay in data transmission, robustness against catastrophic events, the ability to monitor environmental conditions, and high-speed internet access to remote regions. In order to fully unlock the promise of the IoHT, it is imperative to overcome many challenges pertaining to regulation, spectrum management,

power efficiency, security, and integration. The advancement of IoHT has the potential to revolutionize wireless communication as more research is conducted. This breakthrough will facilitate a diverse range of applications and provide an era of uninterrupted connectivity with boundless opportunities. The potential of IoHT to revolutionize industry, reshape society, and foster a globally interconnected world without boundaries is contingent upon continuous research and development efforts [26]. A visual representation shown in Fig. 2 provides a clear and concise overview of the survey's flow, which makes it easier for readers to understanding the intricate relationships between different sections.

A. INTEGRATED IOT HEALTHCARE DEVICES AT A GLANCE

The convergence of these applications or the persistent extension of their operation may lead to a specific IT application that matches the description in the review of the literature. As stated in the study, these more sophisticated valuable ideas would require proper business models [27]. The IoTs consist of a resource-intensive smart device connection that is capable of sensing and processing data. It combines the massive number of intelligent processing devices, i.e. information tools and core devices. The idea of intelligent healthcare has arisen in various countries, where pilot programs of health centers are being studied. IoT health service devices continuously track patients and send the necessary data on an ongoing basis, which must be shielded from malicious activities [28]. Over the last few years, this area has received a great deal of interest from researchers to address the ability of IoT in the healthcare sector by considering several vital issues. As a result, there are now respective applications, facilities, and models in the area [29]. Also, guidelines and policies for the application of the IoTs in the medical sector have been established in many nations and institutions all around the world. Even though, the IoT is still in its infancy towards the healthcare industry. At this point, a thorough understanding of current IoT research in the hospital environment is found to be beneficial for critical parties interested in further study. This paper explores the developments in IoT-based health research and discusses the numerous problems that need to be tackled in transforming medical advancement across IoT innovation [30].

IoT-based healthcare services can be extended to a wide variety of areas, such as pediatric and older population treatment, chronic disease surveillance, and the supervision of personal fitness and health, among others. The internet has been defined more broadly and becomes more commonplace with the Internet of Things. IoT enables seamless interactions between various devices, for instance, sensor devices, security cameras, consumer products, etc. Therefore, IoTs have become more effective facilities in a variety of ways of wireless communications such as in healthcare web development [31]. In health services, IoT includes several types of cheap sensors (portable, embedded, and environmental), allowing older people to enjoy advanced healthcare services everywhere, at any time.

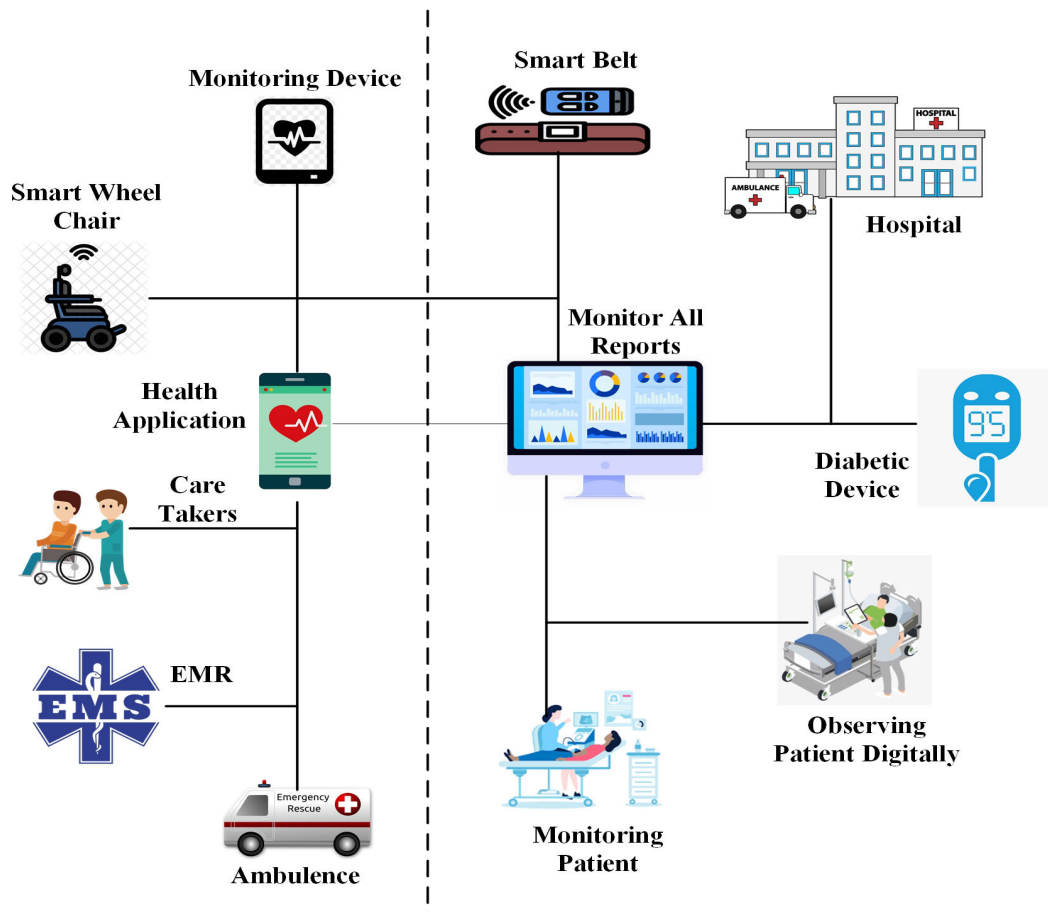


FIGURE 3. A scenario of IoT as well the assistance of medical internet-connected devices in medical industries. The various applications are implemented and operated by the different IoT for specific purposes. Therefore, the whole scenario is depicted for the patient assistance.

This greatly improves the quality of life of older people. In order to preserve the quality of life of individuals without imposing unwelcome behavioral or environmental changes, the community must thoughtfully consider the methods by which care should be provided to them, given the increase in the average lifespan and the community's ensuring progressive aging due to the prevalence of infectious diseases. [32]. Integrated IoT healthcare devices offer a glimpse into the future of healthcare delivery. These devices, equipped with advanced sensors, connectivity, and technologies, enable seamless data collection, real-time monitoring, and remote healthcare management. Through remote patient monitoring, wearable devices, and medication management systems, healthcare providers can collect real-time data on patient vital signs, track their activities, and ensure medication adherence. The integration of IoT devices with telehealth and telemedicine services facilitates virtual consultations, eliminating geographical barriers, and improving access to healthcare. In addition, integration of health data from multiple sources allows comprehensive patient profiles, personalized treatment plans, and data-driven insights for population health management. With the ability to remotely

manage chronic diseases and empower patients to take an active role in their healthcare, integrated IoT healthcare devices are revolutionizing the way healthcare is delivered and experienced [33].

B. THE EVOLUTION OF WEARABLE IoTs

With such rapid growth in the implementation of IoT applications and a growing willingness to provide treatment more cost-effective, personalized, and constructive, IoT is positioned to play important role in all aspects of healthcare services. Currently, 60% of health services already have adopted healthcare IoTs or IoMTs which is recognized as cost reductions, improved profitability, transparency and patient experience [34]. IoMT serves the potential needs of health sector shareholders, including investors, suppliers, distributors, stakeholders and doctors. By enabling the transition from disjointed facilities to structured treatment and proactive patient management strategies, it is ideally positioned to meet the demands of the changing medical industry. For instance, healthcare professionals must look to capitalize on this development by developing the right consumer applications, resources, and business plans in

TABLE 1. This table provides a comparative overview of existing surveys focusing on wireless communication in healthcare, highlighting their strengths, weaknesses, and technology used to the field.

Author	Title	Year	Technology Used	Strength	Weakness
Y. Zhang et al.	Machine Learning-Driven Wireless Networks for Personalized Healthcare in Smart Cities	2024	Machine Learning, Wireless Network	1) Introduces a novel concept of machine learning-powered wireless networks for healthcare. 2) The author discusses potential applications for personalized medicine and chronic disease management and explores integration with smart city infrastructure.	1) Emerging research area, limited real-world validation available. 2) Requires further investigation into resource constraints and Scalability.
M. Chen et al.	Security and Privacy Challenges in Wireless Body Area Networks for Remote Patient Monitoring	2023	WBAN	1) Provides a detailed analysis of security and privacy risks in WBANs. 2) Proposes potential solutions for secure data transmission and access control. 3) Emphasizes the importance of user privacy and regulatory compliance.	1) Focuses primarily on technical aspects,limited discussion on user experience. 2) Does not cover broader healthcare applications beyond remote monitoring.
C. Wang et al.	Enabling Remote Mental Health Interventions through Secure and Reliable Wireless Communication	2023	Low-latency video conferencing	1) Emphasizes the need for reliable wireless communication for remote mental health services. 2) Discusses potential technologies like low-latency video conferencing. 3) Addresses challenges related to patient confidentiality and emotional well-being.	1) Focuses on specific mental health applications, lacks broader discussion on telemedicine. 2) Limited exploration of ethical considerations in remote mental healthcare.
S. Biswas et al.	Wireless Communication Technologies for Assistive Living in Aging Populations	2022	Wearable devices, Wireless communication	1) Explores the role of wireless communication in supporting independent living for older adults. 2) Discusses applications such as fall detection and medication adherence monitoring. 3) Analyzes energy efficiency considerations for wearable devices.	1) Primarily focuses on in-home settings, needs further exploration for outdoor assisted living. 2) Limited discussion on user interface design for elderly users.
Ahmad et al.	Wireless Communications for the Hospital of the Future: Requirements, Challenges and Solutions	2020	Hybrid optical-radio networks, 6G	1) Comprehensive overview of future hospital needs in wireless communication. 2) Discusses potential solutions such as hybrid optical-radio networks and 6G. 3) Identifies key challenges like security and network capacity.	1) Lacks in-depth analysis of specific technologies. 2) Limited discussion on real-world deployments.
A Ray et al.	Role of Wireless Communication in Healthcare System to Cater Disaster Situations Under 6G Vision	2020	6G, IoMT	1) Highlights the importance of wireless communication in disaster response. 2) Discusses potential of IoMT and robots for remote healthcare delivery. 3) Explores 6G capabilities for improved network resilience.	1) Focuses primarily on conceptual framework. 2) Lacks concrete examples of disaster response applications.

order to survive the intense competition that both start-ups and technology companies are fostering. If customers take responsibility with their well-being and demand better access to clinical details, an incremental shift is needed in the process of extracting these data to provide useful insights [35], [36].

The evolution of wearable IoHT devices has witnessed significant advancements, revolutionizing the way we monitor and manage our health. These wearable devices have evolved from basic fitness trackers to sophisticated health monitoring systems that integrate seamlessly into our daily lives. Initially focused on tracking steps and calorie consumption, wearable IoHT devices now offer a wide range of capabilities, including continuous monitoring of vital signs such as heart rate, blood pressure, and oxygen levels. They can also monitor sleep patterns, stress levels, and even detect falls or irregularities in physical activity. The miniaturization of sensors, advances in wireless connectivity, and improvements in battery life have played a pivotal role in this evolution [5]. In addition, wearable IoHT devices have become more intuitive and user-friendly, with sleek designs and customization interfaces that make them comfortable and easy to use [37]. With the potential to empower individuals to take control of their health and facilitate remote healthcare management, the evolution of portable IoHT devices signifies a promising future in personalized healthcare [38]. Table 1 presents the existing surveys of wireless communication in healthcare infrastructure, along with key points.

The marketplace anticipates the release of more advanced, intelligent, and integrated clinical tracking devices in the coming years. These devices will be able to collect the necessary data, including primary characteristics and genetic elements. This links the patients to doctors and facilitates the transmission of medical information over a reliable network, which in turn eliminates unnecessary hospital admissions and dramatically decreases the burden on healthcare systems. As the longevity of people's lives increases with rapid advances in medicine and quality of life, it is significant to monitor the condition of patients on a routine basis [39]. This examination method assesses the role of smart devices and insights in facilitating digital transformation in healthcare [40]. Consequently, the wearable sensor ecosystem that is embedded within and surrounding the object serves to gather and assess, recognize and categorize hazards, alert, make judgments, and take action [41]. The IoMT market has five areas of application with this underlying theory. A scenario of IoHT as well as the assistance of medical internet-connected devices in medical industries is shown in fig. 3.

However, the wearable devices such as smart devices, peripherals and implants are included in the on-body area. Even though the digital/virtual helpers, tracking operation, and home medical equipment are included in domestic environment. In various healthcare applications, IoTs originates from hospitals and plays an important role [42]. By analyzing physiological parameters along with the

symptoms and transferring critical signs to medical review, wearable sensors detect rare and unexpected conditions [43]. Sensors, including triaxial accelerometers, magnetometers, altimeters, and gyroscopes, are used to generate an efficient virtual system [44]. The wearability sensor feature provides credibility to such applications and enables the compilation of behavioral or movement details to be personalized based on the end-user application. This study aimed to explore the growth of present and future applications of wearable technology of the IoTs in the health and care field [45]. A wide variety of metrics, awareness, behavior, diet and lifestyle, analysis, surveillance, and integration are applied to fitness trackers, applications, data search engines, and websites [46]. The wearable IoT (WIoT) approach is a technical infrastructure that interconnects wearable sensors to track human factors, e.g. health, well-being, behavior, and other information, useful to enhance the quality of life of individuals [47]. More than one hospital has begun using smart beds that can sense a patient's presence and automatically adapt to the right angle and pressure to ensure that the caregiver does not have to act correctly. Table 2 presents the recent surveys of IoHT in Medical hospitals along with wireless communication in healthcare.

C. MOTIVATION OF THIS STUDY

The next generation of practical devices to enhance human-assisted lives would be medical equipment connected to the Internet. The current requirements of operations and medical assistance facilitate the patients through advanced enabled Internet connected tools. To cope with medical care issues, the Internet of Things has attracted impressive attention. This is elaborated as a term for the interconnected group of individuals or electronic devices in open space and anywhere on any network. This is also a buzzword for the next-generation technology that could have an effect on the entire industry spectrum. It can be thought of as a connection between uniquely recognizable smart devices objects throughout current social media networks with enhanced benefits [48].

However, the health-care sector is one of the most promising IoT integrated sectors where connected devices could take up several clinical uses, such as remotely medical control, wellness services, chronic diseases, and care for elderly patients. Compliance with care and medications at home by healthcare professionals, which is yet another possible effective use. As a result, various consumer electronics, detectors, and diagnostic imaging appliances may be regarded as advanced objects or devices forming a central part of the IoT approach. An enabled IoT-based healthcare systems is supposed to minimize costs, boost the standard of life, and enhance the customer experience. In fact, the IoT will correctly determine the optimal times for the refueling of the different devices for their rapid and steady operation. Furthermore, IoT allows for the effective allocation of scarce resources by maintaining their optimal

TABLE 2. Recent Surveys Conducted in Internet of Healthcare Things in Medical Hospitals provides an overview of key research studies examining the implementation and impact of IoHT in healthcare settings. The table summarizes essential details including primary focus, key findings, and methodological approach for each survey. This compilation serves as a foundation for identifying research gaps, emerging trends, and potential areas for future exploration within the IoHT domain in medical hospitals.

Author	Title	Year	Main Contribution
Ziwei et al. [38]	The applications of internet of things in smart healthcare sectors: a bibliometric and deep study	2024	1) This study provides a comprehensive bibliometric analysis of IoT applications in healthcare, identifying key research trends, influential authors, and institutions. 2) By visualizing knowledge domains and identifying research gaps, this paper contributes to a better understanding of the current state and future directions of IoT in healthcare. 3) This research explores the integration of IoT with other technologies (e.g., AI, blockchain) to create innovative healthcare solutions.
Shantinath et al. [44]	Revolutionizing Healthcare through the Internet of Things: Current State and Future Implications	2024	1) This study provides a comprehensive bibliometric analysis of IoT applications in healthcare, identifying key research trends, influential authors, and institutions. 2) By visualizing knowledge domains and identifying research gaps, this paper contributes to a better understanding of the current state and future directions of IoT in healthcare. 3) The study offers a systematic review of IoT applications across various healthcare sectors, highlighting their potential benefits and challenges.
Suleski et al. [41]	A review of multi-factor authentication in the Internet of Healthcare Things	2023	1) Identify key challenges and opportunities associated with implementing MFA in healthcare settings. 2) Evaluate the effectiveness of different MFA approaches in the IoHT environment. 3) Propose recommendations for improving MFA solutions to enhance security and usability in healthcare and Highlight the importance of MFA in safeguarding sensitive patient data and protecting the integrity of IoHT systems.
Islam et al. [43]	Multi-level feature fusion for multimodal human activity recognition in Internet of Healthcare Things	2023	1) The paper introduces a specific architecture combining multi-head Convolutional Neural Networks (CNN) with Convolution Block Attention Module (CBAM) for visual data processing and Convolutional Long Short-Term Memory (ConvLSTM) for handling time-series sensor data. This carefully designed architecture enables efficient feature extraction and fusion. 2) The experimental results show that the proposed multimodal HAR framework outperforms existing state-of-the-art methods in terms of various performance metrics, highlighting the efficacy of the multi-level feature fusion approach.
Verma et al. [46]	A Comprehensive review of Internet of Healthcare Things: Networking aspects, technologies, services, applications, challenges, and security concerns	2023	1) Highlights the potential of IoHT in various healthcare domains, such as patient monitoring, remote care, and healthcare management, while also discussing the underlying services that support these applications. 2) Identifies and discusses the technical, operational, and regulatory challenges that hinder the widespread adoption of IoHT. 3) It emphasizes the critical importance of security and privacy in IoHT and provides insights into potential threats, vulnerabilities, and mitigation strategies.

utilization and more patient care [34], [49]. In addition, low adherence to medications is a major concern for both physicians and healthcare providers. Improving health information technology programs and amenities is highly essential to meet the needs of this huge community.

The integration of healthcare and 5G wireless communication technology has immense motivation and potential for transformative advances in healthcare and beyond. The combination of these technologies aims to revolutionize healthcare delivery, improve patient outcomes, and drive innovation in various industries. The motivation behind this

convergence lies in the need for connected and intelligent healthcare systems that can address the challenges faced by traditional healthcare models [50]. IoT and IoHT enable the seamless integration of medical devices, wearable and infrastructure, allowing remote patient monitoring, personalized medicine, and efficient healthcare management. These technologies enable patients to take control of their health, enable healthcare providers to provide personalized and proactive care, and optimize healthcare resources and operations. The introduction of 5G wireless communication technology further amplifies the motivation for integrating

IoT and IoMT. 5G offers ultrahigh bandwidth, ultra low latency, and massive device connectivity, allowing real-time transmission of critical health data, supporting complex medical applications, and facilitating remote consultations and surgical procedures [51].

Through 5G, healthcare providers can take advantage of advanced technologies such as augmented reality (AR), virtual reality (VR), and artificial intelligence (AI) to provide accurate diagnostics, precision medicine, and advanced healthcare delivery. Moreover, the motivation for these technologies with 5G has potential for smart cities, transportation, industrial automation where connected devices, intelligent systems, and real-time data analysis can drive efficiency, sustainability, and innovation. Motivation is driven by the desire to improve healthcare care outcomes, improve patient experiences, and drive advancements in various industries. The convergence of these technologies opens up new possibilities for connected healthcare, personalized medicine, and efficient operations, paving the way for a future where data-driven insights and intelligent systems shape the healthcare landscape and improve the quality of life of people around the world.

D. CONTRIBUTION OF THIS STUDY

- This study explores innovations in IoT-based healthcare technology and discusses the state-of-the-art network designs/systems, implementations, and technological patterns. Further, this study is carried out the unique characteristics of IoT protection and privacy, including safety criteria, vulnerability assessments, and attack taxonomy in a healthcare context. This research also investigates an interactive intelligent safety model to mitigate security risks and explores different technologies such as big data, ambient intelligence, and wearable devices. In the context of healthcare, it can be used to address global IoT e-healthcare policies and laws that support sustainable development in local economies. In contrast, it offers some pathways for potential IoT-related clinical research that focuses on a collection of open problematic concerns.
- This review study provides informative information about medical tools in different ways as crucial components for a series of solutions or implementation. For a more detailed understanding of this topic, it shows information directed to the literature. The subsequent sections address different forms of IoT healthcare facilities.
- To gain a more in-depth insight into market trends and the emerging technologies, this paper offers a wider view of how significant recent advances in sensors, computers, web technologies and other innovations have driven accessible healthcare accessories related healthcare services to broaden the scope of IoT-based healthcare services along with projects and grants and wireless communication to even further advances.

II. WIRELESS COMMUNICATION IN HEALTHCARE NETWORKS

A. REMOTE PATIENT MONITORING

Remote patient monitoring (RPM) is a transformative advancement within the healthcare sector that allows healthcare practitioners to remotely monitor the physical condition of their patients, even in their absence from the hospital. This advanced system is based on wireless communication technology, facilitating the seamless transmission of medical data between patients and healthcare professionals in the business [52]. The use of wireless communication for RPM represents a significant advancement in the field of medical technology. This capacity enables the facilitation of continuous monitoring, early intervention, improved patient convenience, and increased patient engagement [53].

The use of RPM enables individuals to effectively track their essential physiological indicators, physical activity levels, and other relevant health data via the integration of wearable devices, such as smart watches and sensors. These devices have the ability to securely transmit data to healthcare professionals in real time, eliminating the need for patients to often visit the hospital. This enables continuous monitoring of the patient's health conditions [54], [55], [288]. Wireless communication plays a crucial role in facilitating data transit due to its reliability and efficiency. The use of secure networks enables the seamless transmission of patient data, including vital signs, medical history, and even video consultations. The use of wireless connectivity ensures that healthcare professionals can efficiently access accurate and timely information, empowering them to make informed decisions about patient care. The use of wireless communication has facilitated RPM, leading to notable advancements in healthcare systems [56]. To begin with, RPM promotes a proactive and preventive approach to healthcare, as it allows healthcare providers to observe the health patterns of their patients and detect potential problems at an earlier stage.

The metaverse presents a compelling frontier for revolutionizing remote patient monitoring, consultations, virtual rehabilitation, and immersive training within the healthcare landscape [57]. For RPM, the metaverse can transcend the limitations of traditional wearable sensors and video calls by creating shared virtual environments where clinicians can interact with patient's simulated avatars and real-time physiological data displayed in an intuitive, three-dimensional format. This immersive experience can improve understanding of patient conditions and facilitate more proactive and personalized care [58]. Remote consultations can evolve from two-dimensional video conferences to virtual holographic meetings within realistic clinic or home settings, fostering a stronger sense of presence and relationship between patients and healthcare providers [59]. Virtual rehabilitation can utilize the metaverse to deliver interactive and gamified exercise programs tailored to individual patient needs, providing real-time feedback and motivation in engaging virtual

environments that promote adherence and recovery [60]. Furthermore, the metaverse offers unparalleled opportunities for immersive training of healthcare professionals through realistic simulations of complex medical procedures, emergency scenarios, and collaborative teamwork, ultimately enhancing skills and preparedness without risk to real patients [61]. This convergence of wireless communication and immersive virtual environments has immense potential to empower patient care, improve accessibility, and transform healthcare education and training methodologies.

Early intervention in healthcare has been found to mitigate issues, reduce hospital readmissions, and improve patient outcomes [62]. The patient's comfort and accessibility to healthcare services are both improved by RPM. Patients have the option of being remotely monitored from the comfort of their own home, which alleviates the burden of frequent hospital visits. This intervention is particularly beneficial for those affected by chronic diseases or experiencing limited physical mobility. This approach also provides healthcare professionals with more flexibility as they can simultaneously monitor several patients, efficiently allocate resources, and respond quickly to urgent circumstances [63]. The use of wireless RPM serves to promote enhanced patient engagement, empowering individuals to assume an active role in the administration of their own well-being. Patients who acquire real-time data and individualized feedback are prone to actively participate in the design of their care plans, leading to increased adherence to treatment regimens and the adoption of healthier lifestyles [64].

When implementing remote patient monitoring, it is essential to adequately address concerns related to patient privacy and security. In order to ensure the protection of patient's personal information, healthcare institutions must establish robust data encryption measures, enforce rigorous access controls, and adhere to relevant privacy laws and regulations. Furthermore, it is essential that healthcare professionals have the knowledge and training to assess and address remote monitoring data effectively. RPM has the potential to significantly transform the healthcare delivery system by enabling proactive and individualized treatment approaches, while ensuring patient privacy and ensuring the protection of sensitive data. As technological advances continue, the potential for a revolution in the form of RPM may be realized [65]. A visual representation of the RPM system is shown in Fig. 4.

1) WIRELESS SENSORS AND DEVICES FOR REMOTE MONITORING

In recent years, wireless sensors and devices have emerged as significant disruptor in the field of remote monitoring. The aforementioned improvements possess the capacity to improve the delivery of healthcare services, while simultaneously empowering individuals and healthcare workers with more autonomy. These state-of-the-art technologies enable the collection of real-time data pertaining to the health

conditions of patients, even in cases where the patients are geographically far from the medical facility. This approach reduces the need for frequent hospital visits and promotes a proactive and personalized approach to medical care [66]. The use of wireless sensors and devices for remote monitoring has significantly transformed the healthcare landscape, allowing the provision of enhanced preventive measures and personalized therapy, while simultaneously improving patient comfort and participation. These tools enable continued monitoring, prompt intervention, and fast modifications of treatment programs [67]. Instances of such technology include implanted sensors designed to monitor chronic conditions, as well as wearable devices that measure vital signs. These technologies enable people to actively participate in the management of their own health and provide healthcare professionals with crucial data to facilitate better informed decision making. The ongoing advancement of wireless technology has significant prospects for the future of remote monitoring, which could revolutionize healthcare delivery, improve patient outcomes, and foster a patient-centric healthcare system. This study explores a diverse range of wireless sensors and devices used in remote monitoring, examining their impact on the healthcare sector. The technologies investigated include implanted sensors and wearable devices [68].

- Wearable Devices:** Wearable technology, including smartwatches, fitness trackers, and wearable patches, has significantly revolutionized the notion of remote monitoring. These devices are equipped with a variety of sensors, allowing them to effectively monitor an extensive range of data, including vital signs, activity levels, sleep patterns, and other relevant metrics. Heart rate monitors provide real-time data on an individual's pulse, allowing healthcare professionals to detect abnormalities or irregularities in their patient's heart rhythms [69]. Similarly, wearable patches have the potential to evaluate body temperature or wearer blood pressure, enabling remote monitoring of these crucial health indicators. The seamless transmission of data to healthcare professionals or monitoring systems is facilitated by the wireless connectivity of these wearable devices. The collected data are sent in real time through a secure wireless link, enabling the continuous monitoring of patient health patterns by medical professionals. This allows for timely responses to possible emergencies and informed decision-making on treatment protocols. Wearable devices provide individuals with the opportunity to actively participate in the management of their health by providing personalized feedback and promoting the adoption of healthier lifestyle choices [70].
- Implantable Devices:** The advent of wireless-enabled implantable devices has significantly transformed remote monitoring of patients with chronic conditions. Pacemakers, implantable cardioverter defibrillators

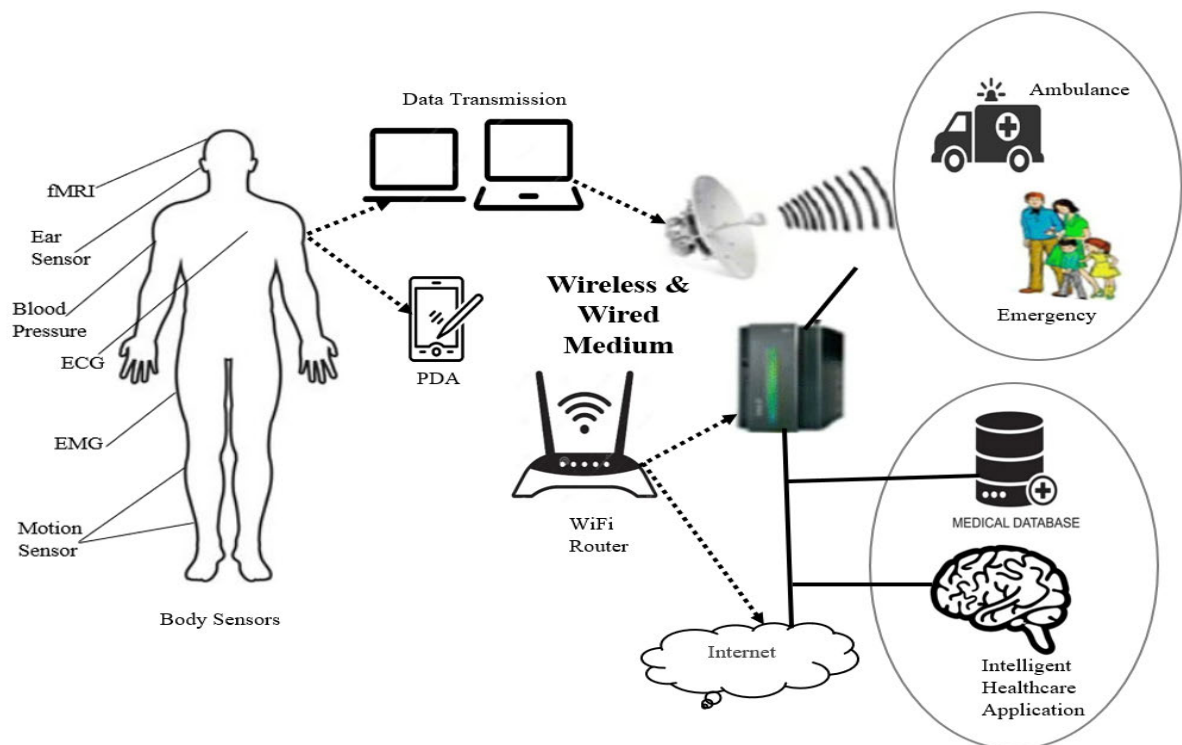


FIGURE 4. The diagram illustrates the interconnected components of an RPM system, including wearable or implantable medical devices for data collection, wireless communication networks for data transmission, and a centralized platform for data aggregation, analysis, and decision support. Healthcare providers can remotely monitor patient vital signs, symptoms, and medication adherence, enabling timely interventions and improved patient outcomes.

(ICD), and insulin pumps exemplify the many medical devices capable of wirelessly collecting and transmitting patient-specific data. For example, pacemakers are involved in continuous monitoring of cardiac activity, detecting deviations from normal functioning, and transmitting this information to relevant healthcare professionals. This obviates the need to conduct in-person visits for the purpose of remotely evaluating the patient's cardiac state and modifying treatment protocols. Implantable sensors play a crucial role in the management of diseases such as diabetes. Continuous glucose monitoring (CGM) devices use tiny sensors that are subcutaneously implanted to assess glucose levels in the interstitial fluid. Sensors provide data transfer to external devices via wireless means, therefore, providing patients and healthcare professionals with valuable information on the management of blood glucose levels [71]. A visual representation of the RPM system is shown in Fig. 4.

- **Ambient Sensors:** The environment in which a patient resides is equipped with sensors that have the capability to monitor various factors that could potentially impact their well-being. Wireless sensors have the ability to monitor several parameters such as movement, temperature, humidity, and air quality. For example, environmental sensors may be used in eldercare facilities

to identify instances of falls or monitor the room temperature, therefore ensuring the patient's comfort and safety. The insights offered by these sources are valuable in understanding the living conditions of patients, as they uncover potential health risks or environmental factors that can contribute to various disorders. The use of wireless connectivity in ambient sensors facilitates instantaneous transmission of data, thus empowering medical professionals to remotely monitor the environmental conditions of patients and make informed decisions based on the collected information [72]. The integration of environmental sensors into remote patient monitoring systems has significant advantages in terms of enhancing patient safety and overall well-being.

2) REAL-TIME DATA TRANSMISSION AND ANALYSIS

Real-time transmission and interpretation of data play crucial roles in modern healthcare systems. These components have significantly revolutionized the approach to collecting, transmitting, and analyzing patient information. The capacity to capture and analyze data in real time has significant implications for decision making within the healthcare sector. This capability facilitates early interventions, personalized medications, and improved patient outcomes [73]. This discussion aims to delve further into the importance of

real-time data transmission and processing within the medical domain, as well as its consequential impact.

The phrase “real-time data transmission” refers to the seamless and prompt transfer of patient information from various sources to healthcare professionals. The use of technologies such as wireless communication, IoT-linked devices, and cloud-based information storage and processing systems is necessary for this purpose. Through the use of these technologies, healthcare professionals can have instant access to crucial patient information, including vital signs, medical records, diagnostic test results, and data derived from wearable devices [74]. The use of real-time data transmission ensures that healthcare professionals have access to current and accurate information readily available, reducing any potential delays in acquiring vital patient data. The use of real-time data transfer also contributes to minimizing potential human errors. The prompt availability of this information enables healthcare professionals to make informed decisions quickly, which is especially advantageous in critical situations. The use of real-time data transmission enables medical personnel to receive timely alerts in the case of a patient’s deteriorating state, allowing them to quickly intervene and perhaps prevent a crisis or mitigate the severity of complications [75].

Real-time data transmission also allows remote monitoring, which is a successful technique to manage chronic diseases and allows healthcare professionals to consistently assess the health status of their patients. Patients are presented with the choice of using home monitoring systems or wearable devices to collect and transmit health-related data to their healthcare professionals. The use of remote monitoring enables the detection of anomalies or deviations from standard health indicators in an earlier phase, thus facilitating proactive interventions and personalized healthcare [76]. Real-time data transfer has several beneficial consequences. Firstly, it enables prompt interventions, which might be crucial in situations when swift action is required to prevent undesirable outcomes. In addition, it improves operational effectiveness by streamlining communication between healthcare providers and reducing administrative burdens related to manual data entry or physical transfer of medical records. This is the way in which it achieves the subsequent objective of improving efficiency [77]. In addition, the use of real-time data transmission fosters patient participation and empowerment by giving individuals the ability to access their own health information. This, in turn, facilitates collaboration and shared decision-making between patients and healthcare professionals. This objective is achieved by giving people autonomy and authority over their own health data [78].

The primary objective of real-time data analysis is to analyze and interpret data promptly upon their receipt. This analytical process works in conjunction with real-time data transmission. The use of sophisticated analytics techniques, such as machine learning and artificial intelligence, is necessary to derive significant patterns and

trends from the vast amounts of real-time healthcare data. These methodologies are crucial to this procedure. Real-time data analysis facilitates the prompt identification of adverse events, giving medical care providers more control. Specialists in the healthcare industry have the ability to identify abnormalities or patterns indicative of deterioration of health conditions by continuous monitoring of data streams and the use of algorithms [64]. The ability to identify potential issues in their early stages can lead to the implementation of suitable treatment strategies, therefore reducing the risk of complications or adverse outcomes. Furthermore, real-time data analysis allows for the development of personalized therapeutic treatments. Medical professionals can customize treatments and interventions to meet the unique needs of each patient using real-time data analysis related to individual patients. This process involves considering several factors, including the patient’s genetic markers, medical history, and contemporaneous health characteristics. The use of a customized method has been shown to improve therapeutic outcomes while also reducing the probability of encountering adverse consequences [79].

Another notable use of real-time data analysis is often referred to as predictive analytics. Healthcare professionals can identify probable future health problems or the development of diseases through the integration of real-time data and historical data, as well as the use of predictive models. This enables the implementation of preventive measures, modifications of treatment strategies, and the initiation of proactive interventions to mitigate the probability of unfavorable outcomes. The use of real-time data analysis significantly improves the management of population health. The study of aggregated real-time data obtained from a cohort of patients enables the identification of population health trends, the surveillance of disease outbreaks, and the evaluation of therapeutic effectiveness [80]. This data-driven approach enables healthcare companies to optimize resource allocation, implement precise public health interventions, and make evidence-based decisions to improve population health outcomes.

The healthcare business is undergoing a significant transformation through the use of real-time data transmission and analysis. This advancement streamlines the process of data-driven decision making and facilitates rapid access to critical patient information. These advances enable medical professionals to act more quickly, customize patient care, and achieve better overall results for their patients [81]. The use of real-time data transmission and analysis is poised to play a progressively significant role in transforming healthcare care delivery, facilitating advances in individualized treatment, and strengthening efforts to effectively control population health, as technological advancements continue to unfold.

3) ENHANCING PATIENT ENGAGEMENT AND SELF-MANAGEMENT

The significance of real-time data transmission and processing is increasing in the provision of contemporary healthcare services. Enhancing patient engagement and self-care is a

TABLE 3. This table presents a comparative analysis of recent surveys focusing on remote patient monitoring (RPM). The surveys are evaluated based on their publication year, primary focus, technological aspects covered, challenges addressed, and proposed solutions. This overview provides insights into the evolving landscape of RPM research and identifies gaps in existing literature that can be addressed by this study.

Author	Title	Year	Main Contribution
Pannunzio et al. [82]	Patient and Staff Experience of Remote Patient Monitoring—What to Measure and How: Systematic Review	2024	1) The authors pinpointed the essential elements of patient and staff experiences related to RPM, providing a structured vocabulary for future research. 2) The paper offers a valuable resource by listing a variety of tools used to measure these experiences, aiding researchers in selecting appropriate methods. 3) The review emphasizes the under representation of staff experiences in RPM research, indicating a need for more focus on this crucial aspect.
Tan et al. [83]	A systematic review of the impacts of remote patient monitoring (RPM) interventions on safety, adherence, quality-of-life and cost-related outcomes	2024	1) Synthesized evidence on the impact of RPM across various patient populations and chronic conditions and Identified trends in the effectiveness of RPM interventions in improving patient safety, adherence, and quality of life. 2) Quantified the potential cost-saving benefits of RPM implementation through reductions in hospitalizations, readmission, and length of stay. 3) Highlighted knowledge gaps and areas for future research to inform the optimal design and implementation of RPM programs.
Pavithra et al. [52]	Secure Impact of Remote Patient Monitoring Systems on Nursing Time, Healthcare Providers, and Patient Satisfaction in General Wards	2024	1) Remote Patient Monitoring (RPM) systems significantly reduce the time nurses spend on routine patient monitoring tasks. By automating data collection and providing real-time alerts, nurses can prioritize their time on direct patient care activities, leading to increased efficiency and improved patient outcomes. 2) RPM systems enhance collaboration among healthcare providers by facilitating efficient information sharing and communication. Real-time access to patient data empowers providers to make informed decisions, leading to improved patient care coordination and potentially reduced medical errors.
Vudathaneni et al. [56]	The Impact of Telemedicine and Remote Patient Monitoring on Healthcare Delivery: A Comprehensive Evaluation	2024	1) Telemedicine and remote patient monitoring (RPM) significantly enhance patient outcomes. Early disease detection, increased adherence to treatment plans, and timely interventions lead to better health management. Chronic disease patients, in particular, benefit from continuous monitoring and personalized care. 2) Geographic and socioeconomic barriers to healthcare are mitigated through telemedicine. Rural and under served populations gain access to specialists and essential services. RPM empowers patients to manage their health proactively, reducing emergency room visits and hospitalizations. 3) Called for more investment in RPM research and development, as well as broader adoption of RPM in clinical practice.
Boikanyo et al. [69]	Remote patient monitoring systems: Applications, architecture, and challenges	2023	1) RPMS significantly improve healthcare delivery by enabling continuous monitoring of patients with chronic conditions. These systems facilitate early detection of health deteriorations, reducing hospitalization rates and improving patient outcomes. 2) RPMS typically consist of wearable or implantable sensors, data transmission networks, and a central monitoring station. Advanced systems incorporate data analytics and artificial intelligence for predictive modeling and automated alerts. 3) Discussed the challenges and opportunities for the future of wearable devices in RSPM.

pivotal component in modern medical practices. Healthcare systems might potentially improve patient outcomes and promote a patient-centered approach by facilitating patient access to their own health data and allowing them to actively participate in controlling their healthcare. The use of real-time data enables patients to assume an active role in their treatment, leading to improved health outcomes, increased patient satisfaction, and a more proactive approach to overall health and well-being. This study aims to examine the impact of real-time data transmission and analysis on enhancing patient engagement and self-management [84].

- **Personalized and Customized Care:** Real-time data analysis allows medical practitioners to deliver customized therapy to patients according to their specific needs. Healthcare practitioners may get valuable insights into the unique health patterns and individualized needs of each patient via the analysis of real-time gathered data. Subsequently, this data may be used to design individualized treatment strategies, define realistic goals, and provide targeted therapies. Individuals afflicted with chronic illnesses such as diabetes or hypertension might potentially get advantages from the provision of customized feedback derived from the real-time collection of their unique data. Healthcare practitioners have the ability to evaluate the data and afterwards provide recommendations for modifying medication, enhancing lifestyle, or implementing behavioral changes [83]. The real-time analysis of data enhances the precision of these recommendations and enables users to engage in more efficient self-management practices. Table 3 represents the analysis of recent surveys in RPM.

- **Patient Education and Empowerment:** The real-time transmission and analysis of data have shown to be advantageous in facilitating the education and empowerment of patients. Patients are provided with the opportunity to get educational materials, helpful recommendations, and reminders based on the real-time data acquired from them. For example, a patient diagnosed with asthma experiencing a decline in pulmonary function may be provided with educational resources pertaining to the identification and avoidance of triggers, as well as techniques for effectively managing their symptoms. These interventions may assist the individual in achieving improved management of their medical condition [85]. The use of real-time data analysis might potentially enhance patient's comprehension of the impact their activities have on their health outcomes. The grasp of the cause-and-effect relationship is enhanced among patients when they are able to see their development and observe the impact of their activities on their health markers. As a result of this comprehension, individuals are capable of making informed decisions, embracing more favorable conduct, and assuming responsibility for their own well-being.

- **Behavioral Change and Motivation:** The real-time transmission and analysis of data facilitate the implementation of remote monitoring and virtual care models, hence enhancing patient engagement and empowering patients to take charge of their own treatment. In the context of virtual consultations or telehealth sessions, patients have the capability to share their real-time data with healthcare specialists responsible for their treatment. As a result of this, healthcare professionals possess the capability to assess the patient's data in conjunction with the patient, engage in a dialogue on the many treatment options that are accessible, and collaboratively reach a decision [86]. This is strongly urged to maintain regular communication between patients and their healthcare providers via the use of remote monitoring. Patients possess the capacity to regularly transmit their health information, while healthcare practitioners possess the capability to provide feedback, address inquiries, and deliver support [87]. The ongoing exchange of information and guidance not only enhances patient engagement but also enables patients to cultivate personalized self-management strategies tailored to their own needs.

B. HEALTHCARE INFRASTRUCTURE OPTIMIZATION

The concept of "Healthcare Infrastructure Optimization" pertains to a purposeful and systematic approach that seeks to enhance the entire functioning of healthcare systems, including their efficiency and effectiveness. This process includes the execution of an analysis, strategic planning, and implementation of alterations to the physical and technological infrastructure with the aim of meeting the ever-evolving needs of patients, healthcare professionals, and the healthcare system as a whole. The objective of this optimization process is to improve patient outcomes, streamline procedures, and ensure the provision of high-quality care to every individual patient [88]. The optimization of healthcare infrastructure is a holistic approach that encompasses several aspects such as resource management, technological integration, workflow optimization, infrastructure resilience, patient engagement, and ongoing improvement. Healthcare organizations have the potential to enhance their operational efficiency, enhance patient care, and effectively respond to the dynamic needs of both patients and healthcare providers by implementing these strategies [89]. Organizations have the capacity to improve the overall efficiency of the healthcare system via the optimization of their infrastructure, therefore facilitating the delivery of patient-centered, high-quality treatment. This is achieved by continuous evaluation and adjustment to evolving demands within the healthcare sector.

The strategic development and architectural design of healthcare facilities play a crucial role in enhancing the overall healthcare infrastructure. The management of patient flow, optimization of spatial resources, and integration of technological advancements are all subjects of meticulous

consideration within healthcare institutions. Optimizing the layout has the potential to enhance patient mobility, reduce waiting times, and increase overall operational efficiency. The use of patient-centered design principles contributes to the creation of a therapeutic setting that augments the degree of comfort and satisfaction perceived by those seeking medical care [90]. The optimization of healthcare infrastructure is contingent upon the effective allocation and management of existing resources. The optimal allocation of resources is contingent upon the proficient management of equipment, supplies, and labor levels that exhibit both effectiveness and efficiency. This entails the use of data analytics and real-time monitoring technology to identify areas with insufficient resources, optimize inventory levels, and ensure the timely availability of essential resources as needed. The effective allocation and utilization of resources not only leads to improved patient care, but also reduces wastage and contributes to cost savings for enterprises [91]. The use of technology is a crucial element in the optimization of healthcare infrastructure. Electronic Health Records (EHRs), which are also referred to as electronic medical records, telehealth platforms, and medical imaging systems, are illustrative instances of digital technologies that enhance clinical decision-making and facilitate the efficient transmission of information. The integration and interoperability of technology systems inside healthcare providers have the potential to enhance operational efficiency, reduce errors, and enhance patient outcomes. Moreover, the use of technology facilitates the ability to carry out consultations from a distance, promotes the exchange of information between patients and healthcare professionals, and streamlines the retrieval of up-to-date data. These advancements together contribute to the enhancement of decision-making processes [92].

The enhancement of healthcare operations quality and productivity relies on the optimization of workflow. Enhancements in the provision of care, reduction in wait times, and elimination of unnecessary steps may be achieved via the analysis and streamlining of processes, identification of bottlenecks, and implementation of standard operating procedures. The streamlining of workflow not only enhances the overall patient experience but also ensures the delivery of consistent and evidence-based therapy [93]. A diagram depicts the visual representation of Healthcare Infrastructure system in Fig. 5.

The preservation of treatment continuity in the face of unforeseen calamities necessitates the establishment of a resilient healthcare infrastructure. The establishment of a resilient infrastructure necessitates the incorporation of protocols pertaining to data backups, redundancy, cyber security, and contingency planning for natural calamities. Healthcare companies may enhance their ability to withstand and rebound from the impacts of pandemics, natural disasters, or cyber security breaches by allocating resources towards the development of resilient infrastructure. This facilitates

the safeguarding of patient data and the uninterrupted provision of therapy [94]. The involvement of patients and the establishment of effective channels of communication are key components in the endeavor to enhance healthcare infrastructure. The use of patient portals, digital communication channels, and remote monitoring systems empowers patients to actively participate in their own treatment. Patients are given enhanced opportunities to retrieve their health information and establish more effective communication channels with their healthcare providers. Enhanced patient engagement results in heightened patient satisfaction, greater adherence to treatment protocols, and improved overall health outcomes.

The incorporation of continuous improvement and evaluation is important in order to effectively use the healthcare infrastructure. By collecting and analyzing data pertaining to key performance indicators, patient satisfaction, and operational metrics, valuable insights can be obtained regarding areas that require improvement. Consistent evaluations and feedback from both patients and healthcare professionals play a crucial role in identifying opportunities to enhance outcomes through the optimization of infrastructure and the refinement of procedures [95].

1) WIRELESS COMMUNICATION IN HOSPITAL ENVIRONMENTS

The advent of wireless communication has had a profound impact on the hospital environment, leading to notable modifications in the modes of interaction, collaboration, and provision of medical treatment among healthcare professionals. The use of wireless technology in hospitals has resulted in significant improvements in communication efficiency, patient safety, and operational effectiveness. The aforementioned progress has been facilitated through the use of wireless technologies. The use of wireless technology enables medical professionals to conveniently access information, monitor patients in real-time, streamline procedures, enhance patient satisfaction, and enhance overall healthcare quality [96]. The rapid progress of wireless communication has greatly enhanced the potential for further innovation and transformation within healthcare settings, particularly when combined with other emerging technologies. The above enumeration comprises significant attributes pertaining to wireless communication within medical environments.

- **Enhanced Communication and Collaboration:** The term “Enhanced Communication and Collaboration” pertains to the capability of wireless communication to provide seamless and immediate contact among healthcare practitioners. The use of wireless technology, including as smartphones, tablets, and pagers, facilitates enhanced communication and information exchange among medical professionals and support staff, leading to improved coordination of patient care. This phenomenon fosters enhanced interdepartmental collaboration, expedited response durations, and

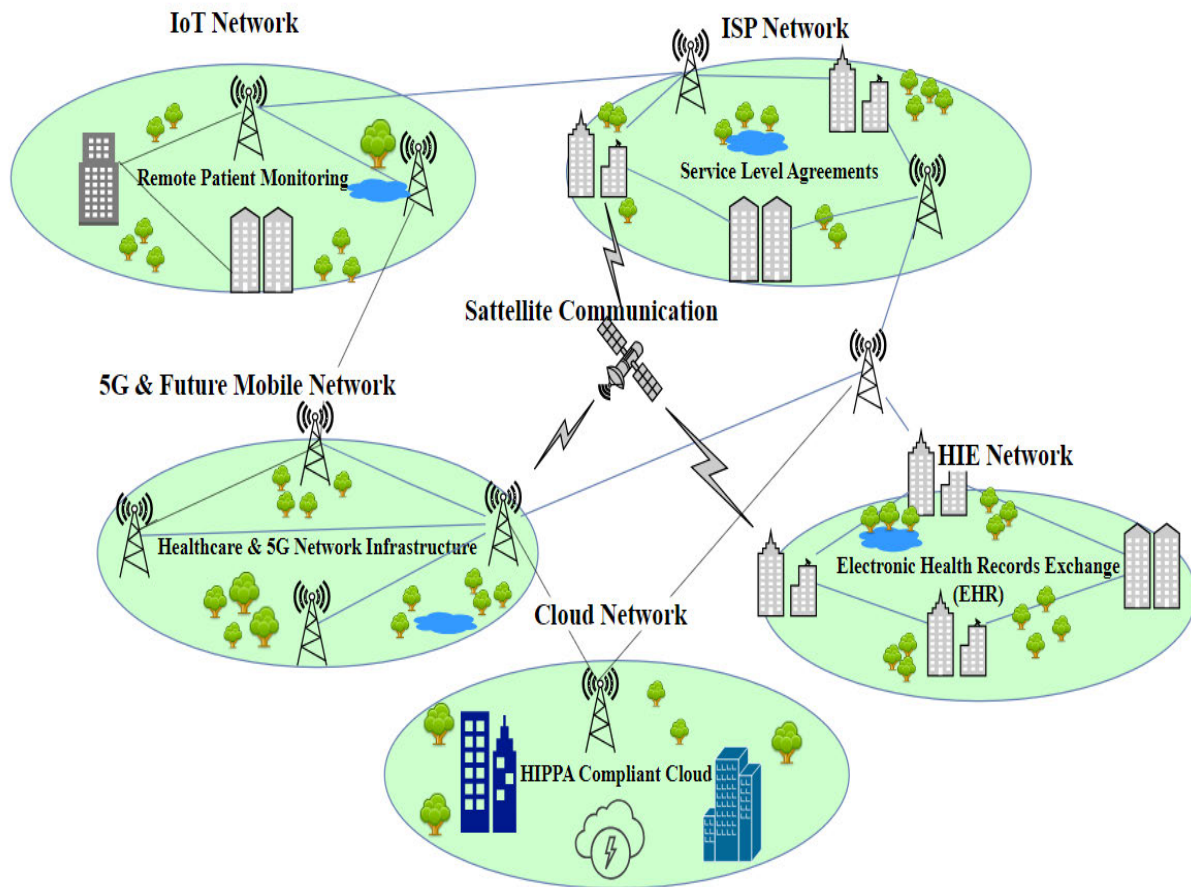


FIGURE 5. This diagram illustrates the primary obstacles hindering the effective implementation of wireless communication technologies in healthcare settings. It encompasses challenges related to network infrastructure, interoperability, spectrum allocation, regulatory compliance, and the potential impact on patient well-being. A comprehensive understanding of these challenges is essential for developing robust and secure wireless healthcare solutions.

ultimately improved outcomes for patients by enhancing communication between different departments [97].

- **Increased Mobility and Flexibility:** Wireless connection enables medical personnel to navigate the facility without constraints and access information from any point inside the campus. In the absence of a specific physical location or wired infrastructure, individuals possess the capability to engage in verbal communication with colleagues, access patient data, and input information directly at the site of medical treatment [98]. As a result of this enhanced mobility, there is an improvement in workflow efficiency, reduction in delays, and facilitation of rapid decision-making.
- **Real-time Monitoring and Alerts:** The use of wireless communication facilitates the ability to monitor patients in real-time and promptly issue alerts, hence enhancing patient safety and treatment efficacy. Wireless telemetry systems, for example, facilitate the transmission of patient's vital signs data to centralized monitoring stations [99]. These devices are designed to provide audible alerts in the event of abnormal readings or

situations that pose a risk to life. Due to the promptness of this notification, healthcare professionals are capable of promptly responding to critical situations, hence minimizing their response time.

- **Streamlined Clinical Workflows:** Wireless connection plays a pivotal role in enhancing the operational efficiency of healthcare systems via the reduction of manual labor required for documentation and procedural tasks. Medical workers have the ability to access electronic health records (EHRs) over wireless means, enabling real-time updates to patient files [100]. In addition, several departments, including radiology and laboratories, may receive electronic orders. The use of this approach enhances the accuracy, effectiveness, and expediency of clinical documentation, hence mitigating the occurrence of errors and delays.
- **Improved Patient Experience:** The use of wireless communication in hospital settings enables healthcare practitioners to allocate more time at the patient's bedside, therefore positively impacting the entire patient experience. Wireless devices have enabled doctors to

conveniently access patient information, document care, and engage with other members of the care team without the need to physically relocate from the patient they are attending to [101]. This facilitates enhanced communication between patients and healthcare professionals, fosters increased involvement, and ultimately results in elevated levels of patient satisfaction.

- **Asset Tracking and Inventory Management:** The use of wireless communication devices enables the real-time monitoring and administration of a hospital's assets and inventories. Hospitals may achieve efficient management of equipment, supplies, and pharmaceutical stocks via the use of radio frequency identification (RFID) technology or wireless tags [102]. The practice described reduces the likelihood of depleting resources or possessing expired stock, enhances resource utilization efficiency, and decreases the duration spent on equipment retrieval.
- **Security and Privacy:** Confidentiality and data security are of paramount importance in healthcare facilities, with wireless communication systems being specifically designed to uphold these principles. The safeguarding of patient data and compliance with relevant privacy regulations are both achieved by using rigorous encryption methods, authentication protocols, and access controls [103]. Ensuring a secure wireless environment necessitates the implementation of regular security assessments and continuous training initiatives for personnel.

2) ENHANCING OPERATIONAL EFFICIENCY AND PATIENT SAFETY

Enhancing operational efficiency and ensuring patient safety are imperative objectives within healthcare facilities, as they significantly impact the quality of treatment delivered, patient outcomes, and the overall healthcare experience. Healthcare companies have the potential to achieve significant progress in several domains by using contemporary technology, enhancing operational efficiency, and cultivating a culture that prioritizes safety and efficacy. The prompt and effective provision of healthcare services is closely associated with the operational efficiency of a healthcare institution [104]. One potential avenue for healthcare institutions to enhance their operational efficiency is via the use of technology to automate administrative tasks, streamline processes, and optimize resource allocation. By using automation in tasks such as appointment scheduling, billing, and paperwork, medical institutions have the potential to reduce the occurrence of human errors and allocate valuable staff resources towards delivering direct patient care. The use of streamlined work procedures facilitates a smooth transfer of tasks and responsibilities across departments, reduces patient waiting times, and improves the overall efficiency of patient flow. Real-time data and analytics provide healthcare firms valuable insights into essential performance indicators, efficient

resource allocation, and patient outcomes. These insights facilitate the identification of areas in need of change, the optimization of operational processes, and the data-driven decision-making inside enterprises [105]. Table 4 represents the comparative analysis of recent surveys on healthcare infrastructure optimization in hospital environments.

Ensuring patient safety is a key concern inside healthcare organizations. The implementation of programs aimed at enhancing patient safety serves to mitigate medical errors, reduce the incidence of adverse events, and foster positive patient outcomes. Healthcare facilities may promote patient safety via several strategies, such as the delivery of drugs, infection control, fall prevention, and effective communication. The use of technology-driven solutions, such as bar code scanning systems, electronic medication administration records (eMARs), and automated medicine dispensing systems, has the potential to mitigate drug errors and enhance drug safety [106]. The adoption of rigorous infection prevention measures, including adherence to recommendations for appropriate hand hygiene, environmental monitoring, and effective cleaning and disinfection techniques, has the potential to reduce the incidence of healthcare-associated illnesses. Efforts focused on fall prevention, including the use of technological interventions such as patient monitoring systems, bed alarms, and mobility aids, contribute to the reduction of potential injuries associated with falls. Efficient communication within healthcare teams is facilitated by the implementation of standardized protocols, EHRs, and secure messaging platforms. These tools enable the accurate and timely transmission of patient information, thereby mitigating the occurrence of errors and enhancing care coordination [107].

Healthcare facilities have the potential to optimize resource utilization, reduce expenditures, and enhance the effectiveness and cost-efficiency of treatment through enhancing their operational efficiency. Enhancing patient safety reduces the probability of adverse events, hence resulting in improved patient outcomes and fostering a patient-centered care culture. These endeavors contribute to a generally positive healthcare experience, benefiting both patients and the healthcare professionals responsible for their treatment. The overall effectiveness and excellence of healthcare establishments are closely linked to the integration of technology, use of data-driven decision-making, and adherence to best practices in ensuring patient safety [108].

C. TELEMEDICINE AND VIRTUAL CONSULTATION

The Healthcare Industry has seen a transformation due to the use of telemedicine and virtual consultations, enabling individuals to conveniently obtain medical care from their residences in a timely manner. Telemedicine refers to the use of technology to provide medical interventions to patients geographically separated from healthcare providers. On the other hand, virtual consultation allows patients to engage in communication with their healthcare professionals using

TABLE 4. Summary of recent surveys focusing on healthcare infrastructure optimization, highlighting key areas of investigation, methodologies employed, and primary findings related to wireless communication technologies and their impact on patient care and connectivity.

Author	Title	Year	Main Contribution
Muramatsu et al. [88]	Next-generation healthcare infrastructure based on cross-layer optimization of bio signal sensing and communication	2024	1) The primary contribution of this paper lies in addressing the critical challenges associated with traditional healthcare infrastructure, namely, the inefficient and fragmented nature of bio signal sensing and communication. 2) By recognizing the intricate interplay between these layers, we propose a novel framework that holistically optimizes the entire healthcare system, from patient monitoring to data analysis and decision-making. Our work is motivated by the urgent need for improved patient outcomes, reduced healthcare costs, and enhanced system efficiency through seamless integration and intelligent resource allocation.
H.M. Ali et al. [89]	Power-Aware Fog Supported IoT Network for Healthcare Infrastructure Using Swarm Intelligence-Based Algorithms	2023	1) Proposed a power-aware fog-supported IoT network for healthcare infrastructure using swarm intelligence-based algorithms. 2) Optimized power consumption by minimizing transmission power and infrastructure costs. 3) Achieved a savings of up to 33 percent in power consumption in the proposed healthcare infrastructure.
P. Cantarelli et al. [93]	The management of healthcare employees job satisfaction: optimization analyses from a series of large-scale surveys	2023	1) Identified key factors associated with healthcare employees job satisfaction, such as environmental characteristics, organizational management practices, and team coordination mechanisms. 2) Developed an optimization model to identify the most efficient combination of factors for improving job satisfaction at different hierarchical levels. 3) Provided evidence-based recommendations to healthcare organizations to improve employee job satisfaction and performance.
H. Dui et al. [94]	Cascading failures and resilience optimization of hospital infrastructure systems against the COVID-19	2023	1) Proposed a cascading failure model of hospital infrastructure systems (HIS) to analyze their failure mechanism against the COVID-19. 2) Developed a method for optimizing HIS resilience by integrating patient flow and supply and demand analysis. 3) Provided simulation results to demonstrate the effectiveness of the proposed method in improving the resilience of HIS.

digital platforms, such as video calls [109]. The use of innovative procedures is leading to a transformative shift in healthcare delivery, offering several benefits. The introduction of telemedicine and virtual consultation has significantly transformed the field of medicine. These advancements have enhanced accessibility to healthcare services, offering more convenience and flexibility to patients. Moreover, they have facilitated the continuity of treatment and prioritized patient safety as a primary objective [110].

The enhanced accessibility of medical care is a paramount advantage facilitated by telemedicine and virtual consultation. Regardless of their geographical location, patients have the ability to get medical advice, receive diagnoses, and receive recommendations for treatment. This is particularly advantageous for those residing in under served or rural areas, since it enhances the probability of their access to healthcare services. Telemedicine has enhanced healthcare accessibility and mitigated treatment barriers by eliminating the need for extensive travel [111]. Telemedicine and virtual consultation provide several benefits, with ease and flexibility being

among the most significant advantages. Patients have the opportunity to schedule appointments at their preferred time, so circumventing prolonged waiting times and obviating the need of taking time off from work or arranging alternative transportation. This is especially beneficial for those who have busy schedules or live in geographically isolated regions with restricted availability of medical resources [112].

The patient has the capacity to get medical care without the limitations imposed by traditional face-to-face visits, hence resulting in time and effort savings. The use of telemedicine and virtual consultation enables the provision of uninterrupted healthcare services. The capacity to remotely observe patients, evaluate their advancements, and modify treatment protocols as deemed appropriate is a useful asset for healthcare professionals. This has great importance in regards to the treatment of chronic diseases or the delivery of postoperative care subsequent to hospitalization. Frequent in-person visits for patients to maintain regular connection with their healthcare team, get timely guidance, or address their issues are not deemed required. Patients have the ability

to engage in all of these activities. This process enhances the seamless transition of treatment and enhances the overall outcomes for patients [113].

The use of telemedicine and virtual consultation may provide another significant advantage, namely the emphasis placed on patient safety. The implementation of alternate healthcare delivery techniques in remote regions plays a crucial role in mitigating the potential spread of infectious diseases to larger populations during pandemics or outbreaks. By reducing the amount of in-person meetings, patients and healthcare providers may effectively maintain social distancing while ensuring the provision of necessary medical treatment. This issue has significant significance for populations who are particularly susceptible, such as the elderly or those with impaired immune systems, who may face an elevated likelihood of experiencing complications due to infectious diseases [114].

The efficacy of telemedicine and virtual consultations has been shown across several medical domains, including general care, mental health, dermatology, and the management of chronic illnesses. Telemedicine enables healthcare professionals to provide distant, superior-quality medical care, including prompt consultations, prescription services, and ongoing support. Patients have the opportunity to promptly get medical assistance for their healthcare concerns, therefore obviating the need of unnecessary visits to the emergency department and hospital admissions [115]. The use of telemedicine and virtual consultation is anticipated to maintain its significance in facilitating patient-centered therapy and advancing the healthcare system as technological advancements persist. The figure 6 demonstrates the process involved in telemedicine and virtual consultation.

1) VIDEO CONFERENCING AND TELECONSULTATION PLATFORMS

The development of video conferencing and teleconsultation platforms has significantly transformed the delivery of healthcare services. These platforms provide a convenient and efficient way of communication for both patients and healthcare practitioners, leading to a revolution in the supply of healthcare. These systems use advanced technology to provide live audio and video interactions, therefore enabling virtual consultations that closely resemble in-person meetings in terms of their entire experience [116]. Video conferencing and teleconsultation platforms provide many significant advantages. Video conferencing and teleconsultation systems have significantly transformed the healthcare environment by enhancing accessibility to treatment, improving convenience, facilitating continuity of care, and ensuring patient safety. During times of crisis, the use of these platforms has assumed particular significance as it facilitates the delivery of healthcare services while adhering to the requisite protocols.

Primarily, these platforms make it simpler for individuals to get medical care, which is particularly advantageous for

those who reside in remote or impoverished areas [117]. The advancement of technology has facilitated the ability of patients to engage in communication with their healthcare providers, irrespective of their geographical location. This development has effectively eliminated the barrier imposed by physical distance. This measure guarantees that individuals living in rural or geographically isolated areas may get crucial medical guidance and recommendations for treatment without the need to endure prolonged journey durations. This phenomenon contributes to the promotion and progress of equality within the healthcare sector. The use of video conferencing and teleconsultation technology offers patients and healthcare practitioners convenient and adaptable solutions to fulfill their individual requirements [118]. Patients have the ability to schedule appointments at their preferred times, hence eliminating the need for them to allocate time away from their employment or make other arrangements to visit a healthcare facility. Virtual consultations provide the ease of conducting appointments from the comfort of one's home, so obviating the need for arduous travel and enduring the tedium of waiting rooms. Medical care providers also experience advantages from more flexibility as it allows them to efficiently organize their calendars and allocate their available time. These platforms facilitate the maintenance of treatment continuity by enabling seamless and uninterrupted communication between patients and healthcare practitioners [119]. Virtual consultations have shown to be a valuable resource in effectively handling follow-up visits, ongoing monitoring of chronic conditions, and the administration of medicines. Patients are more inclined to get care that is congruent and well-coordinated when their healthcare providers possess the ability to assess test results, engage in treatment plan discussions, and provide necessary instructions. This is particularly beneficial for those afflicted with chronic illnesses who need routine medical examinations and ongoing surveillance [120].

The significance of video conferencing and teleconsultation platforms has increased in recent years, particularly in periods of public health emergencies like the COVID-19 epidemic. These platforms have shown to be very effective in mitigating the risk of infection transmission while concurrently ensuring the provision of essential medical care to patients. They aid in the maintenance of social distancing protocols and ensure the protection of both patients and healthcare practitioners by reducing the frequency of in-person appointments. These platforms have the capacity to enhance both patient involvement and overall satisfaction. Patients are given the chance to actively participate in their healthcare decisions, hence resulting in enhanced health outcomes as a consequence of the convenience and ease of access [121]. The establishment of a conducive environment for communication between the patient and healthcare practitioner facilitates a more comprehensive exchange on the patient's concerns. This environment enables the patient to actively engage in the dialogue by posing inquiries

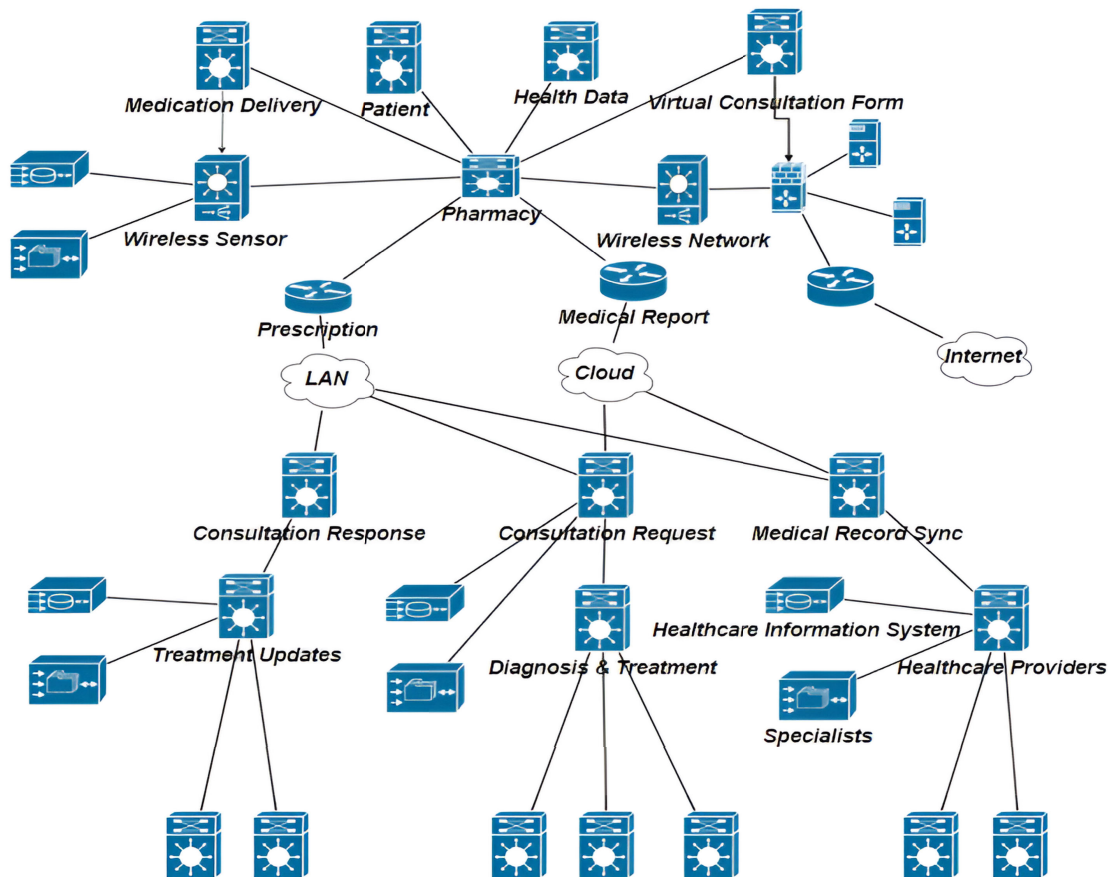


FIGURE 6. This diagram illustrates the core components and processes involved in telemedicine and virtual consultations. It highlights the role of wireless communication in enabling remote patient care, including patient data acquisition, secure transmission, and real-time interaction between patients and healthcare providers. Key elements such as wearable devices, wireless sensors, LAN, Cloud and Internet are depicted to showcase the technological infrastructure supporting these virtual healthcare services.

and seeking customized guidance from the healthcare provider [122]. In the next era of healthcare delivery, the use of video conferencing and teleconsultation platforms will persist as pivotal components in enhancing patient experiences and maximizing the allocation of healthcare resources. The significance of these positions will persist as technological advancements continue to progress.

2) REMOTE DIAGNOSIS AND TREATMENT PLANNING

The use of communications technology and digital platforms has given rise to remote diagnosis and treatment planning, which have emerged as innovative approaches in the area of medicine. These approaches facilitate the delivery of patient care without necessitating in-person visits. This innovative methodology offers many benefits, including enhanced accessibility, ease, and efficacy. The healthcare sector has seen a significant transformation due to advancements in remote diagnosis and treatment planning. These developments have enabled medical practitioners to provide patients with timely, efficient, and personalized care. Healthcare professionals in the business has the capability

to surmount geographical barriers, enhance accessibility, and optimize resource allocation via the usage of communications technologies and digital platforms. The use of remote diagnosis and treatment planning is anticipated to maintain its significance in augmenting the quality of healthcare delivery and patient outcomes, as advancements in technology progress and telemedicine gains broader acceptance [125].

The preliminary patient assessment may be conducted by telecommunication methods, such as telephone or video conferencing, in the context of remote diagnostics. By using virtual consultations, healthcare practitioners may gather crucial information pertaining to a patient's symptoms, medical background, and present condition. Patients possess the capacity to give crucial information that may facilitate the diagnostic process via the act of expressing their symptoms, engaging in dialogue by responding to inquiries, and furnishing pertinent replies. The first assessment serves as a foundation for subsequent stages of diagnosis and treatment planning by providing crucial contextual details [126]. Digital medical records play a vital role in facilitating remote diagnosis. Electronic health records (EHRs) provide

TABLE 5. Summary of recent surveys focusing on telemedicine and virtual consultation, highlighting key research areas, methodologies, and findings relevant to understanding the impact of wireless communication in healthcare and patient care.

Author	Title	Year	Main Contribution
Ong et al. [114]	The Effectiveness of Telemedicine Consultation in Improving Outcomes of Asthma in the Paediatric Population: A Systematic Review and Meta-Analysis	2024	1) The paper addresses a critical gap in the existing literature by conducting a comprehensive systematic review and meta-analysis to evaluate the effectiveness of telemedicine consultations in improving asthma outcomes in the pediatric population. This research is timely given the increasing adoption of telemedicine and its potential to enhance healthcare accessibility and quality for children with chronic conditions like asthma. 2) A key strength of the study is its robust methodology, which includes a comprehensive search strategy, rigorous inclusion and exclusion criteria, and a thorough assessment of study quality. 3) The use of a meta-analysis to synthesize the findings of multiple studies provides a higher level of evidence regarding the efficacy of telemedicine for pediatric asthma management.
Reid et al. [111]	Ethical assessment of virtual consultation services: scoping review and development of a practical ethical checklist	2024	1) The findings of this study contribute to the growing body of knowledge on the ethics of telehealth. By identifying key ethical considerations and developing a practical checklist, this research provides a foundation for future research and policy development in this area. The checklist can serve as a benchmark for evaluating the ethical performance of virtual consultation services and promoting ethical best practices. 2) A rigorous methodological approach was employed, including a comprehensive scoping review adhering to the PRISMA-ScR guidelines. This ensured a systematic identification and analysis of relevant literature. The subsequent development of the ethical checklist was grounded in the identified ethical themes, ensuring its practical relevance and applicability to real-world settings. 3) Outlined key considerations for implementing telemedicine and virtual respiratory care programs.
Dhunno et al. [113]	Evaluation of Telemedicine Consultations Using Health Outcomes and User Attitudes and Experiences: Scoping Review	2024	1) The study's findings offer valuable insights into the relationship between telemedicine consultations and health outcomes, as well as user perspectives. The identification of consistent patterns in patient and healthcare provider experiences can inform the development of effective telemedicine implementation strategies. 2) The authors acknowledge the limitations of the study, such as the heterogeneity of included studies and the potential for publication bias. These limitations highlight the need for further research to address specific patient populations, telehealth technologies, and long-term outcomes.
M.W. Condry et al. [123]	Remote Patient Monitoring Technologies and Markets	2023	1) Provided a comprehensive overview of remote patient monitoring (RPM) technologies and markets. 2) Identified key drivers, challenges, and trends in the RPM market. 3) Highlighted the potential of RPM to revolutionize healthcare delivery and improve patient outcomes.
K.R. Fakhoury et al. [124]	Practical Implementation of Emergent After Hours Radiation Treatment Process Using Remote Treatment Planning on Optimized Diagnostic CT Scans	2022	1) Developed and implemented a practical process for delivering emergent after-hours radiation treatment using remote treatment planning on optimized diagnostic CT scans. 2) Reduced treatment planning time from hours to minutes, making it possible to deliver urgent palliative treatment to patients after hours. 3) Demonstrated the feasibility and safety of this approach, with no treatment errors reported.

efficient and convenient retrieval of a patient's whole medical history, including previous data, test results, and

imaging examinations, therefore enabling medical personnel to access this information expeditiously. The consolidation

of information in a centralized manner provides medical professionals with the capacity to examine the medical records of patients, identify trends, and make informed assessments on the diagnosis and treatment strategies for individuals. The enhanced accessibility of digital records significantly enhances the precision and effectiveness of healthcare services in remote areas [127].

Telemedicine consultations play a crucial role in facilitating distant diagnosis and treatment planning. Through the use of video conferencing technologies, medical practitioners are afforded the opportunity to conduct visual examinations of patients, assess symptoms, and engage in interactive dialogues. The use of real-time communication enables the evaluation of biological indications in real-time, including the assessment of skin condition, joint mobility, and visual cues for mental health evaluations [128]. Telemedicine consultations are particularly advantageous for follow-up visits, medication management, and mental health services due to their provision of effective communication channels, reduction in travel requirements, and decreased patient wait times. This is due to their ability to reduce patient waiting times for appointments. Remote monitoring is a crucial element in the realm of remote diagnosis and treatment planning. Patients are provided with the choice to use home monitoring kits, mobile applications, or wearable devices in order to assess and relay vital signs and other health indicators to their designated healthcare providers. Due to the continual remote monitoring, healthcare professionals are capable of observing the progress of their patients, identifying trends or deviations from typical measurements, and promptly addressing any possible concerns. Remote monitoring is a valuable approach in the context of chronic diseases that need continuous monitoring, as it offers many advantages such as reducing the frequency of patient visits to healthcare facilities and enhancing convenience and adherence [124].

The use of remote diagnostics and treatment planning has the potential to provide substantial benefits for patients, healthcare professionals, and the healthcare system at large. The elimination of geographical barriers and reduction in travel burdens contribute to enhanced accessibility to high-quality medical care, particularly for those living in distant or underserved areas. The use of telemedicine offers many advantages, including reduced wait times, enhanced schedule flexibility for patients, and the ability to get treatment in the convenience of their own homes. These factors collectively lead to heightened levels of patient satisfaction and convenience [123]. The optimization of resource utilization is achieved by the use of remote healthcare services. This phenomenon may be attributed to the enhanced time management skills and resource allocation capabilities of medical professionals, enabling them to efficiently cater to patients requiring in-person consultations, while concurrently remotely monitoring patients who exhibit stable conditions. This optimization facilitates the streamlining of healthcare delivery and boosts the overall efficiency of the system. While

the advantages of remote diagnosis and treatment planning have been shown to be significant, it is important to acknowledge the limitations inherent in these methodologies. The feasibility of remotely diagnosing or treating some medical conditions may be limited due to the need of in-person examinations, diagnostic tests, or interventions. The absence of direct physical contact between healthcare staff and patients might provide challenges in accurately diagnosing some symptoms. Furthermore, the successful deployment of remote healthcare services requires meticulous consideration of patient privacy and data security, with the establishment of a robust patient-physician relationship [129].

3) ENABLING ACCESS TO HEALTHCARE IN REMOTE AREAS

The provision of healthcare services in geographically isolated regions is a significant worldwide problem that necessitates the implementation of creative strategies and collaborative endeavors. Healthcare services in remote places are often impeded by many obstacles, including geographical remoteness, insufficient infrastructure, and a scarcity of healthcare experts. It is important to confront these problems in order to guarantee that individuals residing in remote regions have access to prompt and high-quality healthcare services [130]. Table 5 represents the comparative analysis of recent surveys on Telemedicine and virtual consultation to improve the patient's health and connectivity.

Geographical isolation is a significant barrier that impedes the ability of those living in remote regions to avail themselves of healthcare services. The absence of adequate road infrastructure, transit systems, and connectivity poses challenges for persons in accessing medical facilities within a reasonable time frame. The urgency of this condition becomes more crucial during emergency scenarios, as prompt medical intervention might determine the difference between survival and fatality. Therefore, it is imperative to develop novel solutions that effectively address this gap [131].

The use of telemedicine has emerged as a disruptive option within this particular setting. Telemedicine systems enable persons residing in geographically isolated regions to establish virtual connections with healthcare specialists, therefore facilitating medical consultations, diagnoses, and maybe even treatment. The use of this technology has the capacity to substantially diminish the need for physical transportation, hence enhancing the accessibility and convenience of healthcare services. Patients have the opportunity to get professional counsel and assistance without the need for extensive travel, resulting in significant savings of both time and financial resources [132].

Mobile clinics and community health workers are essential components in the provision of healthcare services to underserved regions. Mobile clinics are equipped with essential medical instruments and staffed by qualified healthcare professionals who travel to remote villages to deliver medical examinations, immunizations, and basic healthcare services. In addition, community health workers, who are

often persons living within the local community, undergo training to provide fundamental healthcare services and health education. They serve as a conduit between the local population and established healthcare institutions [133].

Advancements in medical technology have significantly enhanced the capacity to provide healthcare services in geographically isolated regions. Portable diagnostic gadgets, point-of-care testing, and remote monitoring technologies have become crucial in enabling healthcare practitioners to effectively offer precise diagnoses and monitor the health states of patients, especially under demanding circumstances. This facilitates timely identification of health concerns and enhances the efficacy of chronic illness treatment [134].

The establishment of sustainable healthcare solutions in distant locations necessitates the crucial involvement of government agencies, non-governmental organizations (NGOs), and private sector entities via collaborative efforts. Governments possess the ability to devote resources towards the construction of healthcare infrastructure, the establishment of telemedicine networks, and the implementation of incentives aimed at attracting healthcare professionals to under served areas. Non-governmental organizations (NGOs) and private enterprises have the potential to make valuable contributions in terms of their experience, resources, and financial assistance towards projects aimed at enhancing healthcare accessibility [135].

Also, the act of increasing public knowledge and actively promoting alterations to policies are crucial components in the improvement of healthcare accessibility inside distant regions. When many stakeholders, including communities, organizations, and governments, acknowledge the need of ensuring equitable healthcare, there is an increased likelihood of collaborative efforts to identify remedies and distribute resources accordingly. Furthermore, the implementation of policy modifications aimed at providing incentives for healthcare professionals to practice in under served regions might have substantial effects in terms of enhancing the accessibility of medical services [136].

In a nutshell the provision of healthcare services in geographically isolated regions necessitates a comprehensive strategy that spans several dimensions, including technological advancements, infrastructural enhancement, collaborative alliances, and legislative modifications. Telemedicine, mobile clinics, community health workers, and technical breakthroughs all play a significant role in mitigating obstacles to healthcare accessibility. By adopting these proposed solutions and promoting cooperation, we can guarantee that persons residing in even the most geographically isolated regions of the globe are afforded the chance to experience improved well-being [137].

III. WIRELESS TECHNIQUES FOR IOHT APPLICATIONS

Wireless communication techniques are of utmost importance in the realization of IoHT paradigm. These techniques enable the establishment of uninterrupted connection and efficient data exchange between HAPs and ground-based IoT

devices. In order to tackle the unique challenges encountered by individuals with impaired or limited hearing, a range of wireless communication techniques have been deployed in real-world environments [138]. One strategy that may be used is referred to as Non-Orthogonal several Access. NOMA facilitates concurrent and effective communication across several IoT devices by enabling them to utilize the same time-frequency resources in a non-orthogonal manner.

However, the incorporation of wireless communication into IoHT ecosystem presents certain challenges that must be addressed. Within the context of a constantly changing aerial setting, the establishment of dependable communication emerges as a vital challenge that need resolution. Hazardous air pollutants exhibit susceptibility to displacement and changes in elevation, potentially resulting in fluctuations in channel characteristics and signal strength [139]. Instances of hazardous air pollutants include UAV and stratospheric balloons. In order to mitigate the effects of these alterations, it is essential to use precise channel forecasting techniques and flexible transmission systems [140].

Moreover, the use of HAPs in the airspace raises apprehensions over the management and supervision of interference. The seamless integration of IoHT has become imperative to maintain compliance with aviation regulations and effectively coordinate the operations of several HAPs, therefore mitigating potential interference with terrestrial and satellite communication systems [141].

In the domains of healthcare and critical infrastructure, security and privacy emerge as crucial concerns in the context of wireless communication. Ensuring the prevention of unauthorized access and cyberattacks on sensitive data sent between IoT devices and Home Access Points is of paramount significance. The consideration of energy efficiency is an additional crucial element that requires attention [142]. Ground-powered devices that are integrated into IoT ecosystem often rely on batteries for their operation and need a minimal energy consumption in order to ensure an extended lifespan. The enhancement of energy utilization and the advancement of sustainability in the IoHT network may be achieved by using efficient power allocation algorithms, such as those offered by NOMA.

Moreover, it is essential for IoT devices to possess the capability of smoothly transitioning between the coverage areas of different Home Access Points. These devices must be equipped with the ability to manage their mobility in order to maintain uninterrupted communication connections. The development of efficient handoff mechanisms and resource allocation algorithms is vital to mitigate disturbances in the process of data transmission [143]. Wireless communication techniques are key to unleashing the potential of the Internet of Human Things. These methodologies provide efficient and smooth communication between HAPs and ground-based IoT devices. Nevertheless, in order to effectively harness these benefits, it is essential to adeptly address many challenges. These challenges include navigating through



FIGURE 7. This diagram outlines the key topics and subtopics covered in Section III, providing a structured overview of the research areas explored within the context of wireless communication for healthcare. It serves as a navigational tool for readers to understand the progression of the survey and locate specific areas of interest.

dynamic aerial settings, ensuring compliance with regulatory standards, enhancing security measures, optimizing energy efficiency, and efficiently managing mobility [144]. As research and development in this area progress, the IoHT paradigm will advance towards a linked future, presenting unparalleled opportunities for many applications and industries. A visual representation of this section is shown in Fig. 7.

Existing Techniques:

- **WiFi Technology:** WiFi is widely used wireless technology that has become the pillar of IoHT, thereby transforming the delivery of healthcare. It provides high-speed data transfer, large coverage areas, and consumes less power hence highly suitable for connecting various medical devices and sensors within healthcare environments. By facilitating seamless communication among

TABLE 6. This table presents a structured comparative analysis of three pivotal wireless communication technologies—NOMA, mMTC, and Network Slicing—with a focused lens on their relevance and applicability within the healthcare domain. The comparison explores key performance indicators such as strengths, weaknesses, real-world healthcare applications, scalability, latency sensitivity, security capabilities, and energy efficiency. This comparative overview underscores how each technology addresses distinct healthcare connectivity needs and contributes to the overarching goal of intelligent, efficient, and patient-centric healthcare systems.

Aspects	NOMA	mMTC	Network Slicing
Strengths	1) Efficient Spectrum Usage 2) Supports simultaneous access 3) Low latency 4) High spectral efficiency	1) Scalability for IoT devices 2) Energy-efficient 3) Supports massive connections	1) Customization for diverse needs 2) Improved QoS and security 3) Enables network resource optimization
Weakness	1) Complex signal processing 2) Inter-user interference 3) Power allocation challenges	1) Limited data rate 2) Latency constraints 3) Security vulnerabilities in massive deployments	1) Complex orchestration and management 2) High deployment cost 3) Requires robust slicing algorithms
Relevance to Healthcare	1) Enables simultaneous transmission of patient data (e.g., ECG, BP, glucose levels) 2) Supports real-time telemedicine	1) Ideal for connecting large-scale sensors and wearables in hospital environments 2) Vital for remote patient monitoring	1) Design networks for critical care, admin systems, and patient wearables 2) Ensures SLA-based healthcare services
Real-World Applications	1) Emergency patient triage with simultaneous multi-sensor data upload 2) Real-time video consultations in rural areas	1) Wearable health monitoring systems 2) Smart beds and medical inventory tracking 3) Chronic disease monitoring	1) Isolated slice for ICU with low latency 2) Separate slice for admin systems 3) Secure data sharing among hospitals
Scalability	Moderate (depends on decoding complexity and interference)	High (designed for millions of connected devices)	High (logical separation allows flexibility and expansion)
Latency Sensitivity	Low-latency capable	Latency-tolerant in non-critical scenarios	Latency configurable depending on slice requirements
Security	Needs enhancement for sensitive data handling	Basic security; enhancement needed for HIPAA compliance	Strong potential for customized security policies per slice
Energy Efficiency	Moderate	High (optimized for low-power devices)	Varies per slice (can be optimized)

patients, medical equipment and health care providers, WiFi ushers in a new era of patient-centered care and operational efficiency.

In hospitals as well as clinic WiFi networks enable real-time monitoring of patient vitals via wearable sensors to detect any critical changes before they become fatal or life threatening. Through WiFi, medical imaging devices can transmit images quickly resulting in expedited diagnosis and treatment planning. Moreover, with the aid of WiFi enabled electronic health record systems, there are benefits that come from having easy access to patient data such as improving quality care coordination and reducing mistakes.

WiFi also supports remote patient monitoring which has been instrumental in allowing chronic disease patients to be effectively managed out of hospital settings. This improves both patient satisfaction and relieves pressure on healthcare resources so much. In the healthcare sector, it is important to ensure that WiFi is secure and reliable. It should be noted that encryption and access control are two must-have features to safeguard sensitive patient information. Also, there should be an

installation of parallel network infrastructure as well as more sophisticated monitoring tools which lead to zero downtime in service provision. Lastly, integration with healthcare specific standards and interoperability guidelines can help bring together different medical devices or systems.

The leading edge of wireless technology continues to evolve with advances such as Wifi 6 and Wifi 7 that provide improved speed, lower latency and better capacity. This makes it even more potential for revolutionizing healthcare delivery. By integrating both WiFi potentiality, the health industry can explore new frontiers for improving patient's well being, operational efficiencies in addition; we will see a completely different way of accessing medical services.

- **Bluetooth Low Energy (BLE):** Wireless technology has greatly revolutionized how healthcare providers operate and how patients receive care. IoHT relies on BLE as its cornerstone technology. It is widely used in a wide range of medical applications due to the fact that it combines low energy consumption with robust connection and is relatively cheap. BLE has made patient

care provision easier by allowing for smooth sharing of data among wearable devices, medical sensors as well as healthcare infrastructure. In general, BLE excellent energy efficiency makes it appropriate in IoHT [145]. This is because many medical devices, such as those worn by patients, are battery-powered and must have long useful lives. The power management strategies employed and the low-power protocols integrated into BLE enable extended operation duration without having to charge them frequently enhancing the patient comfort within a given period. Furthermore, BLE short reach capabilities make it suitable for this kind of close proximity health care thus minimizing interferences or security vulnerabilities in place. BLE versatility is evident from its scope of applicability in various IoHT uses. From remote patient monitoring to asset tracking and real-time data exchange, the evolving role of BLE-enabled devices have changed how health care is handled. In this case, wearable health monitors can continuously keep track of vital signs like heart rate, blood pressure and glucose levels while securely transmitting this data to healthcare practitioners. This ensures that diseases are detected early enough and necessary steps taken. In addition, BLE-based proximity beacons can help locate medical equipment within hospitals thereby improving efficiency as well as patient safety.

However, the contribution of BLE towards improved patient care goes beyond just collecting and sending data. By ensuring that there is a link between patients, their caretakers and health systems with ease, BLE encourages people to actively play a part in managing their well being. Patients can receive personalized treatment plans, reminders, or educational materials through BLE-enabled devices, promoting self-care behaviors and compliance with therapeutic regimens. Such solutions based on the technology can allow for remote consultations as well as telemedicine which will increase access to healthcare services especially in rural areas where they are scarce. However, there are some challenges to the full realization of its potential. The transmission of sensitive patient data wirelessly makes data security and privacy non-negotiable. Patient data can be protected from unauthorized individuals through robust encryption and authentication mechanisms.

However, for flawless data interchange and ecosystem integration in the healthcare industry, Bluetooth Low Energy platforms and devices have to operate collectively. These problems can be overcome by standardization efforts and open protocols that will hasten the adoption of BLE in IoHT. As a result, this is a revolutionary technology that has changed the healthcare industry. In terms of developing new IoHT solutions it is essential due to its low power consumption, versatility and security advantages. Thus,

BLE enables patients to take control of their health care delivery systems, leading to better operational efficiencies through wireless communication; thus, a healthier future lies ahead.

- **Radio Frequency Identification(RFID):**

RFID is a wireless technology that has become a game-changer in the healthcare sector. Through the use of radio waves, it is now possible to uniquely identify and track objects, which has transformed patient care, supply chain management, and overall operational efficiency. In healthcare, IOHT refers to RFID as an essential technology to enable connectivity and improve patient care. The ability to automatically detect and follow tags attached on items is the main aspect of this technology. RFID readers can read these tags embedded with microchips and antennas containing unique identifiers. Once within range of the reader an object fitted with an RFID tag will get captured by this reader, and its data will be wirelessly transmitted to a related system. In doing so, real-time tracking, monitoring and management of various assets in healthcare are facilitated by this seamless data exchange.

Patient monitoring and care is one of the most important applications in IoT for RFID technology. This can be done using RFID enabled wristbands or ankle tags which ensure patient safety by accurately identifying patients and prevent medication errors. Likewise, tracking the location of a patient within hospitals allows for highly efficient emergency response and staff productivity. Besides, wearable devices with integrated RFID may check vital signs, drug adherence as well as user activity levels thus providing personalized care and early intervention.

In the context of supply chain management, this technology introduces unprecedented visibility, traceability, and control over medical supplies and equipment with real-time RFID-based tracking. With the use of radio frequency identification tags affixed to goods, healthcare providers will be able to keep track of inventory levels, as well as expiration dates, among other logistics. As a result, these practices lead to effective supply chain management that reduces stock shortages while at the same time mitigating the threat of expired or counterfeit drugs.

Furthermore, proper maintenance utilization and asset management are among benefits realized from the movement control of medical equipment by means of radio frequency identification. RFID has the potential to redesign different components of healthcare operations other than care and supply chain management. For example, it can be used for medical records tracking and management, patient flow improvement, facility layout optimization, and infection control improvement measures. Access controls systems based on RFID technology can restrict unauthorized entrants to sensitive

areas enhancing patient's privacy and safety. In addition, RFID can be combined with environmental monitoring systems that track temperature and humidity levels to ensure proper storage of medications and medical supplies.

Other wireless technologies such as Wi-Fi, Bluetooth or cellular networks enable RFID to expand its IoHT applications. This convergence of technologies enables the creation of comprehensive and interconnected healthcare systems where data from various sources can be seamlessly integrated and analyzed. For example, medical devices enabled by RFID are capable of wirelessly sending patient data to healthcare providers thereby allowing remote monitoring and timely interventions. Despite the above, there are still issues that need to be resolved if RFID is to be used in healthcare. This includes ensuring data privacy as well as security through strong encryption and access restrictions.

The cost of RFID technology and infrastructural requirements that are very specific can also make it difficult to adopt this technology across many health care settings. However, the potential benefits of RFID in terms of improved patient care, operational efficiency and cost savings far outweigh these challenges. With advancing technology, we should expect more exciting applications for the use of RFID technology in healthcare. In addition, by blending AI, machine learning with RFID data; predictive analytics and personalized medicine will be possible. Given this fact, future development could involve low-cost long-range versions which will increase accessibility in underserved areas and remote regions. RFID could be a powerful tool that can change healthcare in terms of patient care and connectivity. This is because RFID technology has the potential to enable real-time tracking, monitoring, and management of patients, supplies, and equipment thus enhancing operational efficiency in hospitals. The usage of internet-based health solutions to improve patient safety will encourage innovation in this area as a result of these advances. As such as far as the future of healthcare delivery is concerned RFID shall remain indisputable. A visual representation of wireless communication techniques is shown in Fig. 8.

Emerging Techniques: Wireless communication technologies are transforming the healthcare industry by facilitating advanced applications of the Internet of Healthcare Things (IOHT). Advanced technologies including ultra-wide band (UWB), millimeter-wave (mmWave), and Near-Field Communication (NFC) provide fast data transmission, minimal delay, and precise location evaluation, which are essential for real-time monitoring, remote patient care, and connecting medical devices. These emerging technologies possess significant potential to enhance patient outcomes, decrease healthcare expenses, and transform the way in which healthcare is administered.

A. THE ROLE OF NOMA IN IOHT ASPECT

IoT is a revolutionary breakthrough that was made possible by the expert innovation of connecting every single thing or "device" to the internet. This has led to the creation of an unprecedented technology known as IoT, which is gradually permeating every aspect of our modern way of life [146]. In the matter of fact, as a result of the significant advantage, a variety of derivatives have come into existence, such as IoHT and IoMT. The IoT is connected with medical equipment, which enables real-time remote monitoring that may detect sickness, give cost-effective medical solutions, cure illnesses and save lives in medical emergency situations, enhance the patient's comfort, and even deliver more personalized healthcare [147]. A scenario for the application of IoMT that incorporates both innovation and scholarship is in-home monitoring and assisted living. Users are able to maintain a connection with their physicians or carers digitally, synchronously, or on an as-needed basis in the event that an emergency occurs. IoMT apps, for instance, are able to trigger the transmission of an emergency signal in the event that a user is recognized as having a heart attack or experiencing an accident such as falling or choking. Response times in real time and an almost imperceptible lag in data transmission are two performance criteria that are very necessary in an emergency scenario [148].

The proliferation of devices connected to IoT poses significant issues for the development of future wireless networks. NOMA has been put forward as a promising solution that can ultimately solidify the horrendous requirements of such networks. These requirements include improving wireless network performance and efficiency, ultra-reliable communication, minimal latency and massive accessibility, and high spectral efficiency [149]. The most important advantage of NOMA is that it increases the capacity and efficiency of wireless networks. NOMA enables several users to communicate with one another at the same time, which simultaneously increases the number of users capable of simultaneous communication while simultaneously reducing the amount of spectrum that is necessary to serve those users [150], [151]. Because of this, transmissions become quicker and more reliable, which is particularly beneficial in areas with a high population density and a restricted spectrum. This technique is of practical benefit to applications where the information is acquired from the sensors in the presence of impulsive interference. Some examples of these types of applications are smart grids, smart homes, and applications for IoHT.

In this regard, it is important to note that IoT devices send their data in the same way as OMA devices do, and that the complexity involved with the identification of overlaid signals is handled by the access point that transmits the data. The most significant issues in IoMT-based systems are effectively managing traffic, allocating resources in an efficient manner, and reducing interference across channels. In this sense, the employment of orthogonal

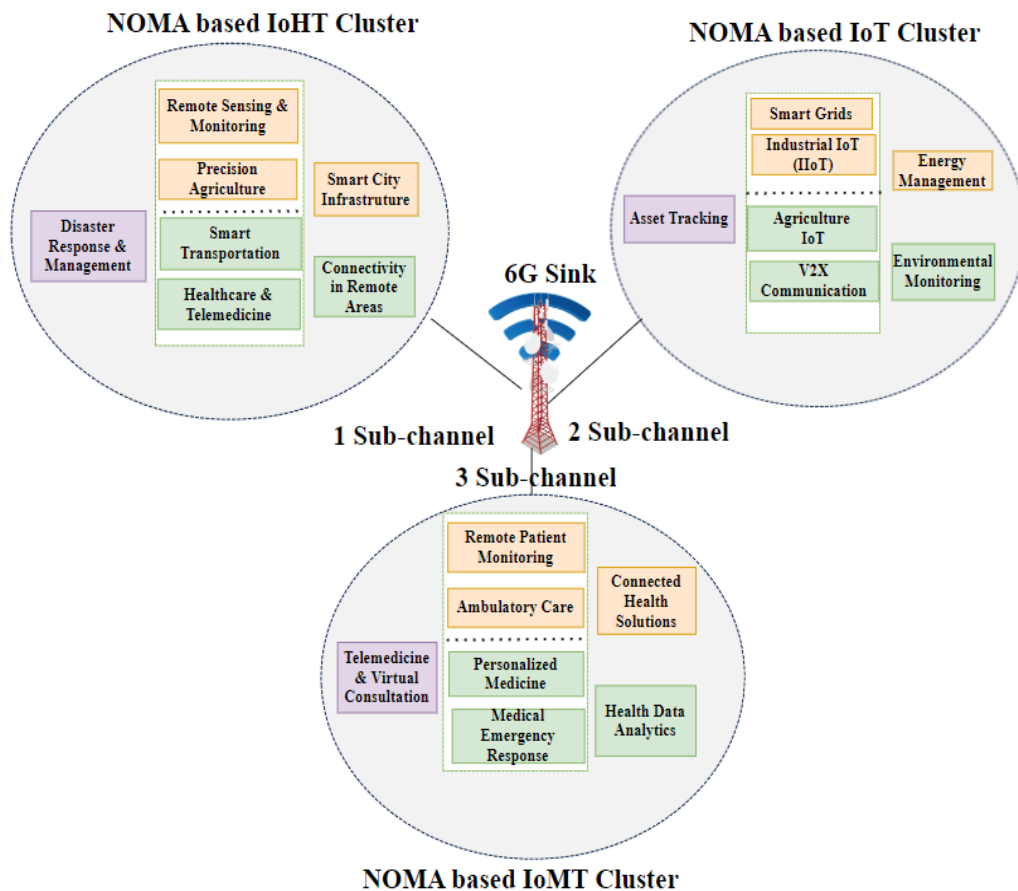


FIGURE 8. Illustrative diagram of a NOMA system in a 6G healthcare network. The system clusters various technologies into three groups: IoT, IoHT, and IoMT. These groups are served by distinct sub-channels through a centralized 6G Sink, enabling efficient and reliable communication for diverse healthcare applications."

codes is helpful since it allows for effective utilization of the channel bandwidth while also preventing interference from noise between the transmissions of the various parties [152]. Multiple sensors have the capability of transmitting their data when using this method, which involves multiplying the data by each orthogonal code obtained from the WH matrix. The goal of the IoMT user scenario is to provide communication between a large number of IoT devices, such as sensors and smart devices, in a manner that is highly dependable, low-cost, and requires very little power. It is not easy to enable this form of communication, however, since there are a number of technological challenges involved, such as interference, scalability, and energy efficiency [153]. An important further hurdle in IoMT-based systems is the limited capacity hubs have available to transmit data packets to access points. In this scenario, NOMA is a relatively new method that has the potential to achieve greater spectral efficiency than orthogonal multiple access, which includes multiplexing techniques [154].

1) BACKGROUND AND MOTIVATION FOR NOMA

Orthogonal multiple access (OMA) systems, such as time division multiple access (TDMA), code-division

multiple access (CDMA), frequency-division multiple access (FDMA), and orthogonal frequency-division multiple access (OFDMA), are widely employed as multiple access technologies. However, these systems possess several notable limitations. OMA systems allocate the available resources into distinct sub-channels that are mutually independent, ensuring that each sub-channel may only be used by a single user at any one moment. This facilitates resource sharing among several users [152]. In TDMA, individual users are allocated specific time slots during which they are permitted to transmit data. Conversely, in FDMA, each user is allotted a dedicated frequency band within which they may send data. The distribution of resources serves the purpose of mitigating interference among users by guaranteeing that each user runs on a unique and non-overlapping sub-channel. This reduces the likelihood of transmission collisions, which may lead to data loss [155]. Nevertheless, the use of this technique leads to a reduction in the overall system capacity, hence being one of the limitations of this approach. The system's capacity to accommodate users is limited by a certain maximum due to the restriction that each user may only transmit on a single sub-channel at any one moment. The limitation is determined by the quantity of sub channels

now available and the duration allocated to each time slot [156]. OMA methodologies have the potential to use existing resources in an inefficient way. For instance, in the context of TDMA, each user is assigned a predetermined time slot, irrespective of their actual data transmission requirements. Users may experience a potential loss of time allocation if they fail to provide any data inside their designated time slots. Similarly, the FDMA system allocates a certain frequency band to each user, irrespective of the user's real bandwidth requirements [157]. Under utilization of frequency bands may occur when a user's data rate is low or when the user's gadgets do not fully utilize the available bandwidth. In order to address the limited capacity of OMA systems, it becomes imperative to provide the same resources to several users simultaneously. The essential concept behind NOMA enables many users to effectively use shared time and frequency resources [151], [158]. The use of methodologies such as signal superposition is employed. The technique referred to as superposition signal is used when attempting to aggregate many signals in a way that enables the receiver to differentiate between them [159]. The figure 9 explains the Illustrative diagram of a NOMA system in a 6G healthcare network.

B. MASSIVE MACHINE TYPE COMMUNICATION (MMTC)

Massive Machine-Type Communication (mMTC) is an essential component within the framework of 5G and IoHT that can support an extremely high connection density of online devices by supporting massive device connectivity in IoT applications. The IoHT serves as a network that enables the seamless connection and communication of a vast array of devices, thereby playing a pivotal role in enhancing healthcare services [151]. This study examines the significance of mMTC inside IoHT, as well as its many uses in the health care industry. This explores the potential benefits that mMTC offers to healthcare professionals, patients, and the whole healthcare ecosystem. By integrating mMTC into IoHT, there are numerous chances to improve patient care, optimize organizational procedures, and change the way healthcare is delivered [160].

The use of mHealth technology enables healthcare professionals to enhance their capabilities, facilitates proactive management of care, and encourages active engagement of patients. This is achieved via the utilization of various applications, such as remote patient monitoring, smart healthcare infrastructure, telemedicine, and health and wellness monitoring [161]. In order to fully harness the capabilities of mMTC in IoHT, it is imperative to address challenges pertaining to scalability, network congestion, power consumption, and data security. The healthcare industry has the potential to adopt a connected and patient-centric strategy by adopting advances developed by mMTC. These factors are expected to result in improved patient outcomes, increased healthcare accessibility, and significant advancements in healthcare service delivery [162].

The convergence of IoT and healthcare industries has provided development to IoHT, a paradigm that facilitates the utilization of networked devices, wearable's, and sensors to enhance the well-being of patients and medical personnel. The concept of mMTC has emerged as a crucial communication paradigm inside IoHT, facilitating the interconnection of several devices that need sporadic and infrequent data transmission. The significance of this lies in the fact that IoHT seeks to establish connections across various entities [163]. The establishment of a link and the exchange of data will serve as the foundation for a transformative shift in healthcare delivery, alongside the advancement of preventive care initiatives and the enhancement of patient outcomes.

1) APPLICATIONS OF MMTC IN HEALTHCARE

- **Remote Patient Monitoring:** The monitoring of patients remotely is one of the most important uses of mMTC in the healthcare industry. Through the implementation of mMTC, healthcare practitioners are empowered to consistently and remotely observe the essential indicators, physiological information, and general well-being of their patients. The use of real-time data collection and analysis enables the timely identification of prospective health issues, the provision of personalized medical interventions, and the implementation of preventive measures to mitigate the advancement of chronic diseases [164]. The use of remote patient monitoring facilitated by mMTC not only enhances the quality of patient care but also diminishes aggregate healthcare expenses by mitigating the frequency of patient readmission to hospitals and visits to emergency departments.
- **Smart Healthcare Infrastructure:** The integration and coordination of various components within the healthcare infrastructure might potentially be facilitated by the use of mMTC. Healthcare firms that use networked technology and sensors may enhance their efficiency by optimizing resource utilization, streamlining procedures, and improving overall effectiveness. The deployment of intelligent healthcare infrastructure, facilitated by mMTC, enables the real-time monitoring of medical equipment, efficient inventory management, and the automation of operations [165]. Consequently, the optimization of patient flow leads to enhanced efficiency, reduced waiting times, and overall improvement in the delivery of healthcare services.
- **Telemedicine and Virtual Care:** The mMTC technology has significant importance in the advancement of telemedicine and virtual care. Due to recent advancements in seamless communication and real-time data exchange, medical practitioners are now able to engage in remote contact with patients, facilitate the diagnosis of ailments, and conduct medical consultations. Telemedicine, facilitated by mMTC, enables patients to get prompt medical interventions regardless

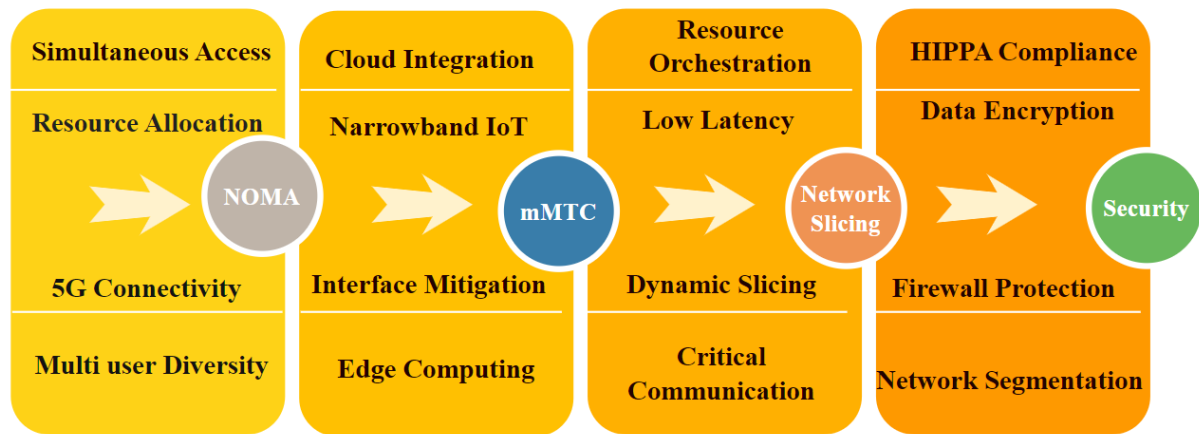


FIGURE 9. The diagram illustrates the various wireless communication techniques, including [NOMA, mMTC, Network Slicing and Security], and their respective roles in enabling different IoHT applications. Additionally, the figure underscores the critical challenges faced in IoHT wireless communication, such as [Dynamic Slicing, Low Latency, Firewall Protection, critical communication], and their potential impact on the delivery of healthcare services. This visual representation offers valuable insights into the complexities and potential solutions for advancing wireless communication in the healthcare sector.

of their geographical location [161]. The use of this approach enhances patient satisfaction and facilitates prompt medical interventions, especially for persons residing in geographically isolated or medically underserved regions. This mitigates the obstacles that impede individuals from obtaining healthcare services.

- **Health and Wellness Monitoring:** The mMTC initiative promotes the development of wearable technology and sensors with the potential to monitor an individual's health and overall state of being. These devices possess the capability to observe an individual's levels of physical activity, patterns of sleep, heart rate, and other significant indications, while also collecting and transmitting the corresponding data [166]. Utilizing mMTC to analyse real-time data may help with proactive therapy, customized insights, and chronic illness management. By using mMTC, people can take an active role in managing their own health, make informed decisions, and improve their general well-being.

2) BENEFITS OF MMTC IN THE IOHT

- **Improved Patient Outcomes:** By using remote patient monitoring and doing real-time data analysis, mMTC enables healthcare professionals to provide personalized and proactive healthcare interventions to their patients. Continuous monitoring of patients' health state enables medical personnel to promptly identify early signs of deterioration, promptly intervene, and modify treatment protocols accordingly. The implementation of this preventive approach yields superior outcomes for patients, reduced rates of hospital readmission, and an overall enhancement in the quality of medical care [167].
- **Enhanced Operational Efficiency:** The adoption of mMTC for healthcare institutions enables the

enhancement of operational efficiency, maximization of resource utilization, and optimization of operations. The real-time monitoring of medical equipment and inventory management through mMTC contributes to the reduction of errors, the decrease in waiting times, and the enhancement of overall workflow management [168]. The use of this streamlined approach leads to cost reductions, enhanced patient throughput, and improved operational effectiveness.

- **Empowering Patient Engagement:** Through the provision of personalized medical data, customized feedback, and self-management tools, mMTC facilitates patient empowerment, enabling individuals to assume a more proactive stance in their healthcare. When patients have access to real-time information about their health and fitness, they are more capable of actively participating in their treatment, making informed decisions, and adopting healthy habits. The use of mHealth technology in patient engagement promotes a proactive stance towards medical intervention, enhances patient satisfaction, and contributes to enhanced health outcomes [169].
- **Facilitating Research and Innovation:** The massive volume of data produced by mMTC in the IoHT opens the door for enormous prospects for study and innovation. The identification of patterns, trends, and correlations may be facilitated by the analysis of aggregated and anonymized data obtained from several sources. This feature enables the preservation of individuals' privacy throughout the analysis of their data [170]. The use of a data-driven strategy enhances research endeavors, reinforces evidence-based decision-making, and facilitates the advancement of novel pharmaceuticals, therapies, and healthcare solutions.

3) CHALLENGES AND CONSIDERATIONS

- **Scalability:** The proliferation of connected devices within IoT ecosystem necessitates a growing emphasis on the issue of scalability. The appropriate management of irregular data transmission resulting from the substantial influx of devices is a crucial need for mMTC [171]. To efficiently manage the ever growing quantities of data produced by medical devices and sensors, it is essential to possess a scalable communication infrastructure and a comprehensive set of protocols.
- **Power Consumption and Battery Life:** The significant number of devices comprising IoHT, are dependent on limited power sources, such as batteries. In order to ensure uninterrupted device functionality and minimize maintenance requirements, it is essential to prioritize the optimization of power use, the extension of battery longevity, and the investigation of energy harvesting methods [172].
- **Network Congestion and Interference:** The growing amount of wireless devices inside healthcare environments may lead to network congestion and interference, hence potentially compromising the dependability and effectiveness of wireless communication [173]. Efficient network management, advanced interference mitigation technologies, and precise spectrum allocation algorithms are crucial for ensuring ongoing connectivity and reliable data transmission.
- **Security and Privacy:** Ensuring the security and privacy of sensitive healthcare data sent via wireless communication in IoHT necessitates a strong focus on both aspects [174], [175]. In order to safeguard patient information, mitigate unauthorized access, and ensure adherence to regulatory obligations, it is essential to implement rigorous security protocols like as encryption, authentication, and access control.

C. NETWORK SLICING AND VIRTUALIZATION

There has been an explosion in the area of IoHT, the healthcare professionals nowadays started using diagnostic and treatment processes enabled with IoT technology in order to the quality of life for many patients. In the realm of healthcare, a multitude of wireless sensors and equipment that are interconnected via IoHT might be used in diverse manners owing to their connection [181]. Patients might potentially experience improved outcomes via the use of sensors and remotely monitored medical equipment, which are driven by artificial intelligence and augmented reality, hence enabling the provision of more precise and expedited diagnostic information [176]. Moreover, network slicing is a virtualized networking paradigm that plays a crucial role in the 5G architecture. Network slicing refers to the procedure of partitioning a singular physical network into multiple logical networks, commonly referred to as “slices”. This division enables the deployment of 5G-enabled services with unique network attributes, facilitating the allocation of essential

resources and fulfillment of networking prerequisites for Internet of Highly-Connected Things applications [177]. It enables the establishment of specialized end-to-end logical networks that are efficient and adaptable, operating on a common network infrastructure. These networks are specifically engineered to cater to a diverse range of services with varying needs, making them particularly advantageous for the medical sector. Network slicing plays a crucial role in facilitating the realization of the IoT within the context of 5G technology. One of the key distinguishing features of network slicing and network sharing is the establishment of a virtualized environment during the whole process, which is filled by artificial intelligence devices. The use of network slicing solutions is crucial in optimizing the performance of services in the IoT due to the demanding requirements associated with its applications, including computer vision, virtual and augmented reality, high-quality video streaming, and intelligent signal processing. The architecture of Network Slicing allows operators to create customized network slices for their customers as a service that is driven by demand, with the aim of facilitating healthcare applications [178]. A visual representation of network slicing for enhanced security and privacy in IoHT is shown in figure 10. However, the primary concern is in the arrangement of computer resources, namely the structuring of these resources into nodes at different hierarchical levels. Subsequently, the process includes the development of performance targets, as well as identification of requirements and constraints. Authentication is a significant challenge in the context of healthcare applications using IoT-5G equipment. Eavesdropping and other types of inadequate authentication often arise due to the increased demand and the dynamic nature of wireless networks in the context of IoT and fifth-generation (5G) linked devices [179]. The use of network segmentation might potentially facilitate the attainment of robust security and privacy measures for crucial healthcare services. The mitigation of attacks may be achieved by using network slicing to isolate IoT applications. This approach ensures that there is no reduction in system performance during an attack.

In the context of IoHT, the issues of network slicing and security assume paramount importance, as they play a critical role in ensuring the efficient and secure operation of interconnected devices and services [180]. In the context of IoHT networks, the concept of network slicing enables efficient resource allocation, provision of distinct services, scalability, and flexibility. The implementation of robust security measures is necessary in order to safeguard sensitive data, uphold patient privacy, and mitigate the risk of security breaches [180]. The approaches to be considered should include device security, data privacy, access control, and interoperability, among other relevant factors. The successful use of IoT and IoHT networks in healthcare delivery relies upon the adoption and implementation of secure network slicing technologies and comprehensive security measures. This will enable the networks to maintain optimal levels

of data integrity and secrecy while actualizing their full potential. This article examines the concept of network slicing and its utilization in the domains of IoHT. This also highlights the need of deploying robust security measures and addresses the challenges associated with ensuring the protection of interconnected networks [181].

The concept of network slicing has emerged as a pivotal virtualized networking paradigm as it involves the partitioning of a single physical network into multiple logical networks, often referred to as *slices*. This division enables the deployment of 5G-enabled services, each with unique network characteristics. Thus, it has ability facilitate the allocation of essential resources as per the requirements for applications in the IoHT [177]. It allows the creation of specialized end-to-end logical networks that are efficient and adaptable within all operating on a shared network infrastructure. These networks are specifically customized to accommodate a diverse range of services with varying demands that indeed makes them particularly advantageous for the medical sector.

Network slicing plays a pivotal role in realizing the potential of the IoT within the context of 5G technology. A notable feature of network slicing is the establishment of a virtualized environment throughout the entire process, which is populated by AI devices. The adoption of network slicing solutions is indispensable for optimizing the performance of IoT services due to the high demands associated with its applications. These applications encompass computer vision, virtual and augmented reality, high-quality video streaming, and intelligent signal processing. The architectural framework of network slicing empowers operators to craft customized network slices customized to the specific needs and demands of their customers, effectively transforming it into a service driven by demand. This is particularly significant in the context of healthcare applications [178]. Nevertheless, while the integration of IoT-5G technologies into healthcare applications holds great promise, certain challenges and concerns must be addressed. Moreover, the increased demand and dynamic nature of wireless networks can lead to vulnerabilities such as eavesdropping and inadequate authentication, posing potential security risks [179].

To address this concern and enhance security and privacy measures for critical healthcare services, network segmentation becomes a valuable tool. Therefore, network slicing can play a crucial role in isolating IoHT applications, effectively creating separate virtualized environments. This segmentation approach not only helps in safeguarding against potential attacks but also ensures that system performance remains unaffected during such security incidents which means that it can provide a robust security framework for IoHT applications. In particular, the issues of network slicing and security assume paramount importance for IoHT applications by ensuring the efficient and secure operation of interconnected devices and services [180]. The implementation of robust security measures is necessary in order to safeguard sensitive data, uphold patient privacy, and

mitigate the risk of security breaches. The approaches to be considered should include device security, data privacy, access control, and interoperability, among other relevant factors. The successful use of IoHT in healthcare delivery relies upon the adoption and implementation of secure network slicing technologies and comprehensive security measures. This will enable the networks to maintain optimal levels of data integrity and secrecy while actualizing their full potential. This article examines the concept of network slicing and its utilization in the domains of IoHT [181]. This highlights the need of deploying robust security measures and addresses the challenges associated with ensuring the protection of interconnected networks.

Application of Network Slicing in IoHT:

- 1) **Resource Optimization:** Network slicing enables efficient resource allocation by allocating distinct slices of the network for the operation of diverse applications and services inside the Internet of Things and Internet of Things of Things domains. Consequently, the optimization of network capacity utilization, minimization of delay, and enhancement of overall network performance may be achieved. For example, network slices may be customized to accommodate real-time remote patient monitoring, essential healthcare applications, or non-essential devices [182]. This guarantees that every application gets the necessary resources for reliable and efficient data transmission.
- 2) **Service Differentiation:** Various applications within the IoHT domain exhibit distinct network requirements pertaining to bandwidth, latency, and reliability. Different applications in the IoHT space have different needs from one another in terms of latency, bandwidth, and stability in their networks. Through the use of specially designed network slices that are adapted to each application's unique requirements, network slicing enables service suppliers to provide their clients customized services. This ensures that essential healthcare applications, such as telemedicine or emergency services, are given priority and allocated dedicated network resources, while non-critical applications operate on separate segments, hence avoiding any impact on key services [183]. Telemedicine and emergency services exemplify essential healthcare applications.
- 3) **Scalability and Flexibility:** The proliferation of IoT and Industrial Internet of Things (IIoT) networks is expected to see rapid growth in response to the increasing number of interconnected devices and services [184]. The concept of network slicing provides a means for service providers to achieve scalability and flexibility via the dynamic allocation and configuration of network slices in response to varying levels of demand. This facilitates the scalability of network slicing in order to accommodate expanding business requirements. In order to accommodate evolving network requirements, it is possible to produce new

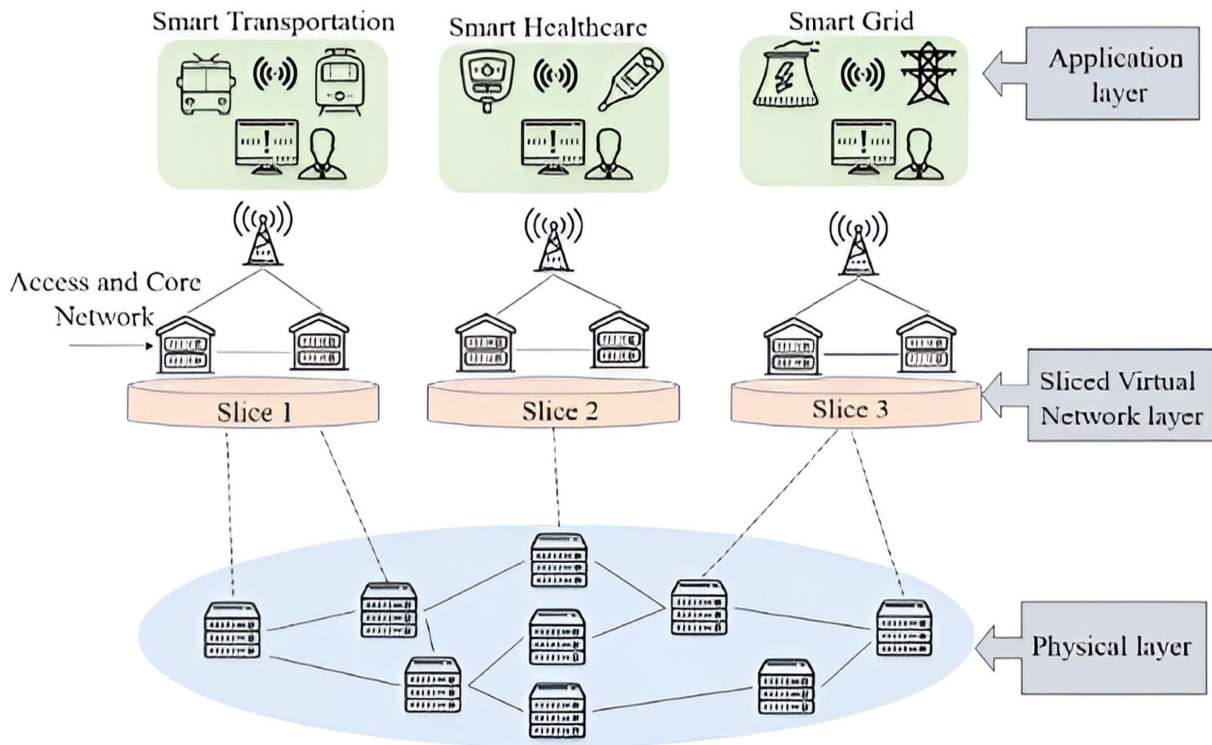


FIGURE 10. Diagram illustrating the architecture of network slicing for enhanced security and privacy in IoHT. The figure depicts how multiple virtual networks (slices) can be created within a shared physical infrastructure to accommodate diverse IoHT applications with varying QoS and security requirements. Key security mechanisms, including encryption, authentication, and access control, are accessed to safeguard sensitive patient data and ensure the integrity of medical devices and services.

slices and make adjustments to existing ones [185]. This guarantees that the network has the capacity to accommodate the increasing quantity of interconnected devices and services, while maintaining optimal speed and quality of service.

• Importance of Security in IoHT:

The significance of security in the IoHT applications is important due to the sensitive nature of the data transmission and to mitigate the potential risks associated with compromised devices and networks. This importance stems from its role in safeguarding personal information, ensuring the integrity of healthcare data, mitigating unauthorized access, and minimizing potential cyber risks [186]. Moreover, the implementation of rigorous security measures is of utmost importance in order to instill trust, safeguard patient privacy, and uphold the confidentiality, availability, and reliability of healthcare services. Security measurements provides a secure environment for IoHT devices and networks via the implementation of robust authentication mechanisms, encryption protocols, access limitations, and proactive monitoring. This is essential to adhere to optimal security protocols, regularly update software, and undertake ongoing security evaluations to prevent the exploitation of emerging vulnerabilities and threats. Ensuring the safeguarding of healthcare systems and

the privacy and well-being of patients necessitates prioritizing the security of IoHT applications [187].

• Security Challenges in IoHT:

- 1) **Device Vulnerabilities:** IoHT devices often exhibit restricted resource availability and may exhibit deficiencies in robust security features. As a result, these entities are vulnerable to a diverse range of attacks, including data modification, unauthorized access, and the infiltration of malicious software. Safeguarding the comprehensive network of IoT and IIoT is imperative [184], necessitating the establishment of robust security measures to prevent these devices from serving as vulnerable access points for cyberattacks [188]. Devices used in healthcare applications often have limited resources and may lack robust security features. Consequently, IoHT devices are vulnerable to various types of attacks, including data tampering, unauthorized access, and the infiltration of malicious software [188]. Therefore, establishing strong security measures is essential to protect IoHT devices from these malicious attacks.
- 2) **Data Privacy and Confidentiality:** The IoHT Network are responsible for the reception and management of sensitive data, such as personal health information, medical records, and real-time patient

monitoring data [189]. Therefore, preserving patient confidentiality and safeguarding the privacy of their data are of paramount importance in order to maintain patient trust and adhere to legal requirements. In order to safeguard patient data and mitigate the risk of unauthorized access or data breaches, it is essential to use strong encryption techniques, ensure secure data storage practices, and employ secure data transfer protocols.

- 3) **Network Access Control:** The Industrial Internet of Things networks must be secured through the implementation of strong access control measures in place because they reduce the possibility that unauthorized people or devices will get access. Strong authentication systems, secure access protocols, and network segmentation made possible by network slicing can all be used to reduce the dangers connected with unauthorized access and unauthorized data exposure [190]. Enforcing access control restrictions and periodically renewing access credentials are essential security protocols for protecting IIoT networks.
- 4) **Interoperability and Standardization:** The ecosystems of the IoT/IOHT include a wide range of devices, platforms, and protocols. The absence of interoperability and established security protocols across different components of the IOHT may give rise to possible security vulnerabilities [191]. Establishing industry-wide security standards and promoting interoperability are crucial in ensuring consistent and effective security measures across networks including the IoT and IOHT applications.

• Security Measures for Network Slicing in IoHT:

- 1) **Isolation and Segmentation:** When a network is partitioned, distinct services and applications are automatically separated and segregated from each other. Every component of the network operates independently, with its own dedicated resources, logical separation, and security protocols. As a result of this partition, any security breaches occurring inside one segment would not impact the other segments, hence ensuring the ongoing provision of critical healthcare services in a secure way.
- 2) **Encryption and Authentication:** Consequently, it has become imperative to include resilient encryption techniques and authentication protocols inside IoHT networks to safeguard data integrity and mitigate unauthorized intrusion. Secure communication channels include many techniques such as encryption mechanisms, secure key management, and mutual authentication between devices and network components [192]. These mechanisms serve to safeguard the transmission of information and ensure that only those with proper authorization are able to get access to the network.

- 3) **Intrusion Detection and Prevention:** In the context of IIoT networks, the implementation of intrusion detection and prevention systems (IDPS) may play a crucial role in the identification and mitigation of potential security vulnerabilities. IDPS are designed to oversee network traffic, do pattern analysis, and identify anomalies indicative of potential security breaches or hostile actions [193]. The mitigation of future damage to both the network and its associated devices may be achieved by the prompt detection of potential threats, followed by suitable and effective response measures.
- 4) **Regular Updates and Patch Management:** For the purpose of resolving security vulnerabilities, it's critical to handle frequent updates and patches for network infrastructure and IIoT devices. The prompt emphasizes the need of promptly installing recently announced security patches and firmware updates [194]. By doing so, organizations may effectively protect their networks against newly discovered vulnerabilities and maintain a resilient infrastructure in the face of emerging threats.

IV. CHALLENGES IN WIRELESS IOHT NETWORK

The integration of wireless communication into healthcare encounters significant obstacles in interoperability, security, and regulatory adherence, demanding careful consideration for successful implementation. Two distinct case studies exemplify these challenges. Firstly, a large-scale deployment of remote patient monitoring in a multi-state US healthcare system highlighted severe interoperability issues. The system aimed to collect data from various wearable sensors and home medical devices, but the lack of standardized communication protocols resulted in fragmented data collection and integration. Data from different devices often required manual entry or complex translation processes, leading to delays and potential errors in patient care. Secondly, a national telehealth initiative in Estonia, while technologically advanced, faced substantial security and regulatory hurdles. The initiative aimed to provide remote consultations and prescription services, but concerns over patient data privacy and security, coupled with strict national data residency requirements, limited the use of cloud-based storage and processing. A series of simulated cyberattacks revealed vulnerabilities in the system's data encryption protocols, prompting significant redesign and investment in robust security measures. These case studies underscore the necessity of developing standardized interoperability protocols, implementing strong security measures, and navigating complex regulatory landscapes to harness the full potential of wireless communication in healthcare.

A. CONNECTIVITY AND COVERAGE

IoHT is a great way to transform healthcare through constant connectivity and data-driven insights. However,

making this vision a success requires surmounting the significant wireless technologies' challenge on connectivity and coverage. Furthermore, there are substantial challenges that hinder information flow in the dynamic health care environment that need to be overcome. Health care systems in particular have strict standards for real-time transmission, reliability, and data security as well as other related stringent requirements.

Firstly, it is important to ensure comprehensive coverage throughout healthcare facilities. In many cases conventional wireless networks fail to penetrate walls, equipment and even human bodies therefore creating dead zones that can compromise patient monitoring and care delivery. Additionally, numerous wireless technologies coexist within a single hospital environment such as Wi-Fi, Bluetooth, cellular as well as emerging standards like Low-Power Wide-Area Networks (LPWANs), hence interference and congestion may occur making communication seamless challenging. Hybrid network architectures among others will be required for addressing these problems using innovative strategies like intelligent signal routing or advanced antenna technologies.

Second, it is important to maintain robust and secure connectivity for IoHT devices. The data of patients who are highly sensitive to any kind of cyber threats must be continuously transmitted in a manner that warrants encryption and authentication mechanisms that are strong. Additionally, the increase in IoHT devices has seen more congestion on networks leading to latency issues and packet loss. These challenges can however be mitigated through efficient network management, prioritization of traffic as well as the use of 5G technology and Wi-Fi 6 among other emerging technologies. Also, optimization of network architectures and protocols is crucial for real-time applications like remote patient monitoring and telemedicine that require low latency communication.

Thirdly, power consumption is a significant concern for IoHT devices especially implantable and wearable sensors. For uninterrupted patient monitoring or minimal device replacements, long battery life is very important. In addition, energy efficiency wireless protocols should be adopted; power management enhancements should also be improved upon and alternative sources (e.g., energy harvesting) can also be exploited to solve this problem. Thus, to unlock the potential of IoHT, it is crucial to address wireless connectivity and coverage challenges. By building strong infrastructure, creating inventive wireless solutions and giving priority to privacy and security of information, healthcare industry will pave way for a world where patients can effectively and efficiently be treated for better results as well as more freedom.

B. RESOURCE CONSTRAINTS

The IoT for healthcare can dramatically change patient care, preventive health, and remote monitoring. This is because IoHT systems are able to receive wireless communication technologies from healthcare gadgets and collect,

send and analyze a lot of patients' information hence allowing their real-time monitoring, early disease detection and treatment customization. However, deploying applications for IoHT is largely limited by inherent resource constraints such as energy, bandwidth and computational capabilities.

Energy efficiency in IoHT devices is critical as battery life affects the device's lifespan as well as maintenance costs. In particular, implantable and wearable devices have strict energy limitations on them due to their size coupled with power source restrictions. Additionally, significant amounts of energy are consumed by continuous transmission of data and processing thus innovative power management techniques must be invented. Researchers are also looking into various energy-harvesting technologies like solar, thermal or even kinetic energy conversion that will help expand the lifetime of these devices. Also there has been an adoption of low-power wireless communication protocols like BLE and Zigbee so that during data transfer less energy will be used. One of the biggest challenges in IoHT environments is limited bandwidth, particularly in regions without much network infrastructure. This problem is further compounded by the increased number of connected devices and growing volumes of medical data. For that reason, efficient data compression algorithms are needed to shrink transmitted data size so as to overcome limitations in bandwidth. Equally important is the use of network slicing and prioritization techniques which makes it possible to allocate enough capacity for important IoHT applications. Furthermore, integration between cellular networks and Wi-Fi as well as other wireless technologies can help improve coverage and capacity.

Edge computing experience some challenges due to inadequate computational resources such as RAM, GPU and CPU power at the IoHT edge. Some medical equipment have low processing capabilities that do not allow real-time decision making or advanced analytics. In such a case, computationally intensive tasks can be offloaded using cloud-based computing platforms. However, this solution introduces issues related to privacy and latency since offshoring takes more time than just executing any required operation from the edge within a tiny net while maintaining all its security measures intact. Thus, edge computing and fog computing models have emerged that allow distributed processing together with analysis of data closer for-source solutions like IoT systems.

Patient data in IoHT systems is extremely confidential, hence the need for high security and privacy. Resource-starved gadgets are usually not well secured which makes them prone to cyber-attacks. To counter these threats, light weight cryptographic algorithms and secure boot processes can be implemented. Moreover, secure data transmission protocols and access control mechanisms play a critical role in safeguarding patient information. In addition to this, privacy preserving data analytic techniques can be used to generate valuable insights while still protecting individual identities.

Interoperability remains another challenge facing IoHT due to the fact that different healthcare devices and systems use incompatible communication protocols or data formats. This interferes with smooth integration of data making it difficult to design comprehensive solutions for patient care. Standardized communication protocols and exchange formats are also necessary to address interoperability. Furthermore, adoption of open platforms and APIs allows integration between different IoHT components. In summary, deploying IoHT applications faces significant problems relating to lack of resources. Nevertheless, full deployment potential of wireless communications in medicine can be unlocked through addressing energy efficiency, bandwidth limitless, computational limitation, security constraints and privacy concerns as well as interoperability issues. This is crucial for driving down these challenges and creating a reliable and patient-oriented healthcare network connected throughout.

C. DATA INTEGRITY AND RELIABILITY

IoHT is a prosperous domain that vows to modify the patient attention by the use of wireless communication in connection with medical devices, sensory objects, and health care systems. As a result, this web allows for real-time checking, remote care and easy data administration. However, successful IoHT implementation hinges on data integrity and reliability in the transmission. Nevertheless, this technique is not without its own set of unique difficulties as far as data quality is concerned which can expose it to potential errors; misdiagnosis or imperiled patient's safety. This article seeks to shed light on crucial data integrity and reliability issues related to wireless technologies used for IoHT applications; it will also delve into their impacts and possible solutions which may lead to unlocking the full potential of wireless communication within healthcare sector. Data integrity is one of the main worries in wireless IoHT. The wireless media is prone to several hindrances, interferences and weakening of signals that can make data packets corrupt during transmission. These misinterpretations may result in false readings from medical sensors, wrong patient information and compromised decision making. To ensure the trustworthiness and completeness of transmitted data are maintained so as to sustain the reliability and efficacy of IoHT systems.

However, another stumbling block is data dependability. In addition, these network links have some fluctuations in signal strength, connectivity glitches or momentary periods of dis-connectivity due to variety of reasons. It results into faults such as loss of data this calls for delays during its transmission or even inconsistencies on the same. Unreliable information in IoHT setup may adversely impede real-time monitoring; it might lead to delaying vital alerts and obstruction timely administration of medical attention where required. Maintaining persistence with unbroken flow is significant for successful implementation of IoHT applications. The security of information that is given and maintained

through wireless IoHT is key. The wireless networks transmit patient information which makes it vulnerable to interception, alteration or unauthorized access by a third party. This may happen when malicious actors take advantage of loopholes in the wireless communication protocols that may render the data integrity, confidentiality and availability compromised. It is important to ensure that patient's data are not accessed by people who are not authorized and keep it secure while being transferred because this will help in retaining trust from patients and safe keeping of sensitive medical records.

Moreover, various types of wireless technologies used in IoHT add more complexities. Different wireless standards such as Wi-Fi, Bluetooth, Zigbee, cellular networks have different levels of performance/security/energy efficiency respectively. Careful evaluation of data requirements, coverage area, power consumption and security issues must be considered before selecting the right type of wireless technology for a particular application in IoHT. A holistic IoHT ecosystem also need to have seamless interoperability among diverse wireless network types. Dealing with the challenges of wireless IoHT data integrity and trustworthiness demands a multifaceted approach. Error-correction codes, encryption of data, and backup techniques are some ways through which integrity can be supported and prevention of corruption caused by data loss. It has been suggested that incorporating strong wireless communication protocols fitted with error detection and correction systems could improve the reliability of such information. This calls for implementation of strict authentication as well as access control measures to protect patient data from unauthorized access.

Careful network planning including optimization alongside multiple technical solutions is important. Deploying redundant wireless access points, optimizing network coverage, and introducing network monitoring tools are among ways to minimize connection issues and enhance data reliability. These practices also entail regular updating as well as maintenance of networks in order to address emerging threats while improving system performance. IoHT depends on standardization to maintain data integrity and reliability. The establishment of common standards for data formats, communication protocols and security practices can support interoperability, data exchange, and analysis. Therefore, it is important for industry participants in IoT healthcare to work together with other players like medical providers and regulatory agencies so as to come up with standardized IoHT solutions [37]. Even though wireless communication is a challenge for IoHT data integrity as well as its reliability, it also presents a great opportunity for enhancing patient care. By dealing with these problems using robust technical measures, careful network planning and collaboration within the industry itself; the health care system can unleash the full potential of wireless technologies hence improving patient outcomes, driving operational efficiency gains and fostering innovation in delivering health care services.

V. SECURITY AND RISK MITIGATION TECHNIQUES

Existing Techniques:

- **Intrusion Detection and Prevention Systems**

(IDS/IPS): IoHT is changing the way treatment is offered to patients by using wireless communication to connect medical devices, sensors and systems. This connected world has great potential for better patient outcomes, remote monitoring and more efficient operations. Nevertheless, the increase in wireless devices in health care environments introduces significant security challenges that require robust intrusion detection and prevention systems to protect patient data and safeguard the integrity of medical devices.

In IoHT environments, IDS/IPS are vital in addressing security threats. These substances continuously supervise network traffic as well as system activities in search of malicious behavior, enabling early warning on any possible attack and proactively preventing them. Considering this fact; advanced detection and prevention techniques can go a long way in enhancing the security posture of IoHT architecture of healthcare organizations. The great diversity of devices that are involved often have low processing power and memory capacity. This calls for lightweight IDS/IPS solutions. In such cases, deploying them at network edges closer to medical devices makes it easy to detect and respond to threats than in other locations. What is more, machine learning and artificial intelligence can make IDS/IPS systems learn better from evolving threats and also improve their detection rates. Anomaly-based detection helps identify network traffic patterns that are out of place, which may indicate malicious intent. By understanding how medical devices should behave and act under normal circumstances, IDS/IPS can tell whenever there is something wrong with them. However, setting thresholds for anomaly detection carefully is important, as false positives can disrupt patient care. Another important approach for the identification of known threats is signature-based detection. A constantly updated database of attack signatures by IDS/IPS can detect and block malevolent traffic within no time. However, accurate and timely threat intelligence is necessary for successful implementation of signature-based detection, which can be challenging to get especially in the case of emerging threats.

An analysis of user and device behavior to identify suspicious behavior defines behavioral- based-detection. IDS/IPS can detect any deviation from normal base behaviors signaling a possibility that a user account has been compromised or unauthorized access has taken place. Behavioral-based detection can be highly effective in identifying insider threats and advanced persistent threats (APTs). Different methods are applied by IDS/IPS to evade successful attacks. Such approach includes the act of barring malevolent traffic, separating

compromised mechanisms, and sending warnings to security officers. Besides this, IDS/IPS may introduce intrusion prevention techniques such as network partitioning, access administration or encryption of valuable patient information.

To be aware of and fix faults in IoHT framework; regular vulnerability scanning and safety assessments should be conducted. Proactive identification of loopholes through which cyber criminals can penetrate is helpful for healthcare organizations to prevent their exploitation. Furthermore, careful monitoring and analysis of audit logs enables detecting incidents that occur in a real-time mode. When it comes to healthcare organizations, training and education of employees is very important in terms of fostering a strong security culture. It can help prevent attacks by making employees aware of the risks that are related to security as well as best practices in this area. Some topics which should be covered during regular security awareness trainings include phishing, social engineering and password hygiene.

In order for healthcare organizations to stay ahead of emerging threats, they need to collaborate with industry partners and share threat intelligence. Thus, by taking part in information sharing initiatives, organizations can leverage on the collective intelligence of the security community to improve their detection and response capabilities against such attacks. To sum up, IDS/IPS are indispensable in order to secure IoHT environment and protect patient data. Healthcare organizations can reduce risks associated with wireless communication, and unlock the full potential of IoHT for improved patient care and connectivity by utilizing advanced detection techniques, preventive measures and continuous security management practices.

- **Security Incident and Event Management (SIEM):**

By using wireless technologies to link health devices, sensors and systems, the IoHT is changing how patients are treated. The connected ecosystem holds great promise for better patient outcomes, efficient operations, and remote monitoring. However, in healthcare settings, the wide scale use of wireless devices also presents major threats to security and privacy. SIEM solutions have become an important part of a comprehensive IoHT security plan as they help to mitigate these risks, thereby safeguarding sensitive patient information. The SIEM is a centralized log management and security information analysis platform that integrates data from different sources, including network devices, servers, applications, and IoT endpoints. This real-time evaluation of information enables the SIEM system to detect abnormalities, identify probable threats, and produce alerts for prompt reaction to incidents. In the IoHT context, this becomes crucial in ensuring patient data is not leaked, and thus maintaining regulatory compliance and system integrity.

TABLE 7. Wireless Communication Connectivity with Different Medical IoT Devices in IOHT. This table provides a comprehensive overview of the various wireless communication technologies utilized by different medical IoT devices within the Internet of Healthcare Things (IOHT) ecosystem. It encompasses key parameters such as data rate, range, power consumption, latency, and security, facilitating a comparative analysis of suitable wireless technologies for diverse medical applications.

Technology	Description	Range
WiFi -RFC 5414	1) Connects various medical devices, including patient monitoring systems, electronic health records (EHR) system. 2) Allows for secure data transmission and fast connectivity.	Moderate
Bluetooth -RFC 7668	1) Used for short-range connectivity between medical IoT devices and smartphones or tablets. 2) Wearable devices, like fitness trackers and continuous glucose monitors, frequently use Bluetooth to sync data with mobile apps.	Moderate
Cellular(4G/5G) - RFC 8822	1) Offer wide-area coverage, making them suitable for remote patient monitoring and telemedicine applications. 2) Can transmit data from virtually anywhere, which is beneficial for patients in rural areas. 3) 5G technology offers high bandwidth and low latency, enhancing the capabilities of medical IoT applications.	Wide
NFC - ISO/ IEC 18000-3 air interface	1) Used for secure access control and patient identification in healthcare facilities. 2) Can be employed in smart cards and mobile apps to enable contactless check-ins, prescription validation, and secure data transfer.	Local
Mesh Networks - IEEE 802.15.4	1) Used for creating self-healing, decentralized communication systems in healthcare settings. 2) Employed for monitoring patients and tracking assets in complex environments, such as large hospitals..	Local
Sattellite Communication - IEEE 4003-2021	1) Satellite communication can be used to connect medical IoT devices in remote or under served areas. 2) Ensures connectivity even in areas with limited terrestrial network coverage, making it essential for emergency and disaster response	Wide
Zigbee - IEEE 802.15.4	1) Employed in medical IoT for wireless sensor networks, especially in remote patient monitoring. 2) Provides low-power, low-data-rate communication and is suitable for applications that require long battery life. 3) Used in home healthcare setups for monitoring elderly or chronically ill patients.	Moderate
RFID - ISO/IEC 14443 and ISO/IEC 18000-3	1) Used in healthcare for tracking medical equipment, patient identification, and asset management. 2) Ensures that the right medications are administered to the right patients and that medical equipment is readily available when needed.	Local
LoRaWAN - RFC 8376	1) Low-power, long-range communication technology used in healthcare for remote monitoring and tracking of assets and patients. 2) Ideal for applications that require extended battery life and cover large geographical areas.	Moderate

One of the biggest security concerns in IoHT is the vulnerability of wireless communication channels. Wireless networks can be used by malicious actors as potential points of interception or modification, or even theft of sensitive patient data. The reason behind this is that they are able to exploit vulnerabilities in these networks. An example could be monitoring network traffic for any suspicious active attacks, if such as unauthorized access attempts, data ex filtration, or denial-of-service attacks so as to save oneself from these possible risks through employing an effective SIEM tool set. By relating network events with other aspects connected with protection matter, the SIEM can

identify certain patterns that may suggest intrusion, and thereby initiate proper countermeasures.

Also, protecting medical devices, many of which have confidential patient data and control important operations, is another important area of IoHT security. Anomalies like unanticipated software updates, non-approved access or an operating defect can be discovered by SIEM through observing device behavior. In case inconsistencies with regular functioning occur, SIEM can help prevent unauthorized use of the device, tampering attempts, or data breaches.

In addition, SIEM provides audit trails and reporting capabilities that facilitate compliance with healthcare

industry regulations such as HIPAA and GDPR. With the ability to capture and analyze system activities as well as user behaviors actions SIEM demonstrates compliance with regulatory standards and it also helps in investigations for cases such as data thefts or other types of breaches. Several critical factors have to be considered when utilizing SIEM in IoHT. Begin by determining and ranking the important assets and data within the IoHT infrastructure. This will enable SIEM monitoring as well as alerting to focus on the most valuable and sensitive parts. The second thing to do is to incorporate clear incident response procedures by defining roles and responsibilities that aim to ensure that security incidents are dealt with quickly and effectively. Third, the healthcare staff needs to keep on being trained so that they become aware of the risks surrounding security issues and also some of the practices that promote integrity. SIEM is a powerful tool for the enhancement of security and risk mitigation on IoHT environments. As such, SIEM gives a broad understanding of network and device activities that enables companies to spot or respond to threats in real time, keep patient data safe while staying within the laws. The integration of SIEM solutions will be crucial in protecting the welfare of patients and upholding confidence in healthcare delivery as IoHT continues to develop. Table 6 represents the comparative analysis of wireless communication technologies in IOHT.

Emerging Techniques:

A. BLOCKCHAIN TECHNOLOGY

The recent development of blockchain technology has led to its implementation as a disruptive option for ensuring secure data sharing within the healthcare industry. The use of blockchain technology is seen appropriate for addressing the challenges associated with data exchange within the healthcare sector. Due to this, it offers decentralization and transparent characteristics. These attributes provide many benefits in terms of data integrity, privacy, and security [195]. Blockchains have the potential to facilitate the establishment of distributed ledgers, which may afterwards serve as a means to document and track transactions. One of the key advantages that blockchain technology provides in the healthcare sector is its ability to uphold data veracity. Every transaction or data exchange is meticulously documented as a block and linked to preceding blocks, forming an immutable chain [196]. The underlying structure of blockchain is based upon a distributed ledger system.

The concept of immutability refers to the inherent characteristic of the blockchain technology, whereby any data that is posted into the blockchain becomes unalterable and impervious to tampering or modification. The establishment of a robust level of trust and confidence in the integrity of the information being disseminated is crucial for the viability and prosperity of crypto currencies. Ensuring the integrity and consistency of patient records,

medical research data, and clinical trial information is of utmost importance in the healthcare business [202]. The use of blockchain technology in the healthcare sector enables firms to authenticate the integrity of received data, ensuring its accuracy and preventing any unauthorized modifications.

The use of blockchain technology enhances the confidentiality and security of patient data within the healthcare industry [203]. In a blockchain network, every participant is assigned a unique cryptographic identity along with corresponding access privileges. This enables the implementation of robust authentication and authorization mechanisms, so guaranteeing that only those with proper authorization may get access to specific data and engage in its sharing [204]. The use of blockchain technology in the healthcare sector empowers healthcare providers to effectively manage and control the authorization of individuals who may access patient data. This technology ensures the provision of access to authorized personnel while simultaneously safeguarding patient fundamental rights to privacy and confidentiality. The decentralization of blockchain technology eliminates the presence of a single point of vulnerability, hence reducing the risk of hackers concentrating their efforts on a specific target. This significantly reduces the risk associated with data breaches and illegal access [200]. The heightened level of security is of significant importance within the healthcare sector, given its handling of highly sensitive and very valuable information.

The use of blockchain technology in the healthcare ecosystem may foster more trust among the many rivals, owing to the inherent transparency and openness offered by this platform. The blockchain technology enables all participating parties to have access to a comprehensive record of transactions, ensuring a high level of accountability and openness. This may be particularly advantageous in scenarios when several entities are involved in the process of exchanging data. An instance illustrating this phenomenon is the exchange of patient data among healthcare providers, insurance firms, and researchers [205]. Blockchain, a kind of distributed ledger technology, facilitates the creation of a comprehensive and immutable record of data transactions, hence enabling the verification of their correctness and validity. This enhances the degree of trust among users and facilitates the expeditious resolution of disagreements [206]. The use of peer-to-peer networks eliminates the need for intermediaries, enabling individuals to directly exchange data among themselves. Consequently, this technique reduces both the administrative costs and delays often associated with traditional methods.

The use of blockchain technology within the healthcare sector has the potential to enhance data exchange and promote interoperability [207]. The conventional approaches to data transfer often encounter challenges arising from disparities in data formatting and the presence of isolated information management systems. The use of blockchain technology enables healthcare institutions and systems to

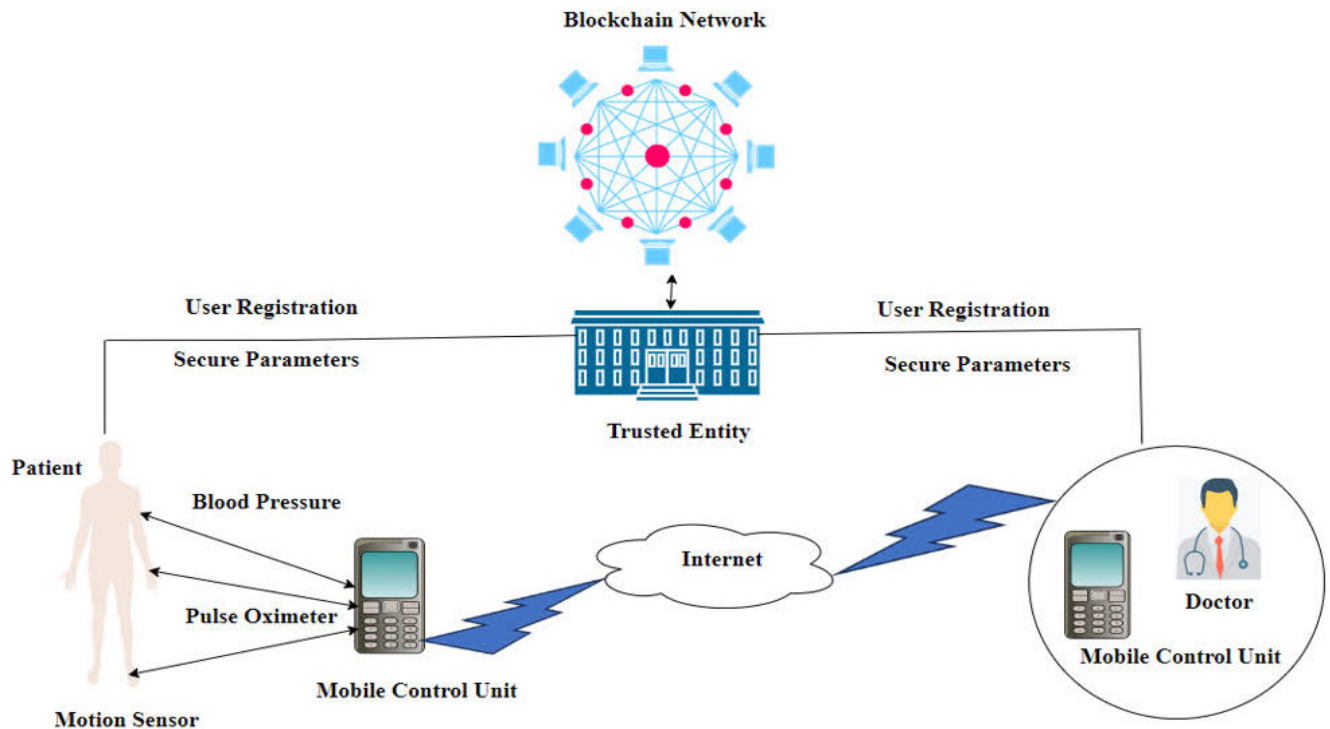


FIGURE 11. This diagram illustrates the application of blockchain technology to safeguard data integrity and privacy within a healthcare wireless communication network. It depicts the key components of a blockchain system and demonstrates how these elements work together to create an immutable and transparent record of patient data. The diagram highlights the role of blockchain in securing data exchange between various healthcare stakeholders, such as patients, healthcare providers, and insurers, while maintaining data confidentiality and preventing unauthorized access.

seamlessly communicate and integrate data via a decentralized and standardized approach. This facilitates the secure exchange of patient information, therefore enhancing healthcare providers comprehension of a patient's medical background and enabling them to make more informed decisions on treatment [208]. Interoperability plays a crucial role within the healthcare sector as it serves to enhance the coordination of treatment, mitigate the potential for medical errors, and ultimately enhance patient outcomes. The use of blockchain technology facilitates the establishment of interoperable healthcare systems by offering a structured framework for the secure and uniform exchange of data [197].

One potential benefit that blockchain technology may bring to the healthcare business is the ability to enhance patient empowerment and provide them with more autonomy over their health data. Patients will own the ability to maintain ownership of their data and exercise control over its accessibility by using cryptographic keys to grant or revoke authorization. The feasibility of this is facilitated by the use of blockchain technology. Patients have the ability to selectively disclose their data to healthcare professionals, researchers, or other reputable entities according to their discretion. This empowers patients by placing them at the core of their own healthcare and affording them more authority over the utilization of their data. One additional benefit of enhanced transparency in the healthcare system is that

patients are able to track the individuals who have accessed their data and the purpose behind such access. Patients may also benefit from more openness within the healthcare system. The level of control and transparency achieved contributes to the enhancement of patient privacy and autonomy [209]. However, the use of blockchain technology in the healthcare sector may encounter certain challenges that need to be addressed in order to provide secure and efficient data exchange. Ensuring seamless integration and exchange of information across diverse systems necessitates the presence of interoperability and standardization of data formats. To ensure compatibility and interoperability, it is essential for technology makers and medical care organizations to collaborate in the development and adoption of shared standards [201]. In order to ensure the preservation of patient privacy, it is essential to consider legislative concerns, including adherence to data protection rules such as the General Data Protection Regulation (GDPR). It is essential to address the limitations pertaining to scalability and performance in blockchain systems, since these limits must be resolved in order to adequately accommodate the volume and speed requirements of data exchange within the healthcare sector [199]. Table 7 represents the comparative analysis of recent surveys on Blockchain technology for secure data exchange and to improve the patient's health and connectivity.

TABLE 8. Summary of Recent Surveys Conducted in Blockchain Technology within IoHT. This table provides a comprehensive overview of recent surveys exploring the integration of blockchain technology into IoHT. The surveys analyzed in this table focus on various aspects including security, privacy, data integrity, scalability, and interoperability. This detailed synthesis aims to offer valuable insights into the current state and potential advancements in the application of blockchain within IoHT frameworks.

Author	Title	Year	Main Contribution
Almalki et al. [197]	State-of-the-art research in blockchain of things for healthcare	2024	1) The paper provides a thorough and up-to-date overview of the existing research landscape in blockchain of things (BLoT) for healthcare. It effectively categorizes and analyzes various BLoT architectures, consensus mechanisms, and data management strategies employed in different healthcare applications. 2) A significant contribution of this paper is the identification of emerging trends and research gaps in the field of BLoT for healthcare. The authors have successfully highlighted the potential of BLoT in addressing critical healthcare challenges such as data privacy, interoperability, and supply chain management. 3) Emphasized the need for regulatory clarity, industry collaboration, and public awareness to support the successful implementation of blockchain in healthcare.
Abbas et al. [198]	Blockchain-assisted secured data management framework for health information analysis based on Internet of Medical Things	2024	1) The framework demonstrates enhanced scalability and interoperability compared to existing approaches. By distributing data management across multiple nodes, the system can handle increased data volumes and accommodate a growing number of IoMT devices without compromising performance. 2) The paper provides a comprehensive evaluation of the proposed framework through rigorous testing and performance analysis. The experimental results validate the system's effectiveness in terms of security, efficiency, and usability, offering valuable insights for practical implementation. 3) Outlined potential solutions and recommendations for mitigating the challenges.
Samadhiya et al.	Unlock the potential: unveiling the untapped possibilities of blockchain technology in revolutionizing Internet of Medical Things-based environments through systematic review and future research propositions	2024	1) The proposed BSDMF utilizes blockchain technology to establish a decentralized and immutable ledger for recording and managing health information. This ensures data integrity, transparency, and accountability, mitigating the risks of data tampering and unauthorized access. 2) The framework incorporates robust security mechanisms to protect sensitive patient data, including encryption, access controls, and identity verification. This safeguards patient privacy and builds trust in the healthcare system. 3) The paper demonstrates the effectiveness of the BSDMF through rigorous evaluation and performance analysis. The results highlight the framework's ability to enhance data security, improve data accessibility, and support efficient health information analysis.
K.Pal [200]	Security Implications of IoT Applications with Cryptography and Blockchain Technology in Healthcare Digital Twin Design	2023	1) Proposed a framework for designing secure healthcare digital twin systems using IoT, cryptography, and blockchain technology. 2) Addressed the security challenges of IoT-based healthcare systems, such as data privacy, integrity, and device security. 3) Included the development of lightweight cryptography and blockchain algorithms for efficient use in healthcare settings.
F. I. Anik et al. [201]	Unraveling a block chain-based framework towards patient empowerment: A scoping review envisioning future smart health technologies	2023	1) Proposed a patient-centric block chain-based framework to orchestrate scientific advancement, technology integration, and patient empowerment. 2) Highlighted the importance of patient access, awareness, and control over their health data. 3) Envisioned future smart health technologies that leverage blockchain technology to empower patients and improve the overall healthcare ecosystem.

The blockchain technology has significant untapped promise in the healthcare sector for facilitating the secure exchange of private data. The decentralized and transparent nature of the system, along with the use of cryptographic techniques, ensures the preservation of user data privacy while upholding its integrity. Healthcare firms may establish a secure and reliable data exchange environment by using blockchain technology [210]. This facilitates the cultivation of privacy, confidentiality, and trust among the individuals involved. Blockchain technology has the potential to enhance

the efficiency of data exchange, promote interoperability, and empower patients by giving them control over their own health data. Despite the presence of various challenges, the potential benefits of blockchain technology in enhancing the security of data exchange within the healthcare sector render it a captivating area of study and implementation. This technology holds promise for establishing a healthcare system that is characterised by increased transparency, responsibility, and patient-centricity [211]. A diagram depicting the application of blockchain technology is shown in figure 11.

B. PHYSICAL LAYER SECURITY TECHNIQUE

Physical layer security (PLS) is a promising approach to improving the security and reliability of communication in the IoHT [289]. PLS techniques exploit the physical properties of the wireless channel to protect data from eavesdropping and jamming. One of the key challenges in developing PLS techniques for IoHT is the resource-constrained nature of IoHT devices. IoHT devices often have limited processing power, memory, and energy resources. This makes it difficult to implement traditional PLS techniques, which can be computationally expensive. Another challenge is the unreliability of wireless channels. IoHT devices often communicate over wireless channels that are subject to noise and interference. This can make it difficult to reliably implement PLS techniques. Despite these challenges, there has been significant progress in developing PLS techniques for IoHT. Some of the promising PLS techniques for IoHT are given in below Table-9.

1) WHY PLS IS CRUCIAL IN IOHT?

Unlike conventional cryptography, which relies on computational complexity for security, PLS customizes the physical properties of the channel itself. Even with unlimited computational power, an attacker cannot break the encryption if they lack knowledge of the specific channel conditions [225]. This offers a stronger guarantee of security against even the most sophisticated adversaries. PLS does not depend on secret keys that can be compromised through leaks or brute force attacks. The security stems from the inherent characteristics of the communication channel, making it significantly more resilient to such attacks. Current cryptographic algorithms might become vulnerable to attacks from quantum computers in the future. PLS, however, relies on the laws of physics, making it inherently resistant to quantum attacks and future-proof in the long run. Traditional cryptography can be susceptible to side-channel attacks that exploit power consumption, timing leaks, or other unintentional emissions [226]. PLS operates at the physical layer, making it less vulnerable to such attacks. PLS eliminates the need for complex key management and distribution, simplifying communication security implementations. PLS techniques can potentially increase transmission rates by optimizing the use of the channel, leading to greater network efficiency [227]. PLS is particularly suitable for securing resource-constrained devices like sensors and IoT nodes where traditional cryptography might not be feasible due to computational limitations. Table 9 represents the comparative analysis of recent surveys on PLS techniques for IoHT applications.

2) OVERVIEW OF PLS TECHNIQUE

- **Definition and importance in the context of IoHT:** The data transmission in IoHT healthcare systems is the sensitive information. The implementation of

rigorous security solutions is of high importance to improve the confidentiality and reliability of healthcare services. It is essential to adhere optimal security protocols for the IoHT devices to regularly update software, and undertake ongoing security evaluations to prevent the exploitation of emerging vulnerabilities and threats. Ensuring the safeguarding of healthcare systems and the privacy and well-being of patients necessitates prioritizing the security of IoHT applications. Therefore, as stated above, the PLS analysis is essential for IoHT systems in order to secure the physical transmission of data that can mitigate potential risks of the healthcare services [26]. PLS is a promising approach to enhance the security and reliability metrics of the IoHT systems that exploits the physical properties of the wireless channel to prevent data from eavesdropping and jamming [27], [28]. The PLS-enabled security solutions provides a secure environment for IoHT devices and/or networks via the implementation of robust authentication mechanisms, encryption protocols, access limitations, and proactive monitoring [29].

- **Challenges specific to IoHT in maintaining physical layer security:** The IoHT systems are relatively complex and diverse as they carries the sensitive data, and constant accessibility of the patients. As a consequence, securing the physical layer of the IoHT Technologies is bit challenging than other wireless systems [30]. One of the key challenges in the development of the PLS techniques for IoHT is the resource constrained nature of IoHT devices. In particular, the IoHT devices often have limited processing power, memory, and energy resources which makes them difficult and computationally expensive to implement traditional PLS techniques [31]. Another challenge is the unreliability of wireless channels as it can be accessed via any unauthenticated users and are subject to noise and interference. Consequently, it is difficult to reliably implement PLS techniques.

VI. COLLABORATIVE RESEARCH EFFORTS

IoHT projects and grants aim to develop and deploy innovative technologies that leverage the power of the IoT to improve our lives and make the world a better place. These projects have the potential to revolutionize the way we live, work, and interact with the world around us. For example, IoHT-enabled precision agriculture technologies can help farmers improve crop yields, reduce environmental impact, and enhance food security. IoHT-enabled smart and connected community technologies can help cities improve traffic flow, reduce pollution levels, and make public transportation more efficient. IoHT enabled healthcare technologies can help improve the quality and efficiency of healthcare delivery, reduce costs, and improve public health.

TABLE 9. A comparative overview of PLS techniques suitable for IOHT applications. The table highlights key characteristics, advantages, and limitations of each technique to facilitate informed selection for robust and secure healthcare communication systems.

Technique	Description	Key References
Channel coding	1) Uses error-correcting codes to make the transmitted signal more robust to noise and interference. 2) Channel coding is essential for IoHT applications, as it can help to improve the reliability of data transmission over unreliable wireless channels.	[212] [213]
Beamforming	1) Focuses the transmitted signal in the direction of the intended receiver. 2) Beamforming can be used to focus the transmitted signal in the direction of the intended receiver, which can help to improve the range and energy efficiency of IoHT devices.	[214] [215]
Artificial noise	1) Transmits artificial noise along with the data signal to confuse eavesdroppers. 2) Artificial noise can be used to confuse eavesdroppers and protect the security of IoHT communications.	[216]
Key generation from CSI	1) Uses the unique characteristics of the wireless channel to generate a secret key. 2) Key generation from CSI can be used to generate a secret key that can be used to encrypt and decrypt IoHT data.	[217] [218]
Directional modulation (DM)	1) Transmits the data signal in a specific direction. 2) DM can be used to transmit the data signal in a specific direction, which can help to improve the energy efficiency of IoHT devices.	[219] [223] [224]
Spatial modulation (SM)	1) Embeds the data signal in the spatial characteristics of the wireless channel. 2) SM can be used to embed the data signal in the spatial characteristics of the wireless channel, which can make it more difficult for eavesdroppers to intercept and decode the signal.	[222] [223] [224]

A. OVERVIEW OF INTERNATIONAL IOHT INITIATIVES

1) DISCUSSION OF GLOBAL TRENDS AND THE IMPORTANCE OF INTERNATIONAL COLLABORATION IN IOHT DEVELOPMENT

IoHT systems are rapidly transforming healthcare delivery, promising personalized medicine, remote monitoring, and improved health outcomes. Recently, the COVID-19 pandemic accelerated the adoption of remote healthcare solutions, including IoHT devices for virtual consultations, chronic disease management, and home-based care. This trend is expected to continue, driven by aging populations, growing healthcare costs, and increased access to internet connectivity, particularly in developing nations. With sensitive medical data being collected and transmitted, robust PLS-based security solutions are paramount. Global efforts are underway to establish secure communication protocols, implement data privacy regulations like GDPR, and foster international cooperation in tackling eavesdropping effects specific to IoHT. The convergence of IoHT with AI and Big Data analysis unlocks incredible potential for personalized medicine, predictive diagnostics, and evidence-based healthcare. International collaboration is crucial to developing AI

models that are inclusive, culturally sensitive, and address the diverse healthcare needs of populations worldwide. Collaborative research, knowledge exchange, and technology transfer facilitate innovation and accelerate the development of effective IoHT solutions. International cooperation is crucial for tackling eavesdropping threats, establishing data privacy regulations, and ensuring ethical development and deployment of IoHT technologies. Collaboration fosters partnerships across developed and developing nations, leading to inclusive solutions that address the diverse healthcare needs of different populations. Collaborative efforts can attract several investments, pool resources, and accelerate the scale-up of successful IoHT solutions that is beneficial to the healthcare systems worldwide.

B. CASE STUDIES OF KEY PROJECTS

1) REMOTE PATIENT MONITORING: THE MAYO CLINIC CONNECTED CARE PROGRAM

The Mayo Clinic Connected Care Program leverages wearable sensors and home devices to remotely monitor vital signs, medication adherence, and activity levels of patients with chronic conditions. This proactive approach

TABLE 10. International projects and grants for IoHT: A table listing significant grants and projects, along with their scopes, countries involved, funding amounts, and impacts: The brief description of different International IoHT projects and/or grants funded by different agencies.

Project/Grant	Funding Agency	Description
IoHT-Enabled Precision Agriculture for Sustainable Food Production	National Science Foundation (NSF)	This grant aims to develop IoHT-enabled precision agriculture technologies to improve crop yields, reduce environmental impact, and enhance food security.
IoHT-Enabled Smart and Connected Communities	US Department of Commerce	This grant aims to develop IoHT-enabled smart and connected community technologies to improve the quality of life for residents, reduce costs for businesses, and enhance the resilience of communities.
IoHT-Enabled Healthcare for Personalized Medicine and Public Health	National Institutes of Health (NIH)	This grant aims to develop IoHT-enabled healthcare technologies to improve the quality and efficiency of healthcare delivery, reduce costs, and improve public health.
IoHT-Enabled Smart Home for Elderly Care	University of California, Berkeley	This project is developing IoHT-enabled smart home technologies to help elderly people live independently and safely.
IoHT-Enabled Smart Farming for Sustainable Agriculture	Cornell University	This project is developing IoHT-enabled smart farming technologies to improve crop yields, reduce environmental impact, and enhance food security.
IoHT-Enabled Smart City for Efficient Transportation and Infrastructure Management	City of San Francisco	This project is developing IoHT-enabled smart city technologies to improve the efficiency of transportation and infrastructure management.
H2020 SECIoT project	European Commission	This project aims to develop a comprehensive security framework for the Internet of Things (IoT) based on PLS techniques.
NSF CPS: SECURE-IOHT project	National Science Foundation	This project aims to develop secure and reliable communication protocols for IoHT applications. The project team is developing new PLS techniques to protect IoHT devices from eavesdropping, jamming, and other attacks.
EU H2020 5G-TRANSFORMER project	European Commission	This project aims to develop 5G-based transformative solutions for the IoT. One of the project's work packages is focused on developing PLS techniques for 5G-enabled IoHT applications.
EU H2020 SECRETS project	European Commission	This project aims to develop secure communication protocols for the IoT based on physical layer secrecy techniques.
NSF CPS: SECURE-CPS project	National Science Foundation	This project aims to develop secure and reliable communication protocols for cyber-physical systems (CPS). The project team is developing new PLS techniques to protect CPS from eavesdropping, jamming, and other attacks.
NSF Smart and Connected Communities program	National Science Foundation	This program supports research on the development and deployment of smart and connected communities. The program is particularly interested in research on PLS techniques for IoHT applications.
EU H2020 Research and Innovation Program	European Commission	This program supports research and innovation in a wide range of areas, including the IoT. The program has a number of funding opportunities for research on PLS techniques for IoHT applications.
UK Research and Innovation (UKRI) Future Leaders Fellowships	UK Research and Innovation	This program provides funding for outstanding early-career researchers to pursue their own research projects. The program is particularly interested in research on PLS techniques for IoHT applications.
Marie Skłodowska-Curie Actions Individual Fellowships	European Commission	This program provides funding for early-stage and experienced researchers to conduct research in Europe. The program is particularly interested in research on PLS techniques for IoHT applications.
China Scholarship Council (CSC) Scholarship	China Scholarship Council	This scholarship provides funding for international students to pursue graduate studies in China. The scholarship is particularly interested in students who are interested in research on PLS techniques for IoHT applications.

enables early intervention, improved disease management, and reduced hospital readmission. This study is also helpful to improve the patient health outcomes, emergency room visit reductions, improving the patient satisfaction, and optimizing the chronic disease via remote monitoring.

2) CHRONIC DISEASE MANAGEMENT: ALIVECOR KARDIAMOBILE EKG DEVICE

The AliveCor KardiaMobile EKG device technology can empower the patients and managing the chronic conditions.

3) MENTAL HEALTH SUPPORT: CHILI (CHILDREN'S HEALTH INITIATIVE LEVERAGING IOHT) PROGRAM

The CHILI Program uses the wearable sensors and mobile apps in order to monitor sleep patterns, activity levels, and mood changes of children with mental health conditions. This real-time data provides valuable insights for personalized treatment plans and remote therapeutic interventions. Studies have shown improved engagement in therapy, earlier

identification of behavioral changes, and increased parental involvement in supporting mental health, highlighting the potential of IoHT in delivering personalized and remote mental health services for children.

4) SMART HOSPITALS: PHILIPS INTELLISPACE CRITICAL CARE AND TRAUMA SYSTEM

Royal London Hospital has implemented the Philips Intellispace Critical Care and Trauma system which is equipped with sensor nodes and medical entities assisted through AI algorithms [228]. As a consequence, the system has the capability to diagnose the patient with real time data and accordingly medical treatment will taken care with faster decision making and enhance efficiency. It is verified through literature survey that with the optimized critical care delivery, diagnosis time can be reduces with improved patient outcomes, and enhanced collaboration among healthcare professionals. Table 9 represents the different IoHT International Projects and Grants funded by different international agencies.

VII. FUTURE PROSPECTS AND EMERGING TECHNOLOGIES

The potential advancements in healthcare and wireless communication have the capacity to bring about significant transformations in the delivery of medical care and interpersonal connectivity. Advancements in technology within the medical industry are facilitating the emergence of customized treatment, hence enhancing overall patient outcomes [229]. Telemedicine has emerged as a prominent field of interest due to its ability to provide remote medical consultations and treatment, hence eliminating the need for patients to physically visit healthcare facilities. In the context of the COVID-19 pandemic, the significance of this technology has grown significantly since it allows healthcare professionals to provide therapy while concurrently mitigating the risk of transmission [230]. The advancement of wearable electronics and health-monitoring sensors has led to the ability of individuals to monitor their vital signs, exercise routines, and overall well-being in real-time. These technologies are rapidly evolving and becoming more sophisticated. These technological devices provide valuable data that may be evaluated to detect first signs of health issues and enable proactive treatment strategies [231]. Moreover, the use of artificial intelligence (AI) and machine learning techniques has been prevalent in the analysis of large quantities of medical data. This application aims to facilitate the process of diagnosing diseases, identifying treatment options, and predicting patient outcomes. The aforementioned technologies possess the capacity to enhance the accuracy and efficiency of healthcare delivery [232].

The advent of 5G technology holds promising prospects for the future of wireless communication. In contrast to preceding iterations of wireless networking technology, 5G networks are anticipated to provide significantly enhanced data transfer speeds, decreased latency, and increased capacity. This will enable the accessibility of possibilities that were previously inaccessible across a range of disciplines, including the healthcare sector. The implementation of 5G technology's ultra-reliable and low-latency communication capabilities holds promise for enabling the precise and timely execution of remote operations and complex medical procedures. This technological advancement will facilitate the acquisition of specialist medical expertise from any geographical area worldwide [233]. Moreover, the IoMT is anticipated to see significant expansion due to the advent of 5G technology. In the near future, there will be a feasible prospect of establishing seamless inter connectivity between medical equipment and sensors, enabling the secure transmission of real-time patient data.

The use of this approach will facilitate the ability to remotely monitor patients, promptly intervene when necessary, and ultimately improve patient outcomes. The integration of 5G technology with the IoMT has significant promise in transforming the provision of healthcare services, particularly in under served regions without adequate medical infrastructure and remote areas [234]. Nevertheless, it is

essential to acknowledge and confront the challenges and complexities associated with this emerging technology, in a manner consistent with the approach taken towards past technological advancements. Preserving patient privacy and safeguarding the confidentiality of their medical records are paramount in the realm of medicine, since they are essential for maintaining the integrity and confidentiality of sensitive data. Ensuring equitable access to medical care and mitigating any unintended consequences necessitates the establishment of a harmonious equilibrium between creative concepts and ethical considerations [235]. The domains of healthcare and wireless communication exhibit promising prospects for transformative advancements in the future. The integration of telemedicine, wearable devices, artificial intelligence, and 5G technology is anticipated to enhance healthcare delivery, provide improved patient outcomes, and facilitate remote access to specialist medical interventions. These technologies have the potential to significantly impact the healthcare industry, leading to a transformation characterized by increased cost-effectiveness, improved accessibility, and a patient-centric approach. The prioritization of privacy and security, together with the resolution of ethical dilemmas, is of utmost importance in ensuring that the introduction of new technology yields benefits for individuals and society at large [236]. The paradigm of medical treatment and connectivity is poised to undergo a transformative shift due to the promising possibilities and advancements in healthcare and wireless communication technologies. Advancements in technology within the medical domain are facilitating the emergence of specific treatment, hence enhancing the overall outcomes for patients. Telemedicine has garnered considerable interest due to its ability to provide patients the chance to get medical consultations and treatment from a distance, hence eliminating the need for in-person visits to health care providers. The future of medical treatment and connectivity is poised to undergo a transformative shift due to advancements in healthcare and wireless communication technologies. Advancements in technology within the medical domain are facilitating the emergence of tailored therapeutic approaches, hence enhancing the overall outcomes for patients. Telemedicine has garnered significant interest due to its ability to provide patients the chance to get medical consultations and treatment from a distance, hence eliminating the need for in-person visits to healthcare institutions [237].

A. 5G AND BEYOND: ADVANCING WIRELESS HEALTHCARE

The advancements in wireless communication technology, specifically the emergence of 5G and the anticipated arrival of 6G, possess the capacity to significantly transform the healthcare sector. These advancements have the potential to revolutionize the delivery of medical services and enhance patient outcomes. The potential of this innovation has the capacity to significantly transform the industry in its entirety.

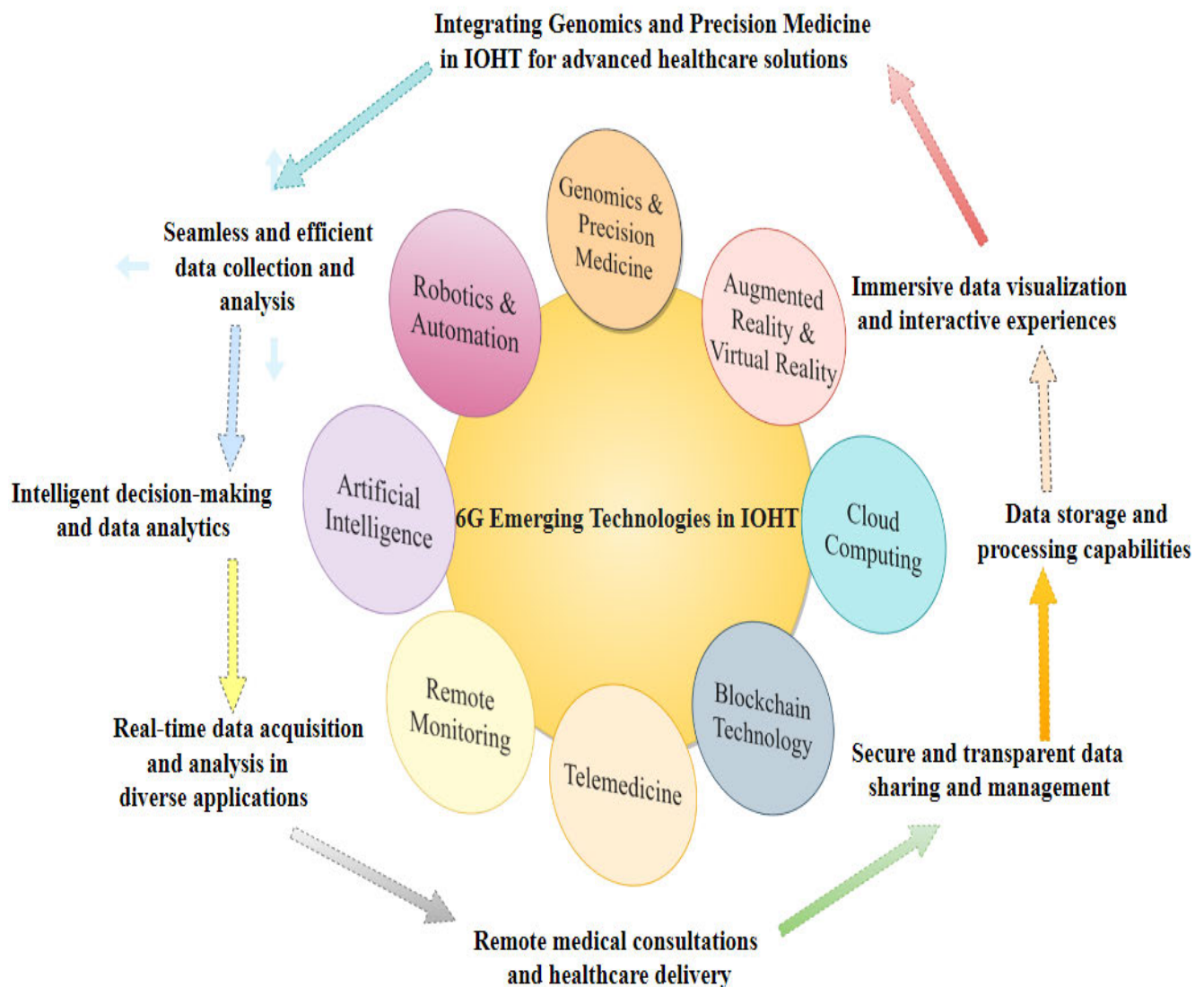


FIGURE 12. This diagram presents a comprehensive overview of the architectural framework underpinning the integration of 6G technologies into the Internet of Healthcare Things (IoHT) ecosystem. It delineates the key components, interconnections, and functionalities of the proposed architecture, highlighting the synergistic relationship between 6G's advanced capabilities and the diverse applications within the healthcare domain.

These technologies provide significant prospects for the progression of wireless healthcare because to their improved speed, reduced latency, and increased capacity [238].

In contrast to preceding iterations of wireless technology, the fifth generation of wireless technology, often referred to as 5G, presents a significant enhancement in terms of both velocity and capacity. Telemedicine facilitates real-time, high-quality video consultations between patients and healthcare experts. The decreased latency of 5G technology will enable medical practitioners to diagnose and treat patients remotely with enhanced accuracy. This will provide the potential for virtual operations and the precise execution of intricate tasks. The enhanced data transmission capabilities of 5G facilitate the rapid dissemination of large-scale medical files, such as diagnostic images, hence fostering efficient

collaboration among medical experts and enhancing diagnostic precision [239]. The proliferation of 5G technology has significantly facilitated the growth and development of IoMT. Wearable devices and medical equipment provide the capability to establish a smooth connection with the network, therefore facilitating the acquisition and transfer of patient data in real-time. Due to the continuous transmission of data, healthcare practitioners have gained the capability to remotely observe patients' essential physiological indicators, as well as their compliance with prescribed medicine and levels of physical activity. Through the use of 5G technology, medical professionals are empowered to get crucial insights pertaining to the present health condition of their patients, hence enabling them to discern early indicators that may signify the emergence of possible health complications. The

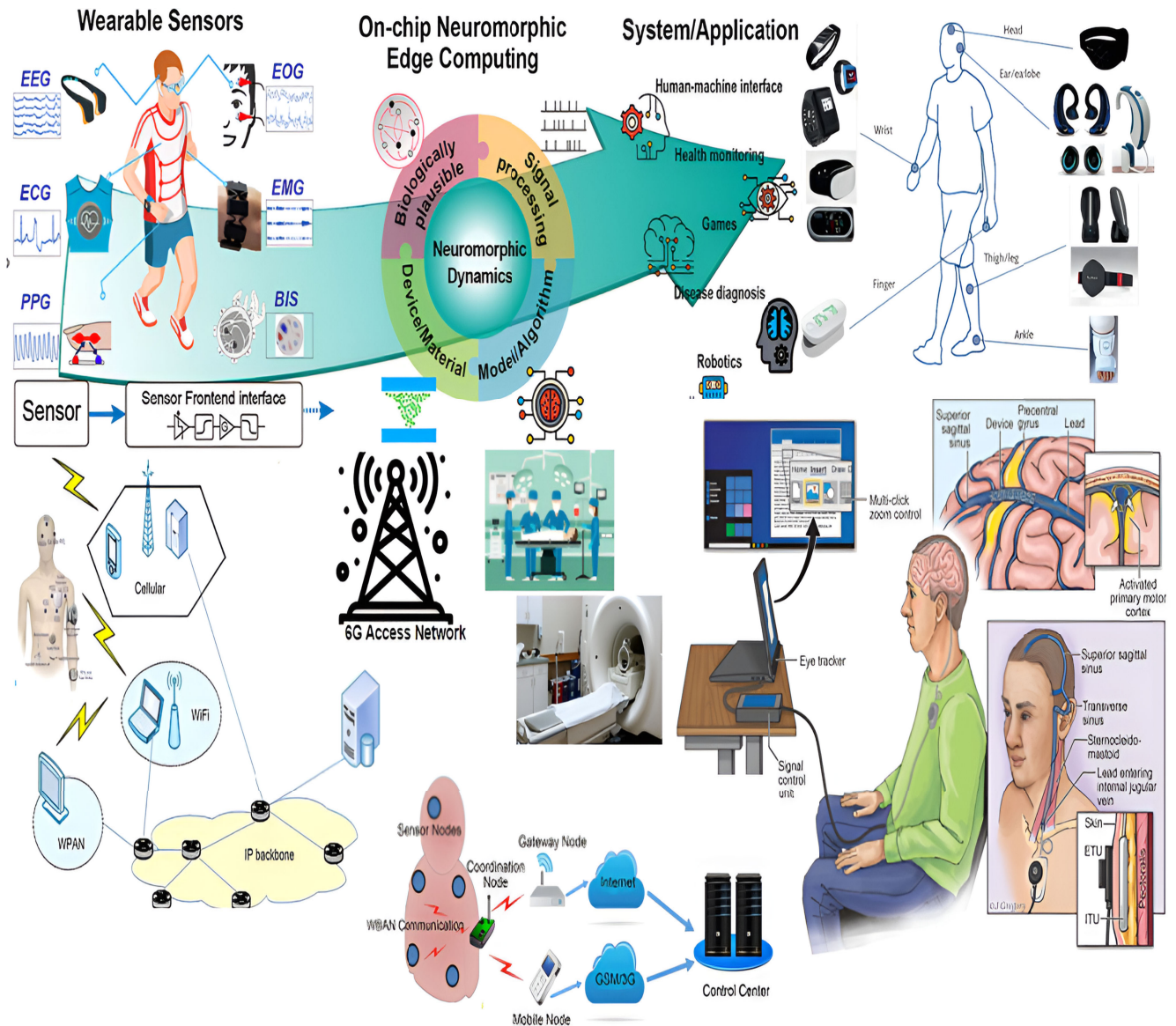


FIGURE 13. The transformative trajectory of healthcare, this diagram encapsulates the remarkable advancements and emerging technologies poised to revolutionize the medical landscape towards a future where healthcare is accessible, personalized, and effective, empowering individuals to achieve their full potential and live healthier, happier lives.

use of this preventive technique enables timely intervention, resulting in improved patient outcomes and reduced healthcare costs [240].

When considering future prospects, it is conceivable that the emergence of 6G technology will provide a plethora of opportunities that have the potential to transform the field of wireless healthcare. The integration of 6G technology into the healthcare sector presents opportunities for novel avenues of advancement due to its capacity for significantly high speeds, minimal latency, and robust data processing capabilities [170]. Terahertz communication, a crucial element of the next 6G technology, facilitates the transmission of vast quantities of data at unprecedented speeds. This facilitates the execution of real-time analysis and the formulation of judgments, both

of which are essential in time-sensitive scenarios, such as medical emergencies. The integration of edge computing into 6G networks enables the processing and analysis of data in close proximity to its point of origin. The use of a decentralized method results in the removal of reliance on centralized servers [241]. Consequently, this approach leads to enhanced response times, heightened security measures for patient data, and the preservation of patient privacy rights. The use of edge computing has the potential to facilitate the implementation of real-time AI algorithms. This, in turn, allows for the expeditious analysis of medical data, therefore equipping healthcare professionals with actionable insights.

The use of 6G technology is expected to significantly enhance the capabilities of telemedicine and other remote

patient monitoring methods, enabling them to achieve unprecedented levels of effectiveness and reach [242]. The use of ultra-reliable and low-latency connections enables uninterrupted transmission of haptic feedback and real-time pictures, hence enhancing the precision of distant operations. The facilitation of technologies such as augmented reality (AR) and virtual reality (VR) might potentially be enhanced via the use of 6G networks. This advancement would allow medical practitioners to fully engage in a simulated environment, hence enabling them to undergo training, plan surgical procedures, and educate patients more effectively [243].

Overcoming these challenges is necessary to fully harness the immense potential that 5G and 6G networks provide in improving wireless healthcare. To ensure the preservation of patient data and uphold the confidentiality of information, it is essential to implement robust security measures and adhere to stringent privacy requirements. Collaborative efforts among technology suppliers, healthcare institutions, and regulatory agencies are essential for the development of standards and recommendations that place patient safety, data integrity, and ethical considerations at the forefront [244]. The latest advancements in wireless communication technology, such as the emergence of 5G and the upcoming 6G standard, provide substantial potential for enhancing healthcare. The use of real-time telemedicine, remote patient monitoring, and seamless integration of medical equipment and wearable is facilitated by these technologies due to their rapidity, low delay, and enhanced capability. The implementation of 6G technology is expected to provide substantial advances in healthcare, particularly in the areas of terahertz communication, edge computing, and augmented reality and virtual reality applications. These developments hold great promise for improving the quality of treatment and improving patient outcomes. However, it is essential to acknowledge and tackle concerns pertaining to security, privacy, and ethics in order to ensure the ethical use of this technology. The potential of 5G and 6G networks may be maximized to usher in a new era of wireless healthcare. This would enable the provision of readily accessible, highly efficient, and specifically personalized medical services to individuals worldwide [245].

• 6G in IoHT

The successful implementation of IoHT necessitates the integration of advanced connectivity, substantial capacity, enhanced reliability, minimal latency, significantly improved data transmission rates, and a decrease in network downtime, all with the overarching goal of delivering a superior healthcare experience. The forthcoming 6G communication system is expected to provide intelligent Internet of Home Things (IIoHT) services to users, with the aim of improving human quality of life and well-being. This contrasts to the current 5G wireless network [246], [247]. There is an expectation that the 6G will replace the IoT with the

IIoT. This transition would facilitate the integration of many intelligent devices capable of collecting vast quantities of data, afterwards translating it into real-time applications. Within the context of the IoT and the IIoT, 6G cellular networks integrate with other multidimensional communication techniques [], including optical wireless communication networks, smart healthcare systems, blockchain networks, and distributed security paradigms [248].

A new era in home connections for medical equipment, healthcare providers, and hospital infrastructure components will be made possible by the development of a high availability and high reliability communication network, among other pertinent fields. IoHT is rapidly incorporating several advanced technologies, such as artificial intelligence, advanced machine learning, big data analysis, pattern recognition, and robotics, as it progresses towards evolving into a dynamic infrastructure that has awareness and intuition [249]. Medical robots have the potential to contribute in several domains such as patient recovery, surgical help, and hospital logistics and cleanliness. Conversely, the implementation of a robust infrastructure grounded on AI and ML has the potential to facilitate the training of medical professionals for surgical interventions, provide assistance to individuals afflicted with post-traumatic stress disorder, and effectively oversee medical procedures for pediatric patients. The advent of 6G technology is anticipated to bring about a significant transformation in the medical domain, as it would facilitate remote surgical procedures through satellite communication and enhance the efficacy of healthcare processes. This breakthrough is expected to transcend temporal and spatial limitations, revolutionizing the field of medicine [250].

B. ARTIFICIAL INTELLIGENCE (AI) AND MACHINE LEARNING (ML)

Communication protocols for e Health technologies fill the gap between information transfer, reporting, and consultation monitoring. ISO/IEEE [251] provide detailed and automatic connectivity with medical equipment and operational device. It facilitates plug-and-play operation with an auto detection facility. IEEE 602 [252] facilitates engineers with recommended usage and functionality for operation and transmission in health care systems. Along with communication technologies, AI is incorporated with synchronous and asynchronous devices.

In [253] deep learning with machine learning tech is implemented to assist patients with paralysis. The deep learning model helps in training and predicting patient behavior and realizing the operational requirements based on ambiance. At present, IoHT is closely associated with smart city requirements where multiple Cyber-Physical Systems (CPS) communicate with each other through various communication protocols for multiple applications. In applications

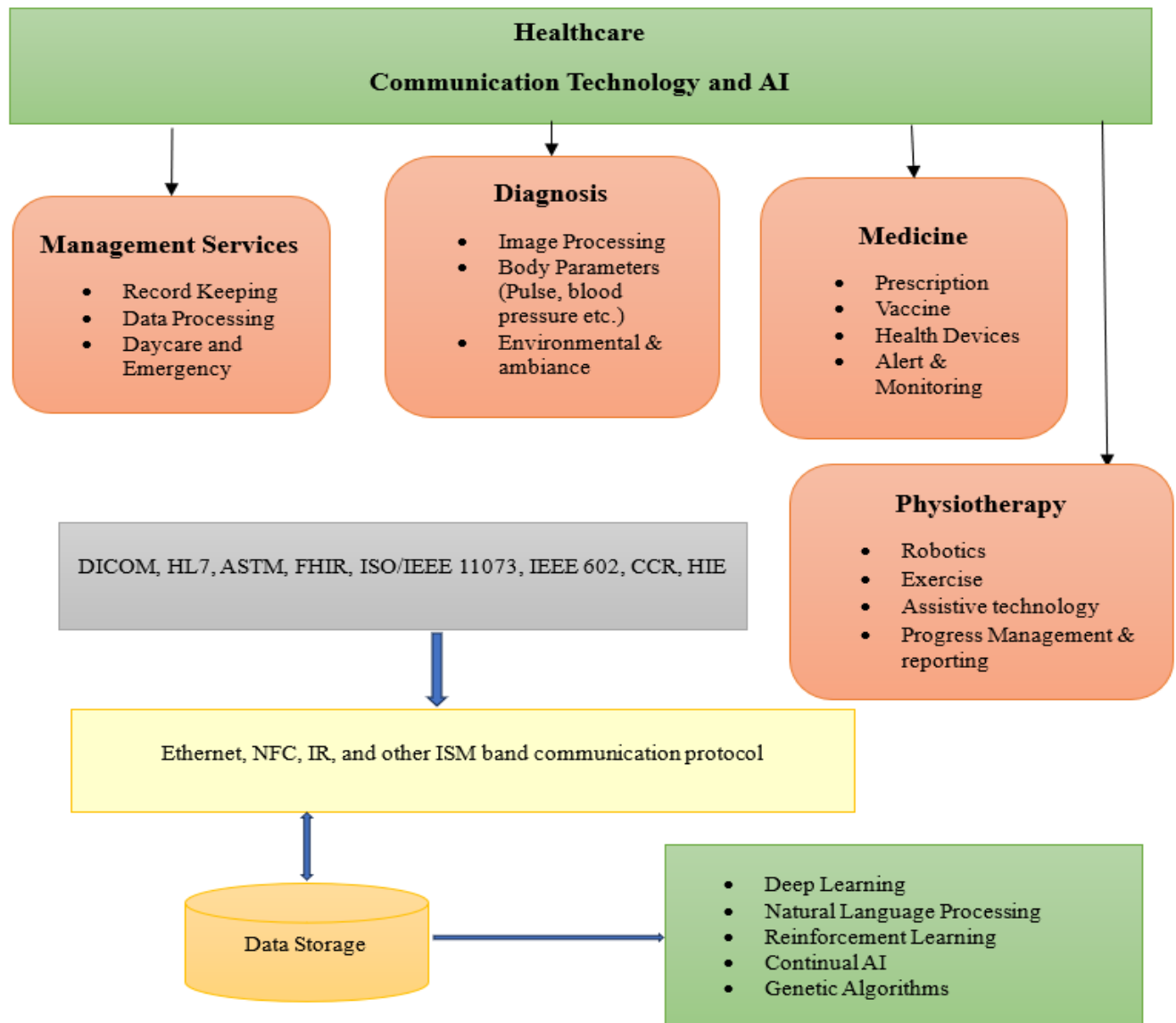


FIGURE 14. This diagram depicts the various AI and ML techniques employed in different healthcare domains, highlighting their potential to enhance patient care, disease management, and healthcare delivery through the seamless integration of wireless communication technologies.

were image processing such as X-ray, CT-Scan and MRI, deep learning has shown promising results [254], [255] [256], [257]. In [258], bariatric surgery have been implemented in the study where ChatGPT provides a significant percentage of comprehensive results. In the area of assistive technology, such as yoga and physiotherapy, using deep learning models shows promising results. In [259] the deep learning model is implemented to assist yoga practitioners where it not only identifies the poses but also assists users with posture correction using text or voice features. With the AI utilization [260] in healthcare, the concern related to trust, and reliability are major concerns. HIPAA, emphasizes on these concerns while covering the importance of consistency of implications

of law on the related aspects with alignment of technologies. In [261], the ethical complications and inclusion of AI tools in specific operations related to the healthcare industry such as medical notes, trialing of patients, insurance claims etc. After the emergence of the AI Act [262], the liabilities of general grounds related to use of AI applications were established with considerations of risks, unacceptable risks, transparency issues and for posting innovations in the area of AI. Considering this, the importance of the right to an explanation is being discussed in [263]. The right to an explanation is also an AI act which provides a feature to know the prime intentions and decisions considered by the developer/deployer, on systems which performs AI-based

tasks, associated with high-risks. It can be considered that the HIPPA, GDPR and AI Act can work as a shield to regulate AI in the area of healthcare domain.

- **Federated learning** Federated learning has a proven significant contribution in general application related to deep learning. In [264], many of the algorithms associated with federated learning in the area of healthcare have good performance. It has been recommended that if certain precautions have been performed such as inclusion standardized FL algorithms, reproducibility of test and train sets, selection of appropriate framework with performing appropriate benchmarking, help in overall performance of FL algorithm in health care environments. In [265] and [266], federated learning is implemented for diagnosis of Parkinson's disease (PD), considering the issues associated with privacy and other restrictions. In the similar way, the decentralized approach of federated learning is very helpful in processing data having Personally Identifiable information (PII) due to its capability of processing data at the host, which does not require data accessibility through the internet or other similar sources.
- **AI driven security** Due to the involvement of Personal Information (PI), Personal Identifiable Information (PII) and in Sensitive Information (SI) it is very important that proper safety majors have been cooperated while handling healthcare data. The [267] presents that compliance with GDPR and similar compliances are important to meet health data privacy. The AI driven security can be utilized in Electronic Health Records (EHRs), [268] reflected in application of Machine Learning (ML) in identification of fraudulent claims, bills, risk assessments and in enhancing operational efficiency. In [269], critical concerns related to implementation of AI for applications such as identification of person centred drugs for specific treatment are mentioned. Apart from that, it has been mentioned that AI based strategies can be very relevant for the treatment of cancer.
- **Wireless healthcare deployments** Healthcare technologies are advancing due to the rapid technology development in the area of IoT, Consumer Technology and Cyber Physical Systems (CPS) [270], [271], [272]. The implementation of wireless sensor systems is presented in [273] with the capability of fetching data for patient wellbeing to assist in medicare. Wearable healthcare devices will have more applications specially in pervasive healthcare systems [274]. Such deployment will help in assisting the patient in real-time, to avoid any threat related to wellbeing. In case of critical care [275] such as cardio, neurological or with the patients with requirement of 24/7 care such system will be most applicable.

C. AUGMENTED REALITY (AR)/VIRTUAL REALITY (VR)

The Healthcare business is seeing a rapid transformation in patient care, medical education, and research due to the fast advancement of AR and VR technology. AR technology enhances the display of patient data and facilitates real-time guidance during treatments by overlaying digital information onto the actual surroundings [276]. The use of this technology allows medical professionals to promptly overlay patient information, such as X-ray or CT scan images, onto the surgical site, so enhancing both the level of accuracy and precision. In contrast, virtual reality immerses individuals inside a fully simulated environment, affording them the chance to engage in authentic simulations and activities [277].

The medical industry uses VR for educational reasons, enabling both students and specialists to engage in simulated practising of complex surgical procedures inside a controlled and safe environment. The provided setting facilitates a fully immersive experience, therefore fostering the development of various talents, enhancing decision-making skills, and improving overall proficiency [278]. Furthermore, the use of augmented reality and virtual reality technologies has been shown to enhance the overall patient experience by effectively mitigating pain and anxiety levels during surgical procedures via the utilisation of distraction-based therapeutic approaches. These technologies provide patients engaging and amusing materials, perhaps contributing to the creation of a positive environment for them [279]. Both AR and VR play a significant role in the visualization and interpretation of data within the framework of academic research. This facilitates the examination of intricate datasets and the replication of physiological processes by researchers. These technologies expedite the scientific discovery process, hence facilitating medication development and improving medical imaging techniques. This is achieved via the construction of immersive and interactive environments [280]. The healthcare sector has significant untapped potential in the use of AR and VR technologies. These technologies have the capacity to better training outcomes, improve patient experiences, and expedite medical advancements.

AR involves overlaying digital information onto the real-world physical environment, while VR creates a fully immersive digital experience for the user. Both AR and VR provide unique benefits within the healthcare sector [281].

- **Enhanced Visualization and Medical Training:** The use of AR and VR technology enhances the capacity for visual representation, allowing healthcare professionals to perceive intricate medical information and images in a manner that is characterized by heightened interactivity and intuitive understanding. Surgeons, for example, may use AR technology to overlay patient data, such as CT scans or X-ray images, onto the surgical field, therefore providing instant and real-time guidance during medical procedures. The use of this technique holds promise

TABLE 11. Definition of acronyms and notations.

Acronym Notations	Definition	Acronym Notations	Definition
AI	Artificial Intelligence	AR	Augmented Reality
CDMA	Code Division Multiple Access	CGM	Continuous Glucose Monitoring Defibrillators
CPS	Cyber Physical Systems	DICOM	Digital Imaging and Communications in Medicine
DRX/DTX	Discontinuous Reception Transmission Cycles	ECG	Electrocardiogram
EHR	Electronic Health Record	E2E	End 2 End Framework
EMR	Electronic Medical Record	FDA	U.S. Food and Drug Administration
FDMA	Frequency Division Multiple Access	GDPR	General Data Protection Regulation
HAPs	High-Altitude platforms	HIPPA	Health Insurance Portability and Accountability Act
HIS	Hospital Information System	HIT	Health Information Technology
ICD	Implantable Cardioverter	ICT	Information and Communication Technology
IoHT	Internet of Healthcare Things	IIoT	Industrial Internet of Things
IoT	Internet of Things	IoMT	Internet of Medical Things
IDPS	Intrusion Detection and Prevention System	IPS	Individual Placement and Support
LTE	Long Term Evolution	LPWANs	Low Power Wide Area Network
MT	Medical Technology	mHealth	Mobile Health
mMTC	massive Machine Type Communication	NOMA	Non Orthogonal Multiple Access
NGO	Non Governmental Organisations	OFDMA	Orthogonal Frequency Division Multiple Access
OMA	Orthogonal Multiple Access	PHI	Protected Health Information
RFID	Radio Frequency Identification Technology	RPM	Remote Patient Monitoring
SIC	Successive Interface Cancellation	SIEM	Security Incident and Event Management
SNR	Signal to Noise Ratio	TDMA	Time Division Multiple Access
UAVs	Unmanned Aerial Vehicles	VPN	Virtual Private Network
VR	Virtual Reality	WAN	Wide Area Network
WIoT	Wearable Internet of Things	3GPP LTE	3rd Generation Partnership Project Long Term Evolution
5G	Fifth Generation Wireless Technology	6G	Sixth Generation Wireless Technology

for enhancing surgical accuracy and concomitantly reducing the risk of errors [282]. Similarly, the use of VR enables the provision of medical education to healthcare practitioners inside an environment that accurately replicates real-life scenarios, thereby enhancing the immersive learning experience. In the context of a simulated setting, medical students and professionals have the opportunity to engage in the practicing of intricate procedures, including simulated surgical interventions and emergency scenarios. This facilitates the acquisition of practical experience by students, eliminating the need for direct patient interaction or substantial financial investment in medical equipment. VR simulations have the capability to replicate diverse environments, providing learners with a secure and regulated setting to cultivate and refine their skills.

- **Improved Patient Experiences and Rehabilitation:**

The use of AR and VR has promise in enhancing both the patient experience and outcomes. VR can be used to provide immersive and diverting experiences for patients who undergo painful surgeries or require anxiety management. Research has shown that patients can experience a reduction in stress and discomfort when exposed to a pleasant and engaging setting. This objective may be achieved through the provision of virtual environments or interactive resources [283]. The use of AR and VR technology has the potential to be implemented within the realm of rehabilitation in order to provide interactive and motivated therapy sessions. Individuals in the process of recovering from bodily injuries or neurological impairments have the

opportunity to participate in virtual activities and simulations to facilitate their recovery [284]. These technologies has the capacity to enhance the entertainment value of rehabilitation for patients, foster patient involvement, and enhance functional outcomes. This is achieved by incorporating gamification elements and providing real-time feedback [285].

- **Research and Data Visualization:** There is a lot of promise for using AR and VR in research and data visualization. These technologies enable researchers to explore intricate information, visualize molecular structures, and simulate physiological processes. The development of immersive and interactive environments can facilitate the acquisition of novel ideas and enhance the pace of learning in several professional domains, as researchers see. Several disciplines that can be cited as examples include drug development, genetics, and medical imaging. AR and VR technologies provide researchers the opportunity to manipulate and interact with data in ways that cannot be replicated on conventional two-dimensional (2D) screens. This phenomenon facilitates the enhancement of creative thinking and deepens our understanding of scientific principles [286].
- **Telemedicine and remote collaboration:** The fields of telemedicine and remote collaboration could potentially undergo significant transformations with the emergence of AR and VR technologies. The use of augmented reality has promise in enabling remote consultations between medical professionals and patients due to its ability to overlay information over real-time footage. In complex surgical procedures, physicians may use

augmented reality technology to provide remote guidance and assistance to patients, irrespective of geographical separation. VR can also be used to enhance remote collaboration and training, thereby facilitating medical professionals to collaborate in a virtual setting and exchange their expertise [287].

VIII. CONCLUSION

Drawing from our exploration of leveraging cutting-edge wireless technologies to elevate patient care and interactions, the integration of IoHT stands poised to revolutionize healthcare delivery. This study illuminates several key insights that require the focus of researchers, policy makers, and healthcare professionals alike. Firstly, a synergistic blend of data science, engineering, and healthcare expertise forms the basis for cultivating truly groundbreaking IoHT solutions, a convergence essential for realizing the transformative potential of wireless networks in medical diagnostics. Secondly, safeguarding the confidentiality and integrity of sensitive healthcare data through robust encryption protocols, secure data exchange frameworks, and the exploration of blockchain technologies represents a fundamental imperative to foster trust and facilitate widespread adoption, particularly in the context of enhanced communication technologies such as 6G. Third, the considerable promise of advanced AI and ML algorithms for enabling predictive analysis, early disease detection, and customized therapeutic interventions requires rigorous and ethically grounded investigation, with a strong emphasis on precision and reliability, especially since these algorithms are integrated into real-time communication and remote monitoring systems. Finally, the establishment of seamless interoperability standards and the adoption of user-centric design principles are indispensable for the effective and intuitive integration of IoHT solutions by healthcare providers and patients, ensuring that advances in wireless communication translate into tangible improvements in the quality of services. Based on these insights, the following recommendations are proposed to propel the field of IoHT forward responsibly and effectively

- Research grants should be prioritized by funding agencies that focus on developing privacy-preserving IoHT architectures and secure data aggregation techniques. Encourage the development of standardized security protocols for IoHT devices and platforms.
- Foster interdisciplinary collaborations between AI/ML researchers and healthcare professionals to define clinically relevant problems and evaluate the real-world impact of AI-driven IoHT solutions. Develop benchmarks and evaluation metrics specific to AI in healthcare care to ensure precision and reliability.
- The development and adoption of national and international interoperability standards for IoHT systems should be driven by policy makers. In fact, healthcare organizations should actively participate in pilot projects to test and implement these standards.

- Emphasize human-centered design principles in the development of IoHT applications, involving end-users in the design and testing phases. Develop comprehensive training programs and educational resources to promote the effective use of IoHT technologies.
- Healthcare organizations should invest in pilot programs to evaluate the effectiveness and cost-efficiency of IoHT applications. Establish mechanisms for continuous monitoring and evaluation of IoHT deployments, sharing insights and best practices between institutions.

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