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5G AND AI IN WEARABLE MEDICAL DEVICES: A NEW ERA OF PREVENTIVE HEALTHCARE

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Abstract: The integration of 5G and artificial intelligence (AI) in wearable medical devices is revolutionizing healthcare by enabling continuous, cost-effective monitoring for patients. 5G connectivity enhances the healthcare industry by offering reduced latency, increased energy efficiency, and speeds up to 100 times faster than its predecessor, 4G LTE. The wearable medical device market, currently valued at over $40 billion, continues to experience significant growth and shows promise for the future. However, as more companies adopt 5G technology, several challenges must be addressed to realize its full potential. Key issues include improving battery life, investing in data security and privacy, and reducing infrastructure acquisition costs, particularly in developing and underdeveloped countries.

Keywords: Artificial intelligence, Wearable medical devices, machine learning (ML), predictive analytics and deep learning

I. INTRODUCTION

The rise and advent of Artificial Intelligence (AI) in the 21st century have brought about very key transformation across all industries, including the education industry, telecommunication industry, health industry, hospitality industry, production, and even the processing industry [29]. The health industry, in particular, has benefitted from the use of AI in that it has helped improve diagnostics through improved medical imaging and pattern recognition, led to personalized treatment plans, and has also led to enhanced patient monitoring and predictive analytics such as risk prediction and hospital management [3]. AI has also proved valuable in fastened drug discovery and development facilitated by the AI's ability to reduce costs in clinical trial stages [5]. AI has played a pivotal role in the healthcare industry by serving as a decision-support tool that assists healthcare professionals in making informed decisions through evidence-based recommendations. Additionally, AI enhances the training of medical students by providing virtual simulations, which bridge gaps in the research. A key focus of this research is the role of AI in advancing personalized treatment, particularly through the development and use of wearable medical devices (WMDs), which have revolutionized patient care by enabling continuous monitoring and tailored healthcare solutions.

Wearable medical devices have revolutionized healthcare delivery, transitioning it from reactive to proactive care. Wearable medical devices, as the name suggests, are electronic devices or rather gadgets that a patient puts in close contact with the skin to measure some health and physical aspects [39]. Wearable devices have come to facilitate faster and better patient care, especially bridging the gap between hospitals and patients, ensuring that patients can receive real-time data in the comfort of their homes. In the majority of cases, these devices are used to measure biometric data such as heart rate, sugar levels, and blood pressure. Some of the popular wearable health devices are smart clothes, optical displays, smartwatches, blood pressure monitors, fitness trackers, ECG monitors, and biosensors [9].

These devices provide patients with real-time data that can be easily transmitted to their physician or doctor for immediate feedback and action, especially for chronically ill patients. Wearable devices have brought the benefit of removing needless in-person appointments to measure such vitals from time to time, therefore reducing costs and saving costs in the process [13]. These benefits of wearable devices have led to a surge in demand in the market, leading to a valuation of the smart wearable health devices market at a staggering $40 billion as of 2023 [14]. Insurance providers have also capitalized on the information and data transmitted through these health devices to formulate detailed personalized health plans. Transmission of data to health providers has also been facilitated by internet connectivity, even in remote areas [5].

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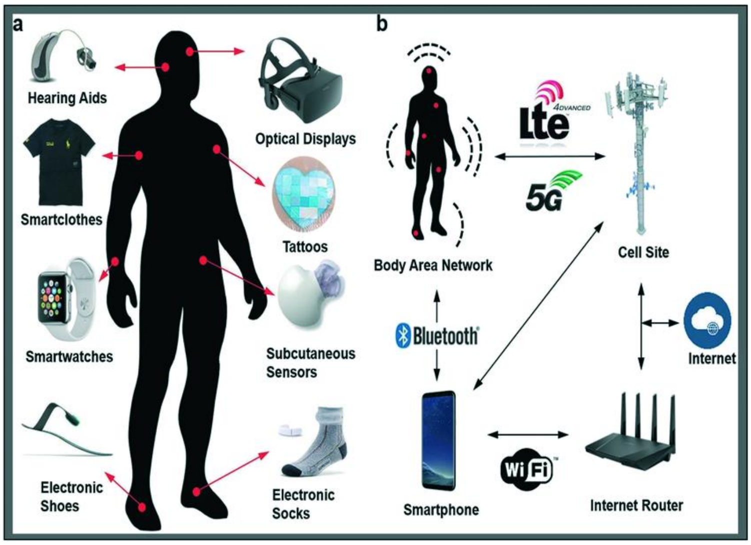

Figure 1: Wearable smart devices for health monitoring (Yetisen et al., 2018)

The emergence of 5G technology and artificial intelligence (AI) has further expanded the potential of WMDs. 5G, with its ultra-low latency, high-speed data transfer, and ability to support massive device connectivity, enables seamless communication between devices and cloud-based systems [4]. Concurrently, AI empowers wearable devices with advanced data processing and analytics capabilities, enabling predictive insights, anomaly detection, and personalized health recommendations [27]. Together, these technologies promise to enhance the efficiency and reliability of wearable medical devices, setting the stage for a new era in preventive healthcare. Preventive healthcare has become a cornerstone of modern medicine as societies face an increasing burden of chronic diseases and rising healthcare costs. Early detection and intervention can significantly reduce the progression of illnesses, improve patient outcomes, and lower costs [14]. Wearable devices, empowered by 5G and AI, are uniquely positioned to facilitate this shift by providing real-time, actionable insights. This growing demand for preventive healthcare underscores the importance of exploring how emerging technologies can optimize wearable medical devices to meet these needs.

The success of wearable medical devices has been tremendous and promises continuous growth in the near future. However, as these progressive milestones continue to be achieved, there are still some challenges and issues that need to be handled to improve on effectiveness and efficiency of the devices [23]. Some of the key challenges reported in the use of wearable medical devices include connectivity issues, limited power processing capacity, and data latency that would inhibit the proper transmission of data from patients to health providers [17]. These issues present areas that would need improvement for a better and faster healthcare experience. If not addressed these issues would lead to compromised health products. For instance, delays in transmitting critical health data or gaps in connectivity can compromise the effectiveness of these devices, particularly in remote monitoring scenarios. Moreover, the lack of robust analytics capabilities in many devices restricts their potential to offer meaningful insights beyond basic data collection [36].

Therefore, this research is geared towards analyzing how the integration of 5G and AI wearable devices can help in addressing some of these major issues. This research will delve into the role of wearable medical devices in preventive healthcare. It will assess how 5G and AI can empower individuals to take proactive steps in managing their health while providing healthcare providers with timely and accurate information for early intervention [42]. It will look into the key provisions of 5G connectivity and how it holds promise for future connectivity. It will also look into the challenges of maintaining and accessing 5g connectivity. Research on the practical implementation of these technologies, such as the technical, regulatory, and ethical hurdles, will also be analyzed, and recommendations made on how the 5G network can help improve healthcare services.

II. LITERATURE REVIEW

2.1 An Overview of Wearable Medical Devices and AI

The 21st century has been a game changer in the field of healthcare, offering advanced technological capabilities that have enhanced the decision-making for healthcare organizations as well as improved patient care. This is attributed to artificial intelligence, which encompasses machine learning (ML), predictive analytics, and deep learning (DL) [40].

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These components of AI have been of tremendous help in how organizations process and interpret big data in pharmaceuticals and healthcare institutions. For instance, predictive analytics involves the study of previous patterns in diseases and patient health to help the healthcare provider make informed and the most effective decisions about a patient's healthcare [11]. It has been beneficial in designing personalized patient care plans through the study of one's genetic composition, lifestyle, and environmental factors. Predictive analytics has also helped in predicting the risk of diseases by analyzing the predisposing factors of certain diseases. By leveraging advanced algorithms, machine learning, and real-time data collection, these devices can anticipate health issues before they manifest into critical conditions. Predictive analytics, therefore, has the capacity to offer preventive medicine and healthcare by analyzing past and current data to make decisions that would affect patients in the future [23].

Machine Learning, on the other hand, is a form of AI that allows machines to learn from data interactions, which aid in the detection of patterns. Machine learning allows for different aspects of data processing and can be configured to perform repetitive tasks and tasks that require the processing of big data [32]. In healthcare, machine learning has been instrumental in the identification of diseases through the analysis of signs and symptoms.

The most common use cases for machine learning in healthcare among healthcare professionals are automating medical billing, clinical decision support, and the development of clinical practice guidelines within health systems [27]. It has also aided drug discovery and development leading to personalized medicine. Machine learning has been able to improve operational efficiency and patient outcomes while reducing errors. For wearable devices, ML can process real-time data to detect irregularities, such as abnormal heart rhythms or changes in activity levels.

Deep learning is another AI provision that uses neural networks to perform complex analyses, such as interpreting medical imaging or genomic data [3]. The deep learning algorithm is able to go through a wide variety of unstructured data and gather evidence on programmable issues. Deep learning has been very useful in the healthcare industry, enabling diagnostic capabilities and early detection of diseases.

These algorithms are able to detect small changes in X-rays that would not have been seen with the naked eye. Wearable devices equipped with DL capabilities could analyze subtle variations in physiological data, providing early warnings for conditions like stroke or heart failure [19]. By analyzing a patient's historical data collected by wearable devices, a deep learning algorithm can predict health issues such as a pending heart attack or hypoglycemia in diabetic patients. Therefore, AI-powered decision support systems assist clinicians by providing recommendations based on wearable device data, enhancing the accuracy and efficiency of diagnoses and treatments [2].

2.2 The Role of 5G in Health care

Prior to the 5G was the 4G which offered good connectivity across regions. 4G LTE network was used by healthcare institutions to improve the quality of care as well as increase efficiency. It enabled basic in-vehicle connectivity where emergency medical persons would send and receive triage details while en route [33]. It did offer connectivity for mobile clinics and access to patient data by mobile caretakers.

The 4G network also facilitated remote medical monitoring and consultation while improving access to healthcare personnel through mobile communications. However, although it did transform the way healthcare institutions communicate, 4G had some significant shortcomings that needed to be addressed to ensure improved service delivery [17]. For instance, 4G connectivity consumes high energy levels and is less efficient. It also has limited support applications and low frequencies, which lead to low-speed data transmissions. 4G network can support fewer devices as compared to the demand, which causes congestion and huge delays in areas where there is a dense population. 5G technology is the latest wireless communication technology that employs high bandwidth technology for data transmission that addresses the limitations of 4G LTE network [21].

5G represents the fifth generation of wireless communication technology that facilitates high-speed connectivity between high-demand areas and businesses. This technology uses cell stations, located every 250 meters on infrastructure like light poles or building roofs, which ensure consistent signal delivery despite obstacles and short-range limitations. Compared to the 4G network, there are tremendous upgrades that make the 5G network better in enhancing how people work and live all over the world. Businesses and industries have embraced 5G networks with the Global Private 5G Network Market was estimated at $1.45 Billion in 2021 and is anticipated to reach around $41.80 Billion by 2030, growing at a CAGR of roughly 49.7% between 2022 and 2030 [7].

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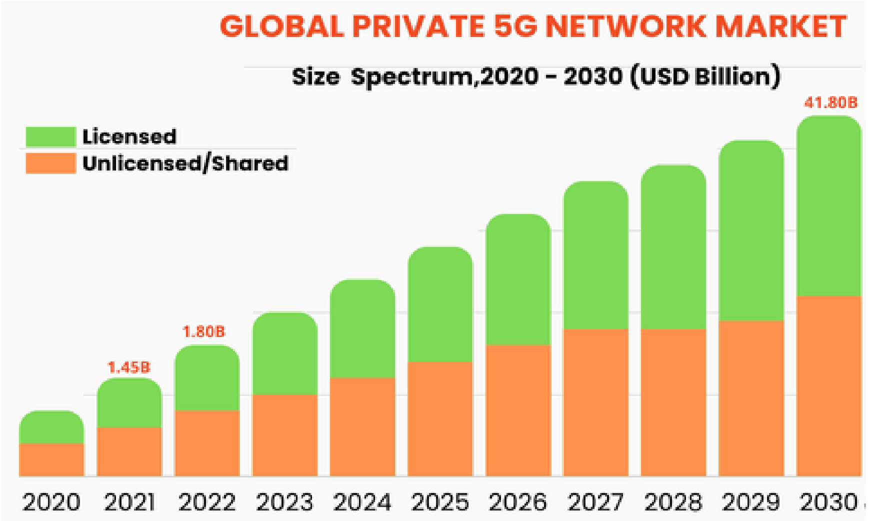

Figure 2: The trend in global private 5G network market (Custom Market Insights. 2023)

2.3 Features of 5G connectivity

The first and most notable feature of the 5G network is the high-speed data transfer feature. In comparison to the predecessor 4G LTE, 5G is almost 100 times faster. It employs high-bandwidth technologies like sub-6 GHz and millimeter-wave (mmWave) frequencies [8]. The 4G network was known to provide up to 100 Mbps of data transfer at peak performance, with the typical speed around the world being an average of 50 Mbps. This is quite low compared to the 5G network, which offers speeds of up to 10Gbps. As such 5G can allow transfer of big data quite easily across devices. this speed also helps in real-time communication, such as health monitoring, without any delays and interference.

The second notable feature of 5G connectivity is the ultra-low latency. Latency can be defined as the time it takes for the transmission of data from the source to the destination and back and is usually measured in milliseconds**.** In comparison, the 4G network has a latency speed of about 70 ms which is slow and can cause delays in normal usages such as video calls and teleconferencing due to the huge data requirements [4]. The 5G connectivity, on the other hand, has a latency of 1ms, which allows for super-fast real-time data transmission without lagging and delays. This is particularly crucial for wearable devices that monitor critical health parameters, where delays in data transmission could lead to adverse outcomes.

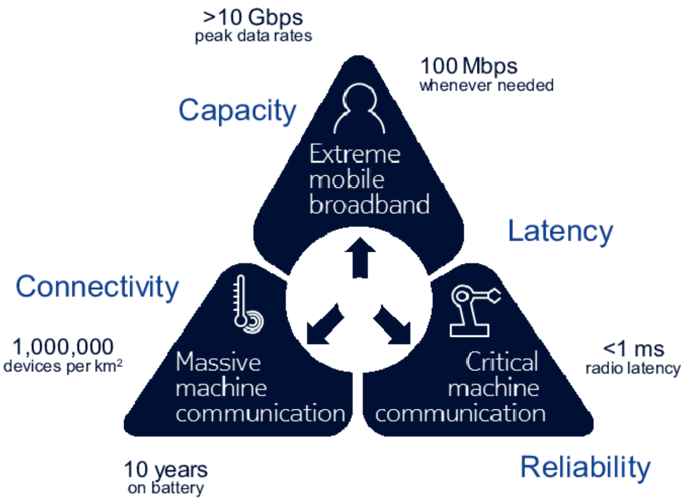

Figure 3: A summary of key 5G features (Yrjola & Jette, 2018)

Thirdly, 5G connection offers enhanced connectivity by increasing the number of devices that can be connected to one station per square kilometer. The 4G connection allowed up to 2000 devices to be connected to one device for every square kilometer [26]. However, with the 5G connection, this number has been increased to 1 million devices which is

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ideal for densely populated areas [1]. This is very useful as it allows for cheaper connections and less resource utilization. This high capacity also allows for scaling as more customers or users can be added to the connection faster and use fewer resources.

Another important feature of the 5G connectivity is low power consumption and better efficiency. The 4G connectivity consumes a lot of energy as it requires more time to transmit data [38]. This means that bigger battery capacities are required to facilitate complete data transmission for larger projects. However, 5G's unique features enable real-time, energy-efficient connectivity by reducing power consumption for connected devices. The low power requirements are also a result of the fast speeds and high connected frequency. This also means that the batteries for 5G devices will need to be recharged less frequently as compared to those of the 4G [24].

2.4 5G in Health wearable devices

The 5G network is considered a revolutionary force, especially in the healthcare and pharmaceutical industry, where it has the capabilities to address the challenges experienced by the 4G network, such as low speeds, low latency, and less connectivity. 5G services have made communication more efficient, sustainable, and impactful in the 21st century [36]. More and more health institutions have embraced the use of 5G networks, and it is projected that in the next ten years ending 2033, it will be over $1T in capitalization [19]. This represents an average growth rate of 34% each year in the healthcare market alone. Some of the most common uses of 5G connectivity in the healthcare industry include tracking equipment and monitoring hospital activities, facilitating remote imaging for instruments such as X-rays and MRIs, and emergency response management through communication with doctors and emergency responders [2].

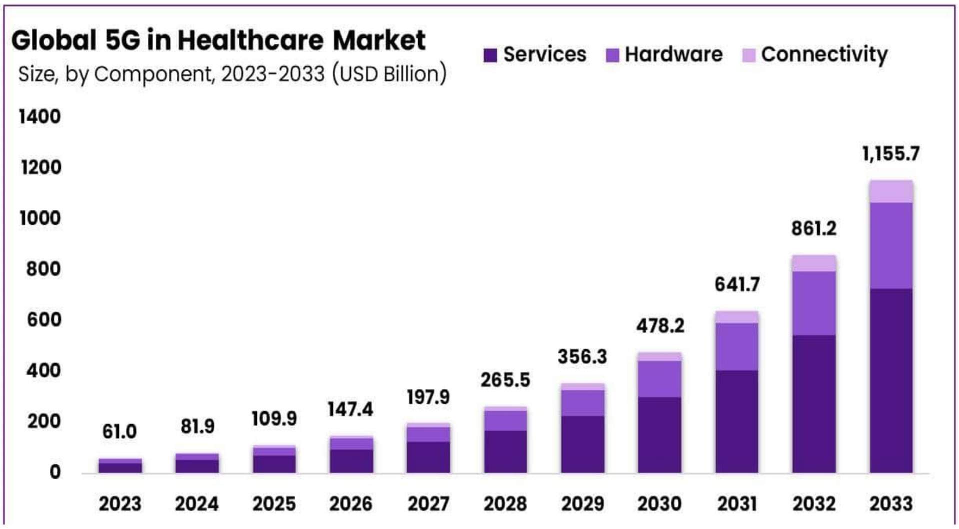

Figure 4: Growth of 5G network by 2033 ((Remote Patient Monitoring System Market Report, 2030, n.d.)

There are some notable high-value acquisitions that have occurred in the last few years .Xnor.ai was acquired by Apple Inc. for $200 million [25]. Xnor.ai is a company that specializes in the production of low-power edge tools and has helped Apple Inc. to integrate special health features into their existing Apple watches. One of the key additions was a feature for monitoring oxygen levels in the blood, another one for monitoring heartbeats and strokes, and transmitting the data to a health specialist in real time for recommendation and on-time action [35].

Telemedicine has greatly improved as a result of 5G connectivity. Telemedicine is termed as the use of telecommunication services to provide medical assistance remotely removing the need to physically attend to hospital services [29]. Telemedicine is particularly important when there are geographical barriers and when there are emergencies that would result in more harm if a patient is transported to a hospital. There are various ways in which telemedicine can be conducted including emails, phone calls, and video conferencing. With the advent of 5G, it has facilitated better long-distance contact between patients and physicians, which has improved the effectiveness of recommendations and improved healthcare [11]. Telemedicine has facilitated on-time reminders, education, remote monitoring, and remote admissions owing to 5G connectivity. A great example of how telemedicine has improved is Medulance Healthcare Ambulance which used 5G from Reliance Jio for smart ambulance services in rural India by connecting an ambulance to a hospital in India [22].

2.5 5G and Cybersecurity

Cybersecurity issues have evolved since the inception of technology and the internet. It is evident how 5G technology has revolutionized data transmission speeds, enabling seamless connectivity for wearable medical devices [16]. However, this enhanced connectivity also brings significant cybersecurity challenges that demand robust solutions. The expansive bandwidth and ultra-low latency of 5G networks facilitate real-time data exchange between wearable devices and healthcare systems, making them essential for critical health monitoring and preventive care. These networks provide opportunities for deploying advanced encryption protocols and sophisticated intrusion detection systems to protect sensitive medical data from breaches and unauthorized access [11]. With 5G's network slicing capabilities, healthcare providers can create isolated, secure virtual networks tailored specifically for wearable devices, ensuring that patient data is transmitted securely without interference from external traffic. 5G represents a shift from traditional consumer smartphones to advanced enterprise services.

One of the key advantages of the 5G in relation to cybersecurity is its ability to integrate edge computing. Edge computing is a phenomenon of data processing in which data processing is done outside the organization at the farthest points which are referred to as the "edge". This means that organizations do not have to handle raw data for the clients but rather receive processed data for decision-making. This aspect of edge computing in wearable devices reduces the risk of data interception during transmission [7]. By processing critical health metrics locally on secure edge devices, potential vulnerabilities from transmitting sensitive information over longer distances can be minimized. Moreover, the use of 5G in edge computing presents new and enhanced security features such as mutual authentication between devices and network nodes, making it harder for malicious actors to infiltrate systems [19]. This is particularly helpful as data collected by wearable medical devices must be maintained safely while enabling real-time transmission of biometric data.

Figure 5: Elements needed to mitigate 5G and cybersecurity issues (Cisco, 2020)

5G presents new challenges in the cybersecurity space, such as increased attack surface, especially as the number of connected devices increases. For instance, there is an increased risk of cyberattacks in how the 5G services-based architecture leverages Application Programming Interfaces (APIs) to enable communications between service functions and optimize infrastructure deployment, configuration, and management [17]. The sheer volume of wearable medical devices linked to 5G networks increases the risk of cyberattacks and data breaches, making the implementation of secure communication protocols imperative [35]. This, therefore, means that companies must ensure continuous monitoring of their networks, including installing AI-driven threat detection systems and automated response systems to address vulnerabilities in real time [11]. With these measures in place, 5G not only enhances the functionality of wearable medical devices but also ensures the integrity and confidentiality of sensitive health data, paving the way for a safer and more efficient era of preventive healthcare.

III. THE ROLE OF 5G IN ENHANCING WEARABLE MEDICAL DEVICES

5G network deployment has transformed communication in healthcare, facilitating a robust and efficient healthcare ecosystem where real-time data monitoring and advanced analytics are seamlessly integrated [34].

The key features that 5G connection possesses, such as high-power efficiency, ultra-low latency, high speed, and high connectivity, make 5G a formidable force for driving innovation and proper patient care. Some of the key areas in 5G connectivity that have aided healthcare are discussed below.

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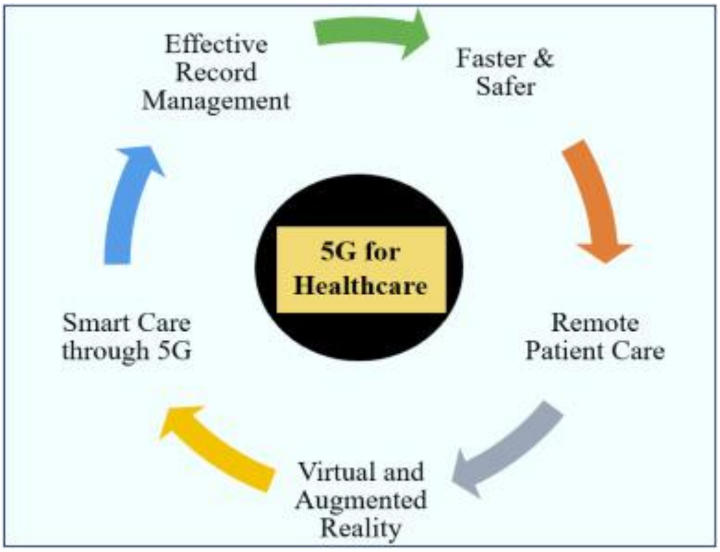

Figure 5: Utilities of 5G network for the healthcare industry (Javaid et al., 2023)

3.1 Patient Health Monitoring Using 5G

5G connection has greatly enabled remote monitoring in collaboration with AI and the use of wearable health devices such as wristwatches and pulse monitors. Connection to a healthcare facility has been a major issue, especially for patients in underserved and rural areas. With the advent of 4G, they have been able to access healthcare, breaking the geographical barriers without the need for frequent visits to the hospital [10]. However, 5G has transformed how they can access medical assistance, especially using wearable devices. with the help of 5G network, patients can collect and transmit data to a professional doctor instantly owing to the ultra-fast 10 GPS speed of the 5g [3]. This instant communication and relaying of data is crucial, especially in cases where any delay results in death or misdiagnosis. For instance, patients with chronic heart conditions need instant relaying of data on their vitals continuously all day long. The capability to utilize power efficiently also facilitates continuous monitoring of the wearable devices without frequent charges. The instant replay of data ensures that in case of an abnormal pattern is detected, the device can alert their healthcare provider, who can intervene proactively [18].

5G technology also enables advanced remote patient monitoring by leveraging wireless body area networks and wearable sensors, thereby reducing health costs and enhancing treatment efficiency. These wearable devices facilitate 5G support with continuous health monitoring for chronic diseases by combining machine-to-machine (M2M) communication and IoT-enabled devices [20]. The wearable devices collect data, and with the help of Machine Learning, data is analyzed instantly to inform the decision-making process. This ensures that interventions are done on time thus improving healthcare accessibility. Therefore, 5G-based eHealth monitoring provides reliable bandwidth, low delays, and efficient resource use to support large-scale patient monitoring [31]. Several emerging technologies that have embraced 5G include the 5GREM system for cardiac health monitoring, which is very useful in computing and task offloading to optimize energy use and enhance emergency responses [6].

3.2 5G Use in the Management of Preventing Infectious Diseases

One of the most important aspects of managing an infectious disease pandemic is to communicate effectively between concerned entities and rapidly transmit data for on-time decision-making. For instance, during the most recent pandemic COVID-19, 5G network played a vital role in providing support for healthcare systems in that it facilitated ultra-massive accessibility and stable connections [30]. This ensured that the pandemic would be managed by monitoring the most vulnerable areas by sharing big data across various access points. This was also particularly helpful in that it enabled quick responses to situations as well as large-scale data sharing. The use of 5G has also enabled proper contact tracing for infectious diseases through analysis of travel history [23]. For instance, during COVID-19, 5G-supported systems facilitated early symptom detection, vaccine development, and widespread information dissemination, ensuring public access to reliable health updates.

5G is particularly helpful in managing infectious diseases by enabling easy tracking of infection spread without necessarily being in contact with the infected areas. This is done through the sharing of real-time data across agencies. It also facilitates the risk of disease spread as data monitoring is done remotely [13].

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5G network also helps reduce the cost of monitoring and managing infectious diseases through optimum resource allocation without the need for physical commuting to infected areas. 5G's high bandwidth and low latency allow for innovative applications such as remote ultrasounds and contact tracing technologies, significantly enhancing disease surveillance and control [16]. Therefore, 5G enhances pandemic response in several ways, including early symptom identification, mobility analysis, and treatment development. These important communication advancements have ensured that infectious diseases are well controlled and monitored, especially by limiting the strain on the medical facilities, thus promoting on-time recovery and proper disease eradication [15].

IV. CHALLENGES IN INTEGRATING 5G WITH WEARABLE TECHNOLOGIES

The benefits of wearable technology integration with a 5G network are clear to see. However, just like any technological advancement, there are challenges that need to be overcome to realize their full potential. For instance, the cost and accessibility of 5G infrastructure and 5 G-supported wearable devices are quite high and a limiting factor. Developing countries are limited in that they lack enough capital to acquire the technology. If the cost of the infrastructure is lowered and made affordable, 5G technology and wearable devices can easily make huge impacts even in developing countries [16]. Another challenge is compatibility issues and interoperability. Wearable health devices need to communicate and analyze data with other devices and systems on a regular basis. Organizations are working hard to ensure that these systems and the 5G-enabled devices have uniform standards that would enable integration and seamless operations [32]. However, until there is a uniform standard, some systems will not be compatible with 5G-enabled devices.

Data security and privacy are always an issue with technological advancements that utilize personal data to operate. Wearable devices collect personal data related to patients which they use to provide personalized care plans [28]. These devices connected via 5G present vulnerability to cyber-attacks and breaches. Therefore, organizations must ensure that they invest heavily in security and data protection software as well as limiting access to sensitive data to only authorized persons. Network stability is another challenge that organizations are working towards stabilizing. Even though the 5G networks have ultra-low latency, it is still an issue to maintain consistent performance, especially in areas that have low or inadequate coverage, such as in developing and under-developing countries [12]. This hinders the real-time data sharing and processing between health systems and the devices.

Another major challenge comes when considering the energy efficiency and battery life of wearable technology. The 5G network raised the energy efficiency levels as compared to the previous 4G LTE network leading to more battery life for the devices. However, the issue of the size of the wearable devices is contentious, which means that the devices can only hold small batteries in them. The wearable devices need to be portable and lightweight, which means that they need to put smaller batteries in them. The size and portability of the devices mean that the 5G devices would require frequent recharging to put up with the increased demand of the processors [37]. Furthermore, the design of wearables must balance functionality with user comfort, as devices that are bulky or intrusive may deter users from adopting them.

V. CONCLUSION

The integration of 5G and AI into wearable medical devices is a transformative leap in healthcare, reshaping patient care and market dynamics. Healthcare professionals see this synergy as a breakthrough in providing personalized, efficient care, with 5G enabling robust telemedicine and remote monitoring capabilities. Technology developers, including major players like Qualcomm and Huawei, are prioritizing interoperability and standardization, investing in 5G-enabled chipsets and AI algorithms tailored for wearables. Future advancements in 5G infrastructure, AI algorithms, and emerging technologies like edge computing and blockchain promise further innovation. Edge computing will address latency and privacy issues, while blockchain will ensure secure and tamper-proof data handling. These technologies will shift healthcare from reactive to proactive models, empowering early intervention and reducing the burden of chronic diseases.

Large-scale population health monitoring will also become feasible, enabling timely interventions during public health crises. Collaboration between tech companies, healthcare providers, and regulators is crucial to realizing this vision, fostering interoperability, and building ecosystems that seamlessly integrate wearable devices into healthcare systems. Together, these efforts can revolutionize preventive care, population health management, and personalized medicine, creating a more efficient and patient-centric healthcare future. Addressing these challenges requires a collaborative effort among technology developers, healthcare providers, policymakers, and users. Innovations in energy management, cost reduction, cybersecurity, and regulatory compliance will play pivotal roles in unlocking the full potential of integrating 5G with wearable technologies.

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