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*Systematic Review*

# Healthcare Internet of Things (H-IoT): Current Trends, Future Prospects, Applications, Challenges, and Security Issues

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**Abstract:** Advancements in Healthcare Internet of Things (H-IoT) systems have created new opportunities and solutions for healthcare services, including the remote treatment and monitoring of patients. In addition, the security and privacy of personal health data must be ensured during data transfer. Security breaches in H-IoT can have serious safety and legal implications. This comprehensive review provides insights about secured data accession by employing cryptographic platforms such as H-IoT in big data, H-IoT in blockchain, H-IoT in machine learning and deep learning, H-IoT in edge computing, and H-IoT in software-defined networks. With this information, this paper reveals solutions to mitigate threats caused by different kinds of attacks. The prevailing challenges in H-IoT systems, including security and scalability challenges, real-time operating challenges, resource constraints, latency, and power consumption challenges are also addressed. We also discuss in detail the current trends in H-IoT, such as remote patient monitoring and predictive analytics. Additionally, we have explored future prospects, such as leveraging health data for informed strategic planning. A critical analysis performed by highlighting the prevailing limitations in H-IoT systems is also presented. This paper will hopefully provide future researchers with in-depth insights into the selection of appropriate cryptographic measures to adopt an energy-efficient and resource-optimized healthcare system.

**Keywords:** healthcare; IoT; big data; block chain; edge computing; software defined networks; machine learning; deep learning

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## 1. Introduction

Over the last few decades, several healthcare applications have been developed to improve medical fields in which recent trends and advancements in information technology have opened the gateway to revolutionary electronic healthcare and industrial research [1]. The Internet of Things (IoT) is an amalgamation of various communication devices that sense and communicate with each other. IoT devices have brought about turbulence in the field of biomedical applications by analyzing the various challenges and complications faced in the past [2]. These IoT devices are capable of generating a significant amount of bio-medical data, which could play a key role in the development of automatic medical data collection systems [3].

When IoT devices are combined with advanced Machine Learning (ML) algorithms, big data becomes an essential part for improvising these health systems in diagnosis, treatment, and decision-making. The IoT in biomedical applications has developed research interest in the Internet of Everything (IoE), which includes symptomatic treatments and the observation and monitoring of patients [4]. Furthermore, the innovation of miniature sensors in healthcare that continuously monitor the vital signs of patients is making the human healthcare system more secure and offers great potential for early diagnosis and treatment. [5]. With the increasing availability of wearable devices, sensors, and other connected devices, healthcare providers can gather a vast amount of patient health data that can be used to improve patient outcomes and quality of care. However, to fully utilize these data, healthcare providers must have effective information processing systems in place. Information processing in the Healthcare Internet of Things (H-IoT) involves the collection, storage, analysis, and dissemination of data generated by IoT devices. These data can include vital signs such as blood pressure, heart rate, and oxygen saturation, as well as patient activity levels, sleep patterns, and medication adherence. Healthcare providers can use these data to detect early signs of disease, monitor patients remotely, and personalize treatment plans for each patient.

The first step in information processing for H-IoT is data collection. Data is collected through sensors, wearables, and other connected devices. The data is then transmitted to a central database or cloud storage system. The database must be designed to handle large amounts of data and be accessible to healthcare providers from multiple locations. Once data is collected and stored, the next step is data analysis. Data analysis involves using advanced algorithms to identify patterns and trends in the data. This can include identifying changes in vital signs, detecting irregularities in patient behavior, and predicting future health issues. Machine learning and artificial intelligence can also be used to analyze data and identify potential health risks. The final step in information processing for H-IoT is data dissemination. Data must be communicated to healthcare providers in a way that is easily accessible and understandable. This can include visualizations such as graphs and charts that highlight key trends and patterns in the data. Alerts and notifications can also be set up to notify healthcare providers of any significant changes in a patient's health status.

In order to address the challenges that come with the increased use of H-IoT devices, which generate large volumes of data that can be overwhelming for healthcare providers to manage, mindsponge theory has been proposed. According to this theory, healthcare providers need to be able to "sponge up" and process this data in a way that enables them to make informed decisions and provide better care to patients. This can be achieved through the use of advanced analytics and machine learning algorithms that can help to identify patterns and trends in the data, as well as prioritize the most relevant information for clinicians. By leveraging the power of IoT data in this way, healthcare providers can improve patient outcomes and enhance the overall quality of care [6,7].

The security issues in IoT devices are bound to increase gradually due to the rapid development and deployment of IoT systems. The security issues in H-IoT are of utmost concern because data breaches can lead to the loss of lives. Figure 1 exhibits the revolutionary features of H- IoT in a hospital environment. Individuals with diabetes are provided with identification cards that will be scanned and connected to a cloud-based platform, where Electronic Health Records (EHRs), prescriptions, crucial laboratory findings, and medical history records are stored. This will make it easier for nurses and physicians to access these records through desktops, laptops, or tablets. While ensuring comfort and security during the sharing of personal health information was considered important, it was challenging to meet these requirements due to the varying security policies and access to control structures.

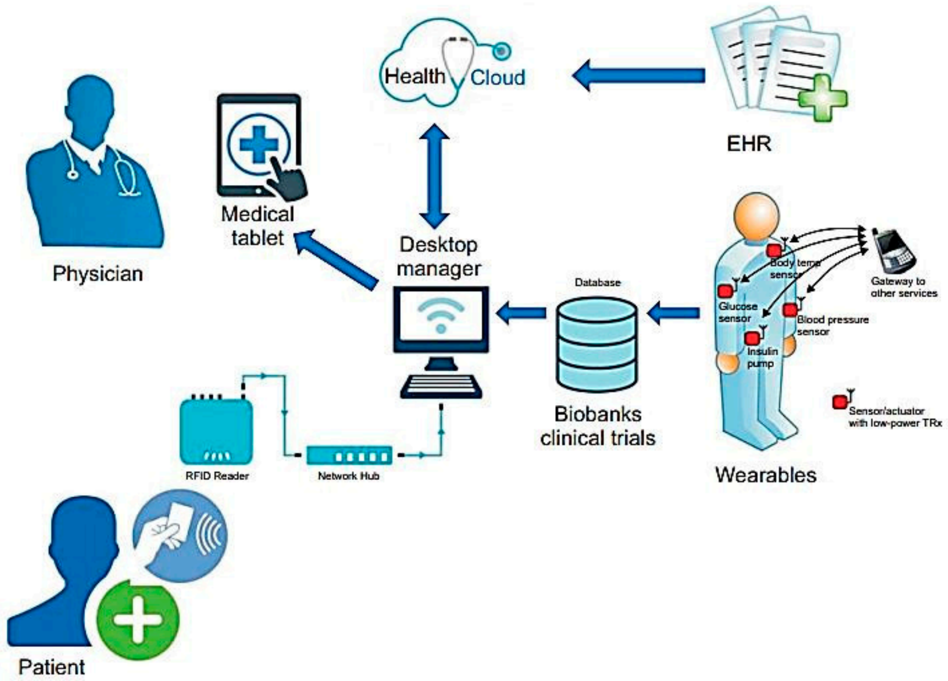


**Figure 1.** Revolutionary features of H-IoT in a hospital environment.

To provide a solution to this, there are various cryptographic platforms such as blockchain, big data, software-defined networks, edge computing, and artificial intelligence. IoT in healthcare has been continuously evolving in accordance with the advances in the aforementioned technologies. The incorporation of blockchain, big data, software-defined networks, edge computing, and artificial intelligence into H-IoT has the capability to revolutionize the sector by providing improved security, efficiency, and precision of data management, along with better diagnosis and treatment options. Nevertheless, implementing these technologies can be intricate and costly—necessitating specific skills. Laws and rules regarding data ownership and responsibility are still evolving, and handling and analyzing extensive amounts of data can pose difficulties. Moreover, specific hardware and software infrastructure may be obligatory, and edge computing may not be appropriate for all H-IoT applications. An important challenge associated with H-IoT is the expense associated with establishing and sustaining the essential infrastructure. The cost of IoT gadgets, sensors, and wearables can be high, and the expense of integrating them with existing healthcare systems can also be a significant hindrance. Moreover, healthcare providers may need to invest in specialized personnel such as data analysts and IT professionals to manage the data produced by IoT devices. Finally, ongoing maintenance expenses can be substantial, including the cost of replacing batteries, upgrading software, and replacing outdated devices. These expenses can be particularly difficult for smaller healthcare providers or those with restricted budgets. As a result, it is crucial to meticulously evaluate the expenses and benefits of H-IoT before making significant investments in this technology. Vuong et al. [8] examined the phenomenon of "near-suicide," where patients stop medical treatment due to financial concerns, leading to fatal outcomes. BMF analytics were used to analyze a dataset of 1042 Vietnamese patients, finding that seriously ill patients were more likely to quit treatment if paying for it would heavily impact their family's financial status.

The H-IoT sector is rapidly developing, with current trends emphasizing remote patient monitoring, wearable tech, predictive analytics, and intelligent hospitals. The combination of AI and telemedicine is projected to result in more accurate diagnoses, increased patient involvement, and better health results. The future possibilities of enhanced H-IoT systems include utilizing health data for well-informed strategic planning, developing more customized treatment strategies, and the possibility of new healthcare devices integrating with IoT technologies. Nevertheless, data confidentiality and safety are possible concerns that require attention to ensure that H-IoT is used safely and effectively.

The significant features of a reliable IoT system in healthcare include high fault tolerance, data security, reliable QoS parameters (such as low power consumption), low latency, good scalability with high data integrity, and interoperability. In addition, ease of mobility, real-time processing, and ease of deployment are also discussed in this paper. The statistical aspect of the explosive proliferation of H-IoT systems keeps on expanding. There are numerous comprehensive surveys [9,10] exploring this aspect; however, the surveys fail to address all of the significant aspects of H-IoT, resulting in important developments, technologies, and applications being overlooked, ultimately leading to inadequate comprehension of the subject matter. The omission of essential details could result in missed opportunities for understanding, decision-making, or meaningful contributions to the field. It is critical to highlight these shortcomings and encourage further research to provide a more comprehensive and insightful analysis. This paper provides an innovative and perceptive viewpoint to the field, presenting novel observations and concepts that have not been previously explored, and provides clear insights to future researchers.

The structure of this paper is organized as follows: In Section 2, H-IoT is discussed in brief along with H-IoT in big data, H-IoT in edge computing, and the detailed use of machine and deep learning in H-IoT. Furthermore, Sections 6 and 7 discuss H-IoT in software-defined networks and blockchain, respectively. A taxonomy of the challenges associated with H-IoT is highlighted in Section 3, and in Section 4, the significance of H-IoT is discussed. The future applications of IoT devices and systems in healthcare are explained in Section 5, and subsequently, a critical analysis of the work is performed in Section 6. Finally, the work is concluded in Section 7.

## 2. Healthcare Internet of Things

The H-IoT is a rapidly expanding field that merges internet-enabled gadgets, sensors, and software applications in the healthcare industry. Its aim is to enhance patient outcomes, increase efficiency, and decrease expenses by offering real-time data, predictive analytics, and remote monitoring. The applications of the H-IoT include wearable devices, remote patient monitoring, telemedicine, and intelligent hospital systems [11]. With the integration of AI and machine learning, the H-IoT has the potential to revolutionize healthcare delivery by providing tailored and efficient care. However, ensuring data confidentiality and safety is a potential issue that must be addressed to guarantee the secure and effective use of H-IoT technologies. In recent times, the IoT has been said to be one of the most promising technologies in the field of healthcare. Along these lines, Rodrigues et al. [12] presented a comprehensive review of IoT in healthcare, which is also expressed as H-IoT. Further, this study identifies technological advances in H-IoT and the corresponding limitations that need to be overcome. Rodrigues et al. also suggested that further research in this field is essential for improvising the current challenges faced by H-IoT. Our extensive review will be a great source of information to the researchers, technology specialists, healthcare providers, and the general population for improvising H-IoT.

A competent cryptosystem for the secure transmission of MRI images in H-IoT environments has been reported by Tsafack et al. [13]. The study delved into the dynamics of a 2D trigonometric map, which has infinite solutions. The study further utilized phase portraits, bifurcation diagrams, and the Lyapunov exponent for showcasing the complex dynamics of the map. The performance analysis of the study's proposed cryptosystem suggested that it is highly secure and can be efficiently included in the field of H-IoT for the secure transmission of medical images. Figure 2 depicts how the utilization of IoT in healthcare is progressively gaining acceptance with the aim of enhancing patient results, augmenting effectiveness, and curbing expenses.

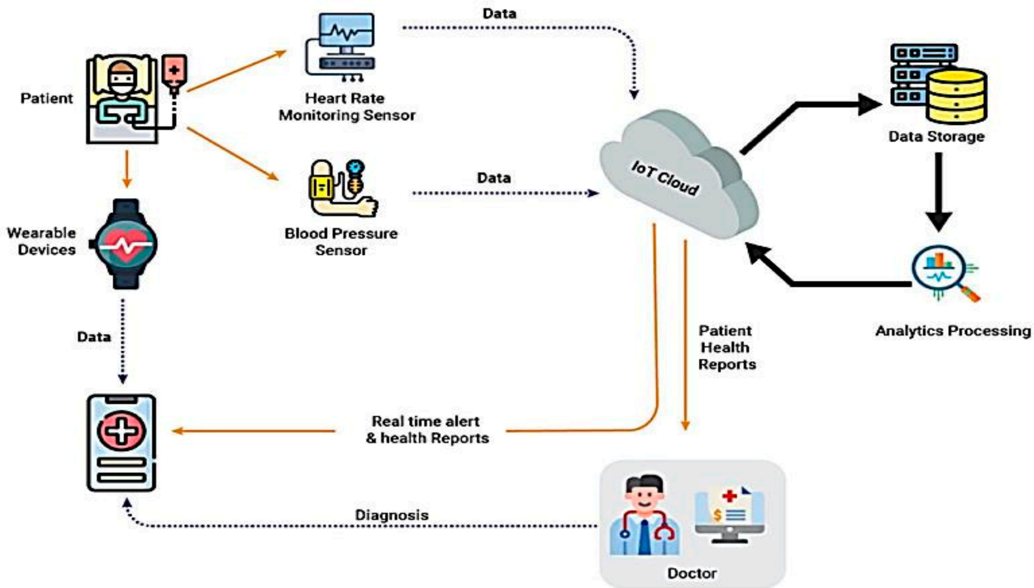


**Figure 2.** Internet of Things in healthcare industries.

### 2.1. *H-IoT in Big Data*

H-IoT relies heavily on big data, as it permits the accumulation and assessment of extensive medical information. The integration of big data in H-IoT has resulted in the development of predictive models, which can aid in detecting possible health hazards and projecting disease advancement [14]. Through the utilization of machine learning algorithms, healthcare providers can analyze substantial data sets to formulate tailored treatment strategies for patients. These things considered, big data analytics in H-IoT can identify patterns and trends, leading to enhanced patient outcomes, decreased healthcare expenses, and streamlined healthcare delivery. The personalized healthcare system can deliver E-health services to fulfill the clinical requirements of aged people. A detailed study on the emerging technologies in healthcare industries regarding big data analytics, mobile-based applications, IoT, fog computing, and cloud computing was performed by Jagadeeswari et al. in [15]. Further, this study analyzed the drawbacks in building an improvised healthcare system for the early detection of diseases and provided insights into feasible solutions to overcome limitations. Our review hopes to help form the foundations for building a better healthcare system in future.

An intelligent H-IoT-driven big data storage system that also secures data has been suggested by Yang et al. in [16]. This suggested system would also possess adaptive access control, provide high-level security to the healthcare data of patients, recognize access control for emergency and normal situations, and support smart de-duplication in saving storage space for big data. The medical files generated by H-IoT were encrypted and stored in a system that could be securely shared with healthcare workers from various medical domains. Further, these access control techniques enable authorized users to decrypt the confidential medical data and support in providing first aid treatment to the patients whose life is at risk. This study suggested a new twofold and secure access control system, which is self-adaptive in the case of emergency situations and normal situations. In critical emergency situations, the medical data of patients can be recovered by utilizing a break glass access mechanism [17]. Finally, the study stated that, this suggested framework is proven to be secure.

Big data accumulates a huge amount of data for numerous professional applications, including H-IoT systems and robotics. H-IoT-driven systems play a significant role in big data analytics. However, sensing may provide challenges when attempting to predict accurate results. Therefore, a H-IoT system that utilizes Artificial Intelligence (AI) for the treatment of Parkinson’s disease (PD) was suggested by Sivaparthipan et al. [18] to enhance the gait of affected patients. Further, this study briefly outlines the significant use of robotics in the treatment of Parkinson's disease. Robotic methods used to treat PD involve predicting walker motion and providing physical training. Robotics can also foster interactions with big data. For the prediction of walker motion, the robots must walk alongside the patients while sensors are used to monitor the patients and robots. Additionally, the study compared the performance of the suggested method with other existing methods.

The applications of big data in healthcare sectors are rapidly growing, and novel discoveries and methods have been published in the last ten years. Big data techniques have been efficiently utilized in healthcare research and biomedical informatics. Recently, researchers, hospitals, patients, sensors, and mobile phones have generated a huge amount of healthcare data. These data are constantly generated by clinical organizations and are utilized to detect and cure new diseases. Various new technologies for collecting these data have been developed by different researchers. Similarly, patients have started to use these technologies in the form of mobile applications for managing their recovery needs. Additionally, by using IoT, these devices and apps can be progressively utilized and combined with telehealth and telemedicine. Mishra et al. [19] discussed big data's biomedical applications as well as its challenges. Their study presented new approaches to the advancements in healthcare systems by utilizing distributed computing systems and big data technologies. IoT is said to be substantial advancement in the era of big data as it supports several real-time applications via enhanced services, as demonstrated in Figure 3.

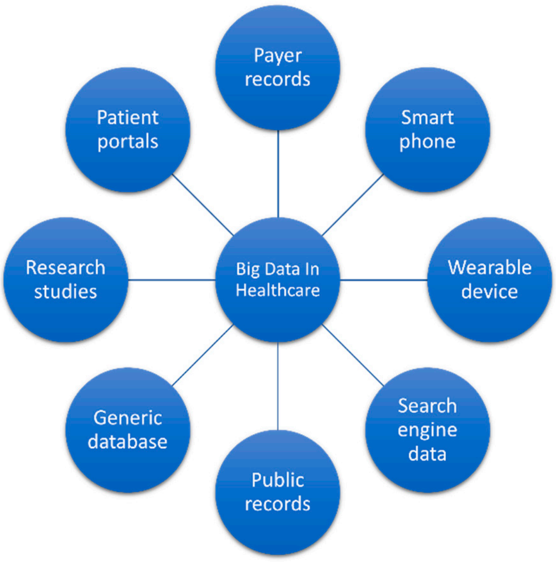


**Figure 3.** Applications of big data in healthcare industries [20].

Generally, the IoT requires every device to generate massive amounts of data, necessitating effective processing and storage. Cloud computing emerged to solve this issue. Nevertheless, the data from healthcare applications must be processed in real-time to improvise performance and reduce latency. Fog computing can be considered a promising solution that is applicable to the healthcare domain as it can reduce delays in data communication, promote flexible services, and distribute resource demands. Moreover, a fog-based H-IoT system was suggested by Feng et al. [21] to reduce energy and network delay. Additionally, the study suggested and provided some essential services of big data infrastructure for medical big data analytics in fog devices.

Smart sensors and IoT devices are utilized in various parts of life, such as communication, transportation, healthcare, surveillance, business, and several other industries. These sensors and devices produce tons and tons of data, which is beneficial and valuable for healthcare organizations if they subject these data to further analysis [22].

### 2.2. H-IoT in Edge Computing

In general, the IoT connects numerous smart sensing devices, such as heterogeneous networks, and they are integrated in various applications, including smart grid, smart home, and smart health [23–25]. Further, when considering IoT-based healthcare systems, the security of IoT devices and data is essential. Edge computing is said to be a promising aspect of IoT that attempts to rectify complex processing issues. Edge computing has the potential to provide less latency data by improvising the computation and communication speed of IoT devices [26,27]. Utilizing AI and building optimized networks can promote load balancing and effective resource usage in IoT-enabled edge computing-based healthcare systems. Nevertheless, these devices possess a lot less power, and its data is more susceptible to security threats. Thus, [28,29] developing a secure structure for IoT-enabled edge computing-based healthcare systems via software-defined networks (SDN) is essential. IoT devices are authenticated by edge servers through utilizing a lightweight authentication approach. After the authentication, the IoT devices will collect and subsequently transmit patients' data to edge servers for storage, processing, and analysis purposes. These edge servers are linked by an SDN controller that facilitates the effective usage of resources, network optimization, and load balancing in healthcare systems. Finally, the suggested method was evaluated by utilizing the computer-based simulations. From the simulation outcomes, the study stated that the suggested method provided better solutions for healthcare systems based on edge computing and IoT.

Advancements in sensing techniques have helped develop smart systems to continuously monitor human behaviors, as seen in [30,31]. Wearable sensor-based frameworks for activity prediction via a Recurrent Neural Network (RNN) on devices such as personal computers or laptops have become popular. The input data, such as gyroscope, accelerometer, magnetometer, and ECG sensors (Electrocardiography), were obtained from different wearable healthcare sensors. The suggested method was compared with traditional methods with available datasets. From the experimental outcomes, the study stated that the suggested method outperforms other conventional methods.

Emerging trends in edge computing have helped to develop effective healthcare applications, including patient remote monitoring via central electronic clouds (E-clouds). This requires better quality of service (QoS), high sensing levels, and clear visualization, the latter of which must be considered the highest priority. Therefore, a Window-based Rate Control Algorithm (W-RCA) has been suggested by [32] for optimizing Medical QoS (M-QoS) in edge computing by considering Peak to Mean Ratio (PMR), delay, Standard Deviation (SD), and network jitter. Further, the study evaluated the suggested W-RCA algorithm and compared it with other prevailing algorithms, such as the Battery Smoothing Algorithm (BSA), to optimize M-QoS. From the experimental analysis, the study represented that the suggested method outperformed other prevailing methods by optimizing applications such as tele-surgery.

The rapid growth in information technology and IoT has promoted the utilization of smart systems. Moreover, cloud and edge computing are significant for intelligent healthcare systems in developed and smart cities. The Emergency Departments (ED) require real-time systems and tailored methods for modelling, simulating, and optimizing service flow and system resources. Therefore, [33] suggested a system for modelling the non-consumable resources, describing and validating it theoretically. Furthermore, the RPN was applicable to real-time scenarios, factoring in performance indicators such as average patient waiting time, usage rate of resources, and the patient's length of stay (LoS). The study simulated the suggested system, which emphasized improvements in the LoS, patient waiting time, and resource utilization.

### 2.3. H-IoT in Machine Learning and Deep Learning

The following section describes the machine learning and deep learning methods used in H-IoT. A new H-IoT-based deep learning (DL) structure was outlined in [34] to detect and classify cervical cancer by utilizing the transfer learning concept. Further, the study also integrated a Convolutional Neural Network (CNN) [35–37] with various conventional ML approaches, such as Support Vector Machines (SVM), Random Forest, Logistic Regression (LR), Naïve Bayes (NB), and K-Nearest Neighbor (KNN). This study performed feature extraction by utilizing the pre-trained CNN models such as ResNet50, SqueezeNet, VGG19, and Inception V3. Moreover, the study evaluated the performance of the suggested H-IoT system, and from these evaluations, the study stated that the suggested model achieved a high classification rate of 97.89%. A DL methodology has been represented in the use of a Softmax classifier and stacked Auto-Encoders (AEs) to efficiently classify and then prognosticate the CKD [38]. The suggested model employed AEs to mine the features and find the multi-model patterns residing in the corresponding dataset. It also assisted in obtaining an enhanced classification performance. This leads to simple classification via feature reduction for individual AEs. Subsequently, a Softmax classifier has also been utilized for the sample classification of varied classes that rely on identical features. This can be found from the outcomes observable by implementing the introduced technique, the Deep Stacked AE model, which classifies the CKD so that it will be an effective diagnostic tool that possesses accuracy, specificity, recall, and precision, all of which are vital in the medical field. Similarly, the paper [39] introduced and assessed a DL algorithm to prognosticate CKD from the retinal images. There are several prevailing studies in the diagnosis of P. vivax. The authors of [40] suggested a new Stacked CNN framework, which improvised the diagnosis of malaria automatically without considering hand-crafted features. Moreover, the process of fivefold cross-validation has gained higher accuracy in the detection of parasites. These outcomes proved that, with changing depth and filter sizes, the convolutional layers could extract various features for the process of classification.

### *2.4. H-IoT in Software Defined Networks*

A software-defined approach enables the network nodes to be regulated through language programming rather than the conventional model of administration [41,42]. To address the various limitations of the IoT, SDNs provide network virtualization, network management, energy management, resource utilization, privacy, and security by means of separating the hardware device control. The major functionality of an SDN is to separate the control plane from the corresponding data plane for the purpose of streamlining network performance. The authors of [43] designed a secured framework for authenticating IoT devices through edge servers with the use of a lightweight authenticating system. After the process of authentication, these devices extract the data from the corresponding patients and transmit them to edge servers for storage, processing, and analysis purposes. These edge servers are interconnected with the SDN controller that performs network optimization, load balancing, and effective resource utilization [44]. The suggested framework has been evaluated using computer-sided simulations with better outcomes. Confidential medical reports and records stored in the cloud must overcome network security attacks [45]. This system sends immediate alerts to the medical worker, thereby controlling many kinds of diseases. The authors of [46,47] suggested an SDN-based framework in which every patient possesses a dedicated virtual machine in the data-sharing system that could be released to authorized consumers. Additionally, the virtual machine was protected by SDN-based gateway processing that acts as a firewall and guarantees privacy and access to patients via VMs with unique MAC addresses.

### *2.5. H-IoT in Blockchain*

Blockchain has been considered as a distributed ledger methodology which could be more effective in the provision of access control in healthcare systems [48]. Since migrating or implementing to a complete blockchain solution seems to be an extremely challenging task, various implementations and designs must be considered, as evidenced in the following: The authors of [49] suggested a novel system based on blockchain that correlated with swarm exchange methods used for facilitating the user-initiated secure and seamless transmission of electronic health records. This study employed various peer open, peer closing, announcement, and swarm intelligence algorithms for the incorporation of the actual pervasive EHR transmission power for optimum healthcare service provision. The suggested system was developed with the use of tools such as IPFS, GnuPG, and Golang. This study stimulated various IoT health sensor nodes in the blockchain-assisted swarm exchange framework, such as pulse rate, body temperature, and oxygen saturation. The authors of [50] combined blockchain smart contracts with IoT devices for the structural health monitoring of underground structures to define an efficient, novel, secured, and scalable distributed network for improving the safety of the operation. Here, the features of globally centralized and locally centralized distribution were activated by categorizing them to the edge and core networks to improve scalability and efficiency. Overall, this proved effective in simulating controlled structures and enabling autonomous monitoring. The authors of [51,52] investigated the monitoring of the vital signs of patients by using blockchain-based smart contracts. This system was designed using hyper ledger fabric and provided various benefits to individuals, irrespective of their location. The study used a Linoleum toolkit for acquiring physiological information. The efficiency of the developed framework was assessed in terms of latency, resource utilization, and transaction per second with the use of a standard benchmark hyper ledger caliper. It was observed from the study that this system is effective in the monitoring of patient data when compared to conventional healthcare systems. The authors of [53] suggested a blockchain-based system that predicts the status of customers and provides rewards in accordance with formulated rules. The results observed from the model suggested that this customer-centric model makes it easier for the business to modernize.

## 3. Challenges

The various performance-related challenges of H-IoT, such as security, latency, reliability, and efficiency, constitute a huge roadblock in the development of H-IoT. An improved H-IoT system should perform with low latency, high reliability, low power operation, and high security. In the following section, the challenges faced by several authors regarding IoT systems are discussed in detail.

### *3.1. Low Latency*

In the field of H-IoT, achieving low latency is crucial for the following processes: real-time data processing and analysis of emergency response systems, remote patient monitoring, and telemedicine. Low latency enables healthcare providers to make timely decisions and respond promptly to emergencies. However, attaining low latency can be complex, requiring specialized hardware and software, as well as the optimization of network infrastructure. The transmission and analysis of data in real-time is a significant challenge in H-IoT, and any delays in processing and transmission could hinder the ability of healthcare providers to make informed decisions. The time-critical nature of a H-IoT system demands very low latency regarding end-to-end transmission and data processing. The total delay is decreased by reducing the transmission delay through the exploration of communication technology with a high availability and high bandwidth. The employment of ML algorithms for channel access and routing could considerably decrease the end-to-end delay, which is in contrast to the advantages of fog and edge computing frameworks. Further, these edge and fog computing frameworks have been found to be highly efficient when integrated with AI [54]. Deep learning methods enhance the big data analytical system designed to handle massive amounts of information; however, the existing challenges remain as an obstacle for the extraction of all reliable information from the provided dataset. Hence, there is an immediate demand for powerful algorithms that could potentially exploit and complete the set of information from the dataset. In order to resolve this, the employment of computing resources near the network edge decreases, as does the transmission delay and the processing delay. The usage of distributed computerized platforms provided by the fog paradigm could ensure minimum latency in time-critical H-IoT systems [55]. Incorporating fog computing in H-IoT can mitigate the adverse impact of cloud latency on emergency response systems. Nevertheless, there are still challenges related to response time, latency, and energy consumption that require attention. To overcome these limitations, the Energy-Efficient Internet of Medical Things to Fog Interoperability of Task Scheduling (EEIoMT) framework has been proposed [56]. This framework optimizes task scheduling by prioritizing critical tasks that need to be completed within a given timeframe while managing energy consumption and processing other tasks.

### *3.2. Security Challenges*

In H-IoT, security is a major concern due to the confidential nature of patient information. As H-IoT devices and systems become more connected and accessible, they become more susceptible to security breaches and cyberattacks. Cybercriminals may find medical data valuable for identity theft, fraud, and other nefarious activities. Furthermore, a security breach in a H-IoT system may cause significant harm to patients due to the potential exposure of confidential medical information and/or the tampering of medical devices. Therefore, H-IoT systems must have strong security measures to ensure patient data confidentiality, integrity, and availability, as well as the safety and dependability of medical devices. H-IoT are resource constrained; thus, it become tedious to frame lightweight algorithms. Furthermore, the main problem exists in maintaining energy efficiency. Hence, the implementation of aspects built for mitigating security threats requires an energy-efficient machine learning or deep learning algorithm which could handle lightweight cryptography [57–59]. However, computational complexities exist in the above discussed system. Hence, a fog paradigm could be adopted, employing a federal system near the devices for security.

Despite its ability to offer efficient healthcare services, the Internet of Medical Things (IoMT) encounters security issues because of its susceptibility to middleman attacks and the insufficient security awareness of inexperienced users. In order to address these risks, a security enhancement approach called RECC-VC was proposed. This method incorporates K-anonymity, optimized neural networks, and blockchain technology, resulting in greater precision and security than existing methods [60].

### *3.3. Real Time Operational Platforms*

In general, the health status of the user might be more deeply understood with the data collected from the sensors. It has to be noted that the amount of generated data is observed to be substantial and requires specialized processing algorithms for the extraction of useful information. However, many existing algorithms have proven to be incapable of entire data processing, necessitating the use of real-time data handling algorithms. Even though deep learning algorithms can handle massive real-time data, the extraction of multiple and redundant features from the dataset is imperative [61].

### *3.4. Energy Consumption*

Although wearable H-IoT devices may be recharged after a particular operational period, the implants need a sustainable battery for hassle-free long-term operation. To overcome this energy constraint, various solutions have been suggested in the literature. One solution to this problem proposes minimal foreign intervention in the process that prevents hazardous side effects in the implementation process [62]. Additionally, better management of resources with a limited processing capability, limited power, and limited memory in the IoT is necessary for improving the network lifetime [63–65]. In fog and edge computing, a short-range power system has been that consumes a considerably low amount of power has been suggested, but availability becomes a problem in these cases. The solutions presented in the literature regarding energy harvesting in nodes need to be cost-effective, capable of fast-charging, and harmless to the user.

### 3.5. Scalability Challenges

To support the large-scale deployment of H-IoT systems, challenges in scalability must be addressed. Furthermore, the delivery of data in H-IoT systems is decisive, and a proper access mechanism should be used to ensure there is no loss of packets. Aside from this, most of the existing routing protocols in H-IoT systems do not perform well due to their dynamic nature. In addition, there are also some important issues in terms of localization and coverage. The standardization of implantable sensors and wearable devices for providing seamless connectivity is essential. The generated data traffic must be processed without the infusion of additional costs and computational delays. Consequently, challenges also deal with the network calibration in the nodes which are continuously changing. Mobility issues also seem to challenge IoT-based systems. The sensors which are employed on a source, e.g., the human body, degrade the network performance when the user changes their present location. Hence, reliable services must be adopted to retain the availability of the network while the user is moving.

## 4. Significance of H-IoT in the Medical Field

In today's world, healthcare providers are facing many challenges. H-IoT increases medial IQ by providing the right information in the right place. Initially, it streamlines the workflow by eliminating simple things, thereby substantially reducing service cost and also provides more quality doctor/patient time. Moreover, higher patient satisfaction and patient outcome scores found in surveys such as HCAHPS could generate revenue by increasing third-party payments. Additionally, H-IoT improvises both patient and business outcomes. According to the IMS Institute, in 2012, the medical sector generated over two-hundred-billion dollars. Increased IQ in the medical field significantly reduces the risk of clinical mistakes occurring. The recent advancements in biometric devices and sensors mean they can provide immediate feedback to doctors. Instead of waiting fourteen days for a patient to respond, with the help of the IoE, instant actions can be obtained. When integrated with big data, additional benefits can be obtained, such as improved patient care. Most importantly, the IoE provides the necessary information required by the healthcare sectors to maintain general wellness [66].

## 5. Applications of H-IoT

### 5.1. Patient Prediction

H-IoT plays a predominant role in predicting patient visits to hospitals. Several articles have discussed the use of big data in predicting patient visits to hospitals. It has been stated that data from different sources are integrated to make daily and hourly predictions. Further, data scientists have implemented the techniques of time series analysis in the admission of hospital records. This has helped to predict patient admission rates as well as the rate of staff availability. Additionally, various ML algorithms act as essential tools for the analysis and prediction of admission rate trends in future patients. When predictions are performed, staff members are able to better anticipate when they will be required. Hence, more staff will be available, thereby reducing the waiting time of patients and also guaranteeing improved patient care.

### 5.2. EHR (Electronic Health Record)

The most common utilization of H-IoT in the healthcare sector is in regard to EHR (Electronic Health Records). These electronic health records are composed of patient reports, such as lab test results and medical histories [67,68]. Moreover, a secured information system has been employed for making these EHRs available for the private and public sectors. Since every record is digitized and the data files are consistently updated, there is no need for paperwork and data duplication.

In addition, electronic health records could generate reminders to track the prescriptions of patients and warnings when required lab tests are being conducted. Even though the implementation of EHR is beneficial, several countries have still struggled to implement them. A study suggested that, in the US (United States), a system named Health-Connect has been implemented, enabling easy sharing and utilization of data [69]. The reports from McKinsey on the integration of systems related to BD (big data) in healthcare indicate that approximately one million dollars have been saved due to reductions in office visits as well as pathology tests for cardiovascular diseases.

### *5.3. Real-Time Alerting*

In the use of H-IoT systems, the real-time alerting of healthcare analytics is considered a predominant functionality. Generally, in hospitals, a real time CDS (Clinical Decision Support) system helps the health practitioners and doctors with prescriptions and advice given on the spot to the patients. However, these real-time systems are costly. Hence, doctors or health practitioners prefer their patients to stay away from their hospitals. In recent years, a personal analytics design was adopted, meaning that the health data of patients are constantly observable via wearable devices, such as smart watches, and information is shared via the cloud [70]. For instance, if there was a rapid increase in the blood pressure of a particular patient, their personal doctor will receive an alarm so that actions can be taken for reducing the patient's blood pressure. Moreover, in an Asthma polis system, the inhaler has GPS access, used for finding asthma trends on an individual level and on a wider basis. These data are aggregated by clinical decision support, resulting in better treatment plans for patients suffering from asthma.

### *5.4. Enhancing Patient Engagement*

It is evident that people are more health conscious nowadays, using smart devices to monitor their own pulse rate, blood pressure, and sleep and also to record their day-to-day routine. This increase in self-monitoring means that health risks of any kind are more likely to be identified and treated. Moreover, heart diseases can also be predicted by chronic insomnia and increased heart rate. Ultimately, by using smart devices, patients will also be involved in health monitoring activities [71]. Additionally, specific health trends can be identified by the H-IoT system and uploaded to the cloud, from which they can be accessed and used by physicians. Due to this enhanced self-monitoring, there will be a significant reduction in the number of hospital visits, and also patients will be independent.

### *5.5. Informed Strategic Planning by Utilizing Health Data*

In today's world, strategic planning within the healthcare sector is essential, and help can be provided by big data analytics. A recent study suggested that Google Maps could aid in illustrating different real-time problems. As such, the spread of any chronic disease among the population can be represented in the form of heat maps. The availability of medical services in intensive care units has been compared to real-time data, and decisions were taken with respect to healthcare strategies, which were augmented by several healthcare units.

### *5.6. Big Data Could Cure Cancer*

By utilizing big data, a system named Cancer Moonshot was developed to help find a cure for cancer. This program aims to cure cancer within a much shorter time period compared to conventional methods. Several researchers from the medical field utilized huge amounts of data to achieve better results and identify useful trends. The results of this system will provide good recovery rates as well as treatment plans. Furthermore, the tumor samples that are stored in bio-banks are linked to the treatment records. These data are referenced in order and the interactions, as well as the mutations, among the cancer proteins mean that treatment plans can be mapped, resulting in better outcomes. This also sometimes yields surprising results, such as the presence of desipramine, which has been found to cure lung cancer.

Additionally, these researches demand collaboration with different hospitals, institutions, and non-profit organizations, in all of which treatment records are available. The samples of cancer tissues of trial patients are sequenced genetically and added to a worldwide cancer database. Nevertheless, the use of big data analytics to identify a cure for cancer has some limitations, primarily surrounding the issue of incompatible data, as some datasets cannot interact with others.

### *5.7. Predictive Analytics in the Healthcare Sector*

In recent years, predictive analytics have been exploited for business applications and will surely be further explored in the future. A recent study suggested that a research project in US (United States) gathered datasets from thirty million people, from which the study observed a good quality of delivery care [72].

These kinds of intelligent tactics assist health practitioners and doctors in making decisions based on available datasets, leading to improved and better patient treatment. For instance, if a patient has a complicated medical history and also suffers from critical health disorders, these tactics could be more helpful. Moreover, there are some new tools which can predict heart disease, blood pressure, and diabetes. Patients suffering from these conditions could be advised to partake in regular physicals, seek regular medical advice, and also make use of dietary plans or weight management programs [73]. The proposed system has been compared, in terms of accuracy, to heart disease prediction via various existing systems [74,75], such as GV + SVM, SVM, MLP, ANN, LR, KNN, NB, DT, and SVM + MLP. The analytical results exhibited a high accuracy with the IoT methods, signifying its potential use in healthcare sector, as shown in Figure 4.

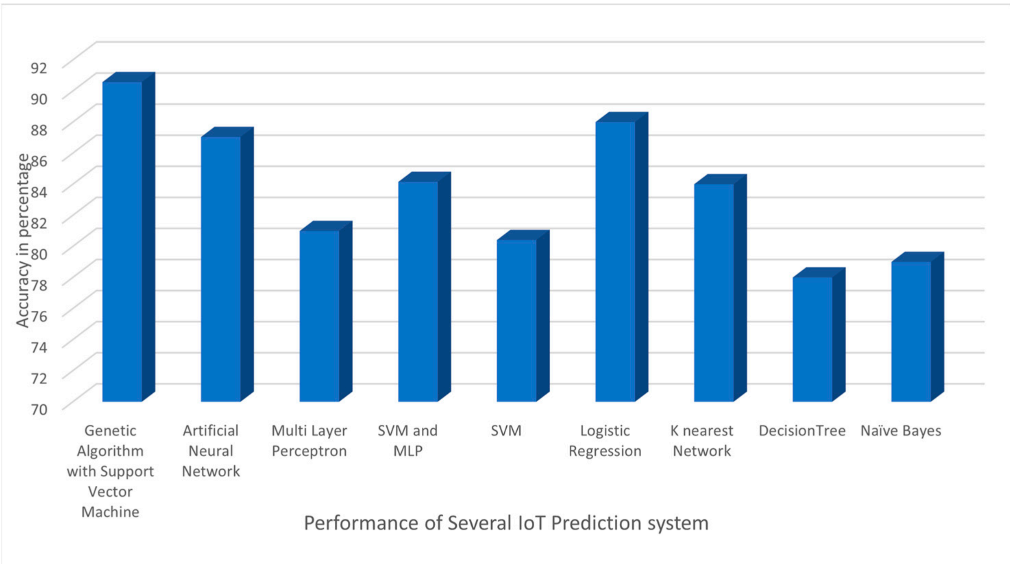


**Figure 4.** Heart disease prediction accuracy across multiple prediction systems [74,75].

### *5.8. Tele-Heleathcare*

Tele-healthcare is used for delivering long-distance healthcare services, offering the remote monitoring of patients. With the help of tele-healthcare, the gap between patients and their healthcare provider(s) has been bridged somewhat. The major advantage of tele-healthcare is the minimization of costs thanks to the reduction in regular hospital visits. Tele-healthcare involves the use of mobile technology, computers, and telecommunications to remotely deliver healthcare services and consultations across geographic boundaries.

Lately, networks have utilized multiple routes for data transmission. Nonetheless, certain experts have devised a dependable route between nodes in networks for tele-surgery objectives. They accomplished this by leveraging medical apps such as health monitors, which comprise tele-surgery functionalities. This optimization of Medical Quality of Service (m-QoS) is especially critical during the current pandemic era, wherein most individuals are unable to travel. To rectify these issues, the authors of [76] introduced a reliable and trustworthy method to help facilitate communication between doctors and patients so that the operation can be performed from longer distances. Further, these communications will be monitored by the suggested method, which receives data without delay. This study examines how it can increase buffer space, which can be efficiently utilized to reduce the delay between the source and the destination. Moreover, this study introduced a novel S-RCA (Smart Route control algorithm) to create virtual smart paths between the source and destination in order to transfer data. This offers a reliable connection that could be utilized in surgeries to guarantee that every instruction is received without delay. This method improvises M-QoS in remote surgery with reliable paths.

A tele-medical service was introduced in [77] to conduct clinical exams directly on patients in a hospital via IoT medical devices. The outcomes of these exams were sent to doctors through the hospital cloud in an automated manner. Specifically, the study discussed distributed scenario, in which the medical doctors, technicians, and nurses belonging to various hospitals form a virtual healthcare team to perform healthcare work by leveraging blockchain technology features. However, the study failed to integrate comprehensive healthcare scenarios involved with various organizations, such as pharmaceutical companies. Telemedicine has been a part of the industry for over 40 years and has adapted to incorporate various new technologies such as smartphones, wireless devices, online video conferences (VCs), and wearables. The remote medical services involve medical professionals monitoring patients remotely. Moreover, telemedicine offers personalized treatment plans, preventing re-admission or hospitalization. Healthcare data analytics help doctors predict critical medical events in the lives of patients and prevent health issues. With the help of telemedicine, the number of admissions in hospitals have significantly reduced, and the QoS (Quality of Service) has increased. Since the condition of patients can be monitored from anywhere and doctors can be consulted at any time, hospital visits are not needed, thereby significantly reducing waiting times.

### *5.9. Big-Data and Medical Imaging*

Big data has made major contributions to medical imaging, e.g., several radiologists can individually investigate medical images, analyze them, and store them so that they are accessible for many years. However, this method is more costly and time-consuming.

The Carestream algorithm can analyze numerous images, find specific patterns within the pixels of the medical images, and convert them into numbers. These numbers play a vital role in diagnosis, thereby helping doctors treat diseases. This concept saves doctors from having to remember numerous medical images, which is incredibly difficult due to the fact that they are so highly detailed. Therefore, the Carestream algorithm has a positive impact in the field of medical industry. Table 1 shows a survey from the healthcare industry and H-IoT solutions.

**Table 1.** Survey on the prevailing challenges in the healthcare industries associated with the possible IoT solutions.

| S.No | Challenges | IoT Solutions | Author |
|---|---|---|---|
| 1. | Lack of smart hospitals | • IoT (Internet of Things) offers smart hospitals by utilizing connected dedicated networks as well as automation.<br>• An IoT device consists of sensors, which provide proper and relevant information about the patient's abnormalities.<br>• A smart hospital provides all information in a digitized manner and also significantly reduces the patient's waiting time.<br>• Data analysis could help day-to-day operation and aid the care of COVID-19 patients. | [78,79] |

**Table 1.** *Cont.*

| S.No | Challenges | IoT Solutions | Author |
|---|---|---|---|
| 2. | Storage of patient data (COVID-19) | • The IoT device effectively transmits, stores, and analyzes the patients' data to offer better treatment in future.<br>• This helps to analyze and check the recovery of patients.<br>• Increases awareness regarding the causes of COVID-19. | [80,81] |
| 3. | Treating COVID-19 patients | • Various clinical devices such as pumps, scales, and nebulizers are utilized to effectively monitor COVID-19 patients.<br>• IoT devices are also capable of monitoring and regulating environmental conditions such as humidity, temperature, etc.<br>• IoT devices possess real-time location services, which are utilized in the treatment of COVID-19 patients. | [82,83] |
| 4. | Lack of accurate decisionmaking | • IoT devices are beneficial in making accurate decisions as they can predict and regularly monitor patient data.<br>• Accurate surgery requires good communication, IOT technology records all data and makes quality decisions. | [84,85] |
| 5. | Improper patient monitoring | • IoT devices regularly monitor the cleanliness and infections levels in support areas and hospitals.<br>• IoT devices also monitor the proper medication and protein administration of the patients.<br>• Further, IoT devices check for improvements in the patient's condition in day-to-day life.<br>• The role of the cloud in preserving privacy. | [86–88] |

## 6. Critical Analysis

The following graph (Figure 5) provides detail about the number of papers involved in the review according to various cryptographic platforms. Numerous research papers have focused on the advantages of using blockchain technology in healthcare, yet they fail to sufficiently address the difficulties that come with its implementation, such as concerns regarding scalability, interoperability, and regulatory compliance. While many researchers have explored the potential of edge computing in the healthcare sector, few have conducted a thorough assessment of its limitations. Although edge computing can enhance the speed and efficiency of data processing, it requires significant computational power and infrastructure, which smaller healthcare organizations may find challenging to acquire. Similarly, some researchers have offered a general overview of the potential applications of AI in healthcare, but they have not provided an in-depth analysis of its limitations and ethical implications.

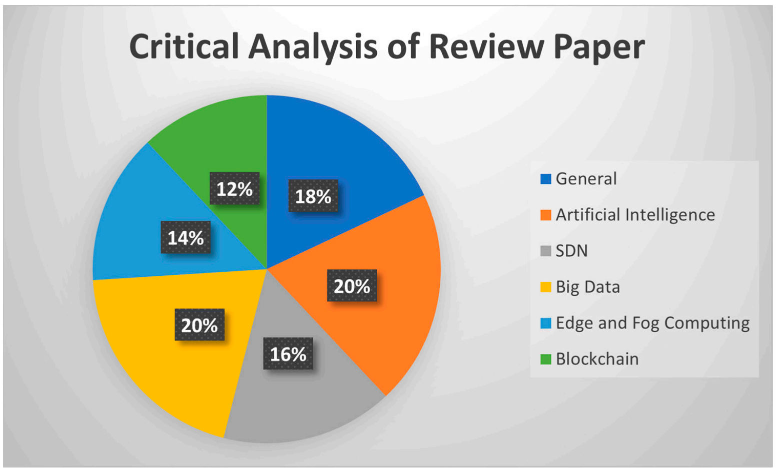


**Figure 5.** Visualization of the different aspects of IoT discussed in this paper.

## 7. Conclusions

Securing and ensuring user privacy has been considered the most important challenge for the extensive adaptation of IoT devices in healthcare systems. Several novel methods were used to enhance security, but they had certain limitations. In this work, we conducted a review of secure data accession by employing cryptographic platforms such as H-IoT in big data, H-IoT in blockchain, H-IoT in machine learning and deep learning, H-IoT in edge computing, and H-IoT in software-defined networks. We have also discussed the challenges associated with the H-IoT, along with potential applications. The paper also discusses current trends and future prospects in H-IoT, paving the way for the creation of advanced applications and solutions that augment patient care and optimize healthcare results. The solutions provided in this paper could address the discussed challenges and enable the mass adoption of reliable H-IoT devices and systems. Hence, the study recommends the need for legislative action and policies that outline frameworks designed to maintain cooperation between the legislative bodies and community of researchers in the field of H-IoT. Ensuring user security and privacy is vital for the widespread acceptance of IoT in healthcare systems, and this research paper suggests investigating the use of cryptographic platforms such as H-IoT to improve security. The paper examines the challenges and uses of H-IoT, proposes solutions for establishing a dependable H-IoT system, and emphasizes the need for legislative action and policy frameworks. It may serve as a reference for researchers interested in working with H-IoT.

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