Application of Cloud Computing in Healthcare – A Comprehensive Study

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***Abstract*—A new approach to successfully offering IT services is provided by cloud computing. The body of research implies that cloud technology can raise the quality of services across a range of sectors, especially healthcare. Before being widely used, cloud computing should indeed be thoroughly assessed, like any other technical advance. Many researchers and clinicians are interested in the availability of large, quickly available, and reconfigurable resources including virtual systems, platforms, and applications with minimal service costs. This study gives a thorough analysis of academic literature on cloud computing in the healthcare industry. To propose a categorization methodology with five different categories — Cloud-based framework development in healthcare, virtual machine placement in healthcare, cloud-based Green healthcare, security in cloud-based healthcare, and broker development in healthcare. The authors reviewed 227 articles before narrowing them down to 40. At the end some future research prospects have been highlighted.**

***Keywords*—cloud computing, healthcare service, security in cloud, broker development, green healthcare**

I. Introduction

National Institutes of Standards and Technology (NIST) defines "cloud computing" as a model for enabling ubiquitous, convenient, on-demand access to a shared pool of configurable computing resources. Cloud computing's important features are (1) self-service on demand, (2) broad network access, (3) pooling of resourceswith other tenants, (4) rapid elasticity, and (5) measured services. Resources offered by cloud computing promise advantages like scalability, flexibility, and ubiquitous access to resources at any time. The advantages of cloud computing have led to its increased adoption in many industries including the healthcare industry [1]. The opportunities in cloud computing in the field of healthcare are shown in Fig. 1.

At 57%, cloud computing has, till date, highest adaptation by the retail industry, whereas, the healthcaresector has only 31% adaptation. Percentage adaptation of cloud computing by different sectors is shown in Fig. 2.

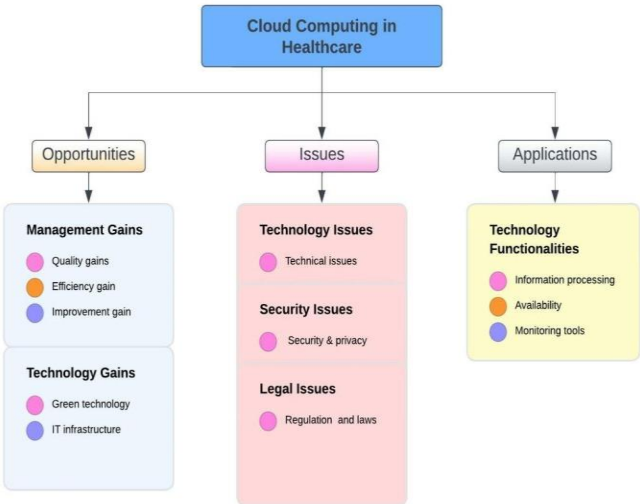

Fig. 1. Opportunities of cloud computing in healthcare industry.

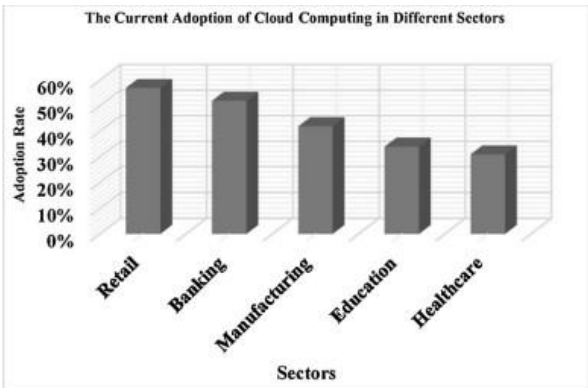

Fig. 2. Adaptation of cloud computing by different sectors (The Economist Intelligence Unit, 2015)

The trend of research publication on healthcare cloud is shown in Fig. 3. It reveals that from 2020 onward the trend is moving upward as more and more meaningful publications are coming up.

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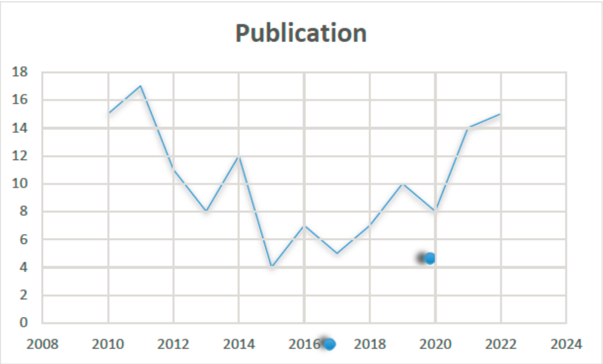

Fig. 3. Research trend on healthcare cloud computing for past one decade.

A. *Need for Cloud Computing in Healthcare*

Medical science is becoming increasingly data-intensive, leading to the generation of large amount of data that need to be stored, and accessed later. This has led to the increasing call for dynamic and scalable resources. Most of the time these data are used temporarily. Thus, keeping a permanent infrastructure is not cost-effective. In the field of medicine, data is not only complex but diverse also, leading to a challenge for storage, integration, and analysis. Cloud computing is thus a solution to the problem because it can handle the increasing volume of medical data. Electronic health records (EHRs) can be safely stored and retrieved as and when required. As the world is becoming more pollution conscious the healthcare industry is compared with other industries in terms of carbon footprint generation. One way to reduce that is to opt for Green IT using cloud computing. Cloud computing in healthcare had reached $5.4 billion in 2017 [2].

Hospitals and research centers, traditionally, conducted the computation and data storage on their own premises. Large servers needed to be maintained and the organization was responsible for its housing, maintenance, physical and cybersecurity [3]. Maintenance involved constant power supply and cooling of the servers. As application becomes complex and data generation also increases by manifolds, it leads to the purchase of moreservers. This in turn leads to the security and maintenance challenges as well.

In many studies, it has been found that medical errors are largely a result of a lack of communication and restricted access to patient records in the healthcare sector. Healthcare performance and medical errors could be improved through cloud computing, as well as service delivery, medical research, and investment. More number of publications focused on management gains than on technical gains. Management gains include lessening of healthcare expenditures, thus, enabling the organization to concentrate on other areas of healthcare needs [4]. IT canbe made more affordable with cloud computing, which reduces the need to buy or invest in physical infrastructure. Because the cloud model supports IT solutions, internal employees are no longer required to maintain IT problems, which also reduces expenditures by reducing staff and eliminating IT training. Besides cost reduction there are other benefits such as faster use, flexibility, and access by all users from any location. This eliminates the need for other service providers to modify infrastructures; data and services are more easily available in less time and as a result, the standard and swiftness of service delivery is increased [5]. Doctors' prescriptions, references, lab reports, diagnoses can all be accessed can all be accessed through cloud. This allows timely decision and more precise diagnosis along with easier scheduling of clinical appointments.

In larger organizations, cloud computing transfers responsibility for IT storage and maintenance to theirthird-party vendors, reducing costs while increasing scalability and flexibility. Existing facilities can be optimizedfor ICT and a web browser-based application can be used as an interface to cloud-based applications [6]. Since the Internet is the source through which this data is shared, it ensures portability and continuous access to all locations. With cloud services, the eHealth system can meet the IT needs of solutions multimedia, the ability to store and analyze big data and provide relevant information to public institutions. Conventional ICT systems are not environmentally friendly due to their carbon footprint. Cloud computing supports lower power consumption on a basis, making it less expensive to operate data storage facilities. Not only is energy saved, but also less materialsare needed for cooling and emissions to the environment. This is also considered to be one of the main drivers ofcloud adoption in the healthcare sector as the impact on the environment has been reduced [7].

Nevertheless, despite all of its promise, determining the true impact of cloud computing is a difficult undertaking that depends on figuring out the various aspects of its adoption and the difficulties it faces. The latterhave been found through surveys and research that reviewed the relevant literature, with the majority focusing onconcerns with privacy and data security, trust in partners and suppliers, and adherence to rules and laws [8]. Cloud computing model for the healthcare sector is given in Fig. 4.

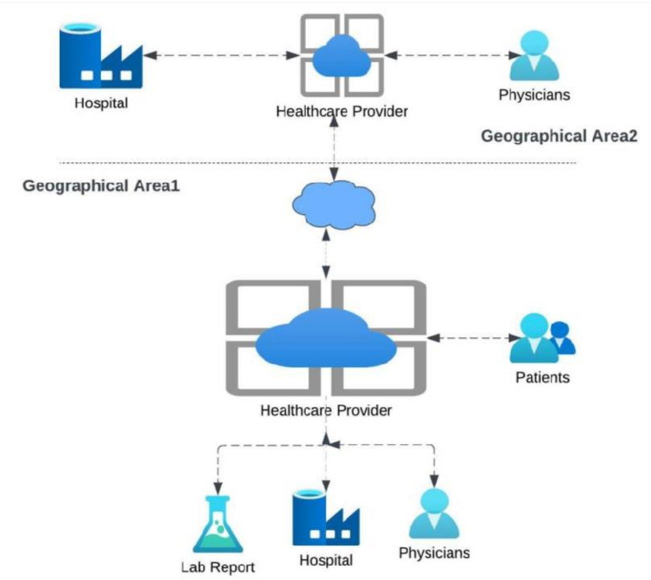

Fig. 4. General cloud computing model for the healthcare sector.

B. *Case Studies*

Some of the case studies of cloud implementation in the hospital setup are given below:

1) *Mayo clinic case studies*

In mid 2000s the staff at Mayo Clinic connected through the VPN to virtual machines. Amazon Web Services (AWS), that was launched in 2006 enabled them to adopt cloud computing. This transition ensured easier data access and power of computation. They were also able to develop and deploy novel analytical tools for research and patient care. Machine learning and deep learning-based techniques could be used for research purpose as they require higher computational power [9]. One example is the automation of Breast Cancer risk scoring tool, which, traditionally required several inputs that are dispersed among different medical records. However, the advent of the Google AI tools enabled the computation of the risk-scores on a real-time basis. In future, Mayo Clinic plansto migrate 10 million anonymised patient data to Google Cloud Platform to enable researchers worldwide to access and use the data.

2) Rush university medical center

They extract, analyze, and run all the critical patient information using all the cloud-based applications. All the unstructured data such as lab results, doctors', and radiologists' notes etc. are collected and cloud-analyzed [10]. Patient diagnosis does not only just depend on the current data, but also on the secondary or the tertiary past datathat appear in the chart of the patient (Thomas, 2022).

3) King Fahad Specialist Hospital (KFSH)

KFSH is government hospital in Saudi Arabia. The IT solutions for some of their objectives were enhancing resource consumption and availability, improving customer satisfaction, and increasing the productivities of the IT staff. Their IT strategic goals were realized by adopting a private cloud [11]. Use of private cloud allowed the customization of the existing hardware, software, and the storage. Virtualization reduced both the maintenance effort and the cost.

4) Taiwan's healthcare system

A major objective for Taiwan's healthcare system since 2009 has been the advancement of medical cloud computing technologies. Since this technology will make the creation of Electronic Medical Records (EMRs) systems easier, it has been accorded such high importance. The partnership between four institutions in central Taiwan is one such early effort to embrace a cloud-based health care strategy. In order to share imaging data and patient information throughout these collaborating institutions, they collaborated to createa cloud-based CIDC [12].

A CIDC was introduced starting in 2009 to address this issue because conventional healthcare information systems in hospitals were paper-based standalone systems that did not fully utilise digital technologies. As a result, if additional information or data analyses were required, supplemental manpower was required. Since then, Taichung Veterans General Hospital (TVGH) has established itself as Taiwan's first hospital network to fully incorporate a CIDC in all hospital units [13]. Three main benefits for the system's deployment were noted.

- By copying data less frequently, hospitals might save time and labour. Because mobile provider stations employ web interfaces, they may use browsers to operate the system from anywhere within the hospital. Additionally, this system's server and storage capacity might be virtualized. Therefore, it would be simpleto adjust the server resources and expand storage capacity if the capacities were insufficient.
- Healthcare professionals may promptly review the most recent medical advice and patient reports anywhere in the specific hospital or even remotely at other hospitals in the TVGH system without going back to individual wards [14].
- The whole healthcare team may access the medical data contained in the system.

This paper is organized as follows: Section II describes how the authors searched the literature; in Section III the results of the search, i.e. the different research works are discussed; Section IV summarizes the future research scope, and the conclusion of the work is given in Section V.

II. Methodology

The review was carried out in four phases:

- Gathering publications and research articles from different databases such as IEEE Xplore, Springer, ACM Digital Library, PubMed, Elsevier, and Google Scholar.
- A relevance screening to filter the results. The initial search by the authors found 227 articles. A primary evaluation was done by reading the abstract and excluding 47 articles based on exclusion criteria such as papers not involving healthcare, business reports, and review papers. From rest of the papers those which were published in reputed journals or conferences were retained for review.
- A review of the pertinent papers.
- Summarizing the content and finding the scope of further research.

The focus of the review encompasses the categories listed in Table 1. The keywords included in the searchingprocess were cloud computing, eHealth, healthcare cloud, virtualization in healthcare, virtual machine placement in cloud, electronic health record and telemedicine, cloud security etc.

Table 1. Categories of research work on which the study is based

Category	Focus of the research work
Cloud-based framework development in healthcare	Research works that focused on the designing of new cloud-based applications to ensure efficient use ofmedical resources.
Broker development.	Research works to develop applications for handlinglarge amount of medical records.
Security in cloud-based healthcare	Research works that deal with various privacy andsecurity related challenges in handling patient data.
Virtual machine (VM) placement in healthcare	Research works to maximize the resource usage andreduction in time in executing the medical requests.
Cloud-based Green healthcare	Research works into the saving of energy consumption due to huge data store and infrastructure

III. Results

The findings of the search are divided into five categories and they are discussed as follows:

A. Cloud-based Green Healthcare

Complexity of the healthcare technology contributes to around 8% of the carbon footprints in the US. The scenario is almost similar throughout the world [15]. Cloud computing and eHealth services are some of the recent IT technologies that are used by the healthcare industry. It was found that most of the energy consumption and carbonemission occur from patient wards and surgery areas. The best way towards green healthcare is to implement virtualization for IT data center devices such as servers, data storage, desktop etc. This is made possible by privatecloud maintained by the hospitals [16]. The virtualization techniques which reduced the number of physical servers, also brought down the cost of hardware and the carbon-dioxide footprint. It was found that virtualization reduced the power consumption by 400 watts, i.e. a cost reduction of $380 per year per server.

In virtualization, several logical machines or VMs are run by a single Physical Machine (PM) by the process of abstraction [17]. Hypervisor-based VMs were introduced to overcome the problems of sequential processing. Since, cloud virtualization makes adequate use of available resources and reduces the time required to compl777ete a task, it automatically reduces a lot in power consumption [18]. Motochi et al. noted that the hyper- visor selection process affects the power utilisation values. Also, launching the optimal number of VMs based ontheir workloads help reduce the power consumption.

B. Cloud-based Framework Development in Healthcare

Benharref *et al*. [8] proposed an eHealth system known as Service Oriented and Cloud-Based eHealth System (SOCBeS) that is able to track, monitor, and avoid any chronic disease. The system is based on Service Oriented Architecture (SOA) in cloud environment. SOA integrates heterogeneous technologies and applications to communicate [19]. The cloud environment module provides eHealth data processing, device management, and other cloud related processes. It offers IaaS, SaaS, and PaaS for implementing physical infrastructure, OS, and integration of different components of healthcare system respectively.

Multi-layer SOA-based eHealth framework was proposed by authors consisted of six modules that defined interaction among the different layers. The system, however, was never implemented practically. The framework proposed by Kart *et al*. [15] used SOA to design, implement, and manage healthcare services. Numerous devices interacted with the clinic, pharmacy, and patient-interface module of the framework. The system was used to provide home-care delivery to patients that suffered from chronic disease. The system lacked any kind of prevention services such as lifestyle adjustmentfor the patient [20].

Jung *et al*. [14] proposed a method for transmitting vital sign of the patient to the cloud using routing, resource allocation, semantic interaction, and data security. The authors of created a handheld device such as a smart phone that is used to collect ECG data of the patient and send them to the cloud where processing of the signal is done. The result of the diagnosis can be shared with the physician whois in a remote location [21]. In 2010, IBM along with the EU Consortium, developed a patient-oriented home healthcare service platform based on cloud infrastructure. It was used for remote monitoring, and diagnosis of the patients outside of hospital environment. All the patient details are stored in cloud environment and can be accessed by both the pharmacist and the clinicians [22]. Electroencephalograph, a cloud-based signal analysis systemevaluates the brain signal using machine-learning algorithms to detect epileptic seizures and other brain-related ailments. Two cloud-based telemedicine systems, SickleREMOTE and caREMOTE, were developed to provide healthcare facility to paediatric sickle-cell division patients and cancer patients respectively.

Liu *et al.* [18] developed a system called iMAGE – a three-layered hybrid cloud that was used to deliver medical image processing service to the city of Wuxi, China. Electronic medical record and medical images were received and integrated with hybrid regional healthcare network. Image processing moduleprocessed the mages in the cloud and the results were communicated to the users using the virtual desktop. Theyhad also taken into consideration the security feature [23].

Dai *et al.* [9] proposed a model for the implementation of cloud computing in bioinformatics research. Instead of downloading the data from the public sites and separately installing software tools, they proposed placing data and software into the cloud and distributing them as services such as SaaS or DaaS [24]. This would provide a lightweight programming atmosphere to help people develop modified pipelines fordata analysis.

A mobile phone application for cerebral stroke detection is suggested in this study by Garcia *et al.* [10]. It makes it possible to ascertain whether users are experiencing brain stroke symptoms. A specifiedindividual can be contacted by the programme through SMS [25]. In order to lessen the amount of time the user has abrain stroke without receiving medical attention, medical emergency is also called. Additionally, the cloud maybe used to store and analyse user demographic information to provide statistics on the frequency of cerebral strokes.

C. Security in Cloud-based Healthcare

In cloud systems, security threats present greater challenges than they do in conventional IT systems. This is especially true when public clouds are used [26]. For this reason, security is being offered as a service to help cloud service providers provide their customers with a cost-effective turnkey and hosted security solution. Other studies have shown that security and privacy are the most threatening barriers for cloud users. As cloud computing is a relatively new concept, privacy controls are still a concern when transferring applications and highly confidential data [27]. Besides cloud computing, the concept of accountability also applies to services requiring stringent security or privacy measures, especially for sensitive health-related information. Because of legal constraints and patient privacy rights due to sensitive health and medical data, the healthcare industry has stricter security needs [28]. Data protection is a recurring issue, especially when considering the possibility of someone without authorization accessing health details. Greater security precautions must be employed since it is particularly difficult to transfer such massive, highly secret material. Access management, data management, and safe storage are further securityneeds [29].

Ogiela *et al*. [25] conducted a study on intelligent data management and cloud security. Their main concern was maintaining data secrecy and protection. They applied cryptographic thresholdtechnique to fragment the secret data in a definite trustee's group [30]. An intelligent data protection scheme was developed to safeguard data against unauthorized access, and managing individual portion of the shared secret. The authors of proposed a solution using Fuzzy Analytical Hierarchy Process (FAHP) for proportionate security of network. Wu et al. worked on the strategies to ensure the security and confidentiality ofthe outsourced data. They proposed a channel-free certificate-less searchable public key authentication encryption [31].

BAMHealthCloud was proposed by authors to ensure the security of eHealth data access. They trained the system with signature samples to ensure secure data access on the Hadoop MapReduce framework using Resilient Backpropagation neural network [32]. The system not only takes care of the security access of the data but also handles the management of the huge data that is generated. Bazm *et al*. [9] addressed the challenges related to the virtualization layer isolation. The threat lies in side-channels that are created during the sharing of hardware resources in the cloud environment. VMs and containers are susceptible to attacks. The objective of the Moving Target Defence (MTD) approach is to force the cloud scheduler to migrate a malicious or victim virtualized instance to another host in the cloud [33]. This may also be applied to VM hypervisor or container-OS attacks. MTD is a promising approach for multi-cloud and decentralized cloud infrastructure.

El-Gammal encryption technique based linear network coding and re-encryption can be used to providesecurity to eHealth information over the cloud. Huang *et al.* [12] proposed an identity-based data sharing and profile matching system. This method allows clinicians who satisfy certain pre-defined conditions to authorize the cloud platform to convert the ciphertext into new ciphertext without compromising any sensitive information Muthurajan *et al.* [24] explored how the integrity and security of data transmission could be improved, based on the Elliptic Curve based Schnorr scheme. They propose a VM based cloud model with Hybrid Cloud Security Algorithm (HCSA) for signature proof creation or validation and blooming filter to avoid to remove the duplicate entry. Roy *et al.* [30] proposed a novel method to identify fine-grained data access control over multiple cloud servers in a mobile cloud computing atmosphere. This method offers a mutual approach of mutual authentication of users and fine-grained access control over the multi-server setting [34].

The swift development of cloud applications and the creation of data pose several challenges to data privacy in the cloud. Health related cloud applications the data are continuously added or updated, which requires the re-anonymizing the entire dataset from the scratch. This is a costly process. Aldeen *et al*. [3] proposed a new anonymity technique to handle the incremental dataset. They used distributed and incremental scheme for anonymizing the full-domain generalization [35].

Healthcare cloud is compromised by malware and other cyberattacks. Identity management at network edges is necessary to protect healthcare cloud computing from malware and other security concerns by ensuring that only authorized users may access the system. Additionally, systems integration makes it feasible to secure theplatform used by servers and clients [36]. Maintaining correctness and consistency of the sent data is a need for healthcare system integrity. Integration in this context refers to the claim that healthcare information in a virtual environment has not been accessed by an unauthorised user, which is a characteristic that is necessary for healthcare cloud computing. Yu *et al.* [32] suggested the sHype hypervisor security architecture to impose segregation at the level of a cloud virtual environment. It is a specific method that may segregate the sensitive and personal data for greater safety.

Ali *et al.* [6] have proposed an integrated model to manage risks in cloud services, which outlines four types of risk resolution, including stakeholder engagement, technology development, innovation planning, and control, and three types of risks, including services, technology, and process-related risks [37]. Managers may use this model to profile their risk situations and potential actions in order to benefit from innovation brought forth by cloud services.

D. Virtual Machine Placement in Healthcare

VM technology in healthcare not only saves energy and hardware cost, but also increases efficiency and security. Mejhad *et al*. [22] used particle-swarm optimization for the same purpose. Smart placement problems arise when a requested service is dynamically comprised of basic services that are deployed.The prime challenge faced by CSP is to provide dynamic and accurate resources to eHealth services according todemand. Task scheduling algorithms are needed to optimize the use of allotted physical resources. Auto-scaling mechanism can dynamically assign resources for both parallel and serial tasks in hybrid cloud environment [38]. The tasks are distributed to different available VMs. Execution deadline of the tasks was taken as a metric, based uponwhich allocation was done. However, it did not take into account the instantiation and setup time of the Roy *et al.* [30] addressed this issue by constructing a predictive model. They used a second-order Auto Regressive Moving Average (ARMA) to forecast the workload performance for the subsequent time intervals. This is known as look-ahead approach which enables new VMs to boot before the workload increases. Linear Regression model can also be used to predict the workload. This model supportsboth horizontal and vertical scaling. In horizontal scaling VMs can be added or deleted, whereas, in vertical scalingphysical resources of a VM are increased or decreased.

Ahn *et al*. [2] considered real-time eHealth application where data transmission rate varies depending upon the condition of the patient. Moving average filter predicted the future performance for scaling physical resourcesof the VM to meet the pressure of the workload. None of these systems consider the increase in usage of the service and the mobility of the patient at times that could exceed the resources allocated to VMs [39]. This might inversely affect the QoS. Rachkidi *et al.* [29] proposed a cost-effective auto-scaling method for real-time eHealth applications using Multi-site Orchestration System (MOSt++) that is implemented using Iterative GraphMapping (IGM). The system was able to fulfil the deadline of the healthcare providers 99% of the time.

VM migration itself is costly. Pushpa *et al.* [28] proposed a model that hybridizesbee colony optimization and cat swarm optimization to minimize the resource load, migration cost, and the powerutilization. An upgraded version of Genetic Algorithm was used to optimize the energy consumption of the CSPs

without compromising its availability addressed the problem of virtual machine placement in healthcare-cloud in the hospitals of Saudi Arabia, with theaim of minimizing power consumption and resource utilization. A measurement of the SLA violation rate provided the appropriateness of the QoS. To optimize the SLA violation as well, while maintaining the QoS, they used fuzzy grouping genetic algorithm. Fuzzy logic-based fitness function was used to determine the impact of different objectives on the problem. The simulation had shown a high-level performance of the model in a multi-objective scenario [40].

E. Broker Development in Healthcare

It is necessary for healthcare providers to exchange valuable information about the patients to reduce the wastage of medical resources and the cost of treatment. eHealth systems are heterogeneous with different platforms and databases. System integration is, thus, required which is the major challenge in sharing medical records between healthcare providers. Web services in cloud environment are formally deployed using the broker concept [41].

Wu *et al.* [41] proposed a novel broker approach to allow interchange of informationbetween heterogeneous eHealth systems. The broker service they developed search for healthcare services while the healthcare requesters could search for information on particular patients. Peddi *et al.* [27] developed a cloud-based eHealth application that monitored a patient's daily activities to classify the foods eaten according to calorie content. It also calculated the overall calorie content of each food with high accuracy. Gain in overall time taken to process images in the cloud was about 45%. When 60 images were processed the systemwas found to reduce the average time usage by 72% [42].

Brokering architecture in multi-cloud environment should combine relevant medical information to allow informed decision-making. Brokers installed in eHealth services might fall short of meeting such standardsdue to two crucial actions. The first includes violation of international health-data protection laws by allowing user privacy and limiting user access rights. Second is that, brokers claim to provide reliable transactions between concerned parties that rely on user feedback, a tactic prone to manipulation by mischievous users. This data security and trust issues were addressed by a system called Healthy Broker which is designed precisely for patient-centric cloud eHealth services. It allows transactions to be completed securely and access the relevant patient data as and when required in compliance with data protection laws [43]. It also identifies malicious performance by evaluating the trust relationship and tracing it using a neutral, tamper-proof, distributed blockchain ledger. T-Broker implements security-aware service brokering scheme in multi-cloud environment. A trust feedback algorithm is used for the assessment of trust. Both positive and negative feedbacks are collected to produce a global appraisal score.

As the Personal Health Records are located in the cloud, the brokering mechanism proposed by Wang etal. schedules a real-time signal between multiple hosts while transferring a minimal amount of information. Additionally, they evaluated the bandwidth of the model and compare different predicting methods to find the ideal bandwidth-allocating algorithm. Using a simulated inter-host environment, they tested the bandwidth- allocating method against various data coherence protocols that control PHR cloud domain, and the results demonstrated that the model was very effective at identifying the best-performing service. Their approach was authenticated by inserting the service.

IV. Discussion

There are currently more cloud usage data than web-related utilities. Cloud applications can provide access to multidimensional information for decision making, but the use of cloud computing to support decision making inthe healthcare sector is an area that is not well studied and justifies attention for future investigation. These additional health services may be viewed as essential support aids for health professionals, including physicians and nurses.

The authors found that the current research on cloud computing in the healthcare industry offers a relatively limited perspective of the model for delivering IT services, focusing mostly on process enhancement and cost reduction. Studies of the cloud's major prospects for the healthcare industry are done via the lenses of quality, efficiency, and technological advantages, such as infrastructure as a service. Contemporary conceptions of "service," on the other hand, emphasise creative approaches to providing clients with value. There is currently little evidence of cloud applications being used for network administration and optimization. As a result, problemswith availability and service dependability affect cloud applications. Consequently, we recommend that future study include a broader view of IT service delivery that includes service value components like scalability, reliability, and security.

Future studies should examine the advantages and difficulties of data sharing as well as the regulatory compliance of CSPs in providing these services. Recent study has emphasised the necessity for efficient privacy protections in cloud computing for the healthcare sector as a crucial factor for further research. The study by Ali *et al.* [6] lays a strong platform for future work on cloud computing potential, problems, and applications for healthcare services centred around risk management. The research focus should beon maintaining separation of responsibilities between security policy enforcement and IT operations by thinking of information security as a collection of adaptable services coupled with compliance needs and healthcare cloud architecture/design. According to Fig. 2, 2014–2016 had witnessed some fall in the cloud related research in healthcare application. This could be due to the unwillingness of the healthcare sector to implement cloud for security issues. However, since 2020 this trend has started going up again as more and more research works in cloud security are being carried out and implemented.

V. CONCLUSION

The most recent developments in cloud computing research for the healthcare industry have been covered. Numerous articles were carefully selected from the internet database and then classed into five major categories. This study provides insight into current cloud computing research and its practical use in the healthcare sector. The material reviewed for this research study provides enough support to conclude that cloud computing can present important potential for the healthcare industry. Nevertheless, given the stringent rules that regulate the healthcare industry, concerns about the security and privacy of patient data as well as the loss of control over data management must be carefully considered. Due to this, a lot of businesses are attempting to enhance and modify their patient data security policies in order to encourage confidentiality. However, integrating cloud computing for decision support in the healthcare industry is a big potential for academics and practitioners. Cloud applications can offer access to multidimensional data needed to make decisions.

COMPLIANCE WITH ETHICAL STANDARDS

The compliance is not required as the authors are not using any form of patient data.

CONFLICT OF INTEREST

The authors have no conflict of interest.

AUTHOR CONTRIBUTIONS

Anindya Bose: Conceptualization, Methodology, Validation; Visualization; Roles/Writing – original draft; Writing – review & editing. Sandip Roy: Data curation; Formal analysis. Rajesh Bose: Writing – review & editing; all authors had approved the final version.

REFERENCES

[1] Y. W Ahn *et al*., "An autoscaling mechanism for virtual resources to support mobile, pervasive, real-time healthcare applications in cloud computing," *IEEE Network*, vol. 27, no. 5, pp. 62–68, 2023.

[2] Y. Ahn, "Autoscaling method in hybrid cloud for scientific applications," in *Proc. The 16th Asia- Pacific Network Operations and Management Symposium*, pp. 1–4, 2014.

[3] Y. Aldeen, M. Salleh, and Y. Aljeroudi, "An innovative privacy preserving technique for incremental datasets on cloud computing," *J. Biomed Inform*., vol. 62, pp. 107–116, 2016.

[4] N. Alharbe, A. Aljohani, and A. Rakrouki, "A fuzzy grouping genetic algorithm for solving a real-world virtual machine placement problem in a healthcare-cloud," *Algorithms*, vol. 15, no. 128, pp. 1–17, 2022.

[5] F. Alharbi *et al*., "Strategic value of cloud computing in healthcare organisations using the balanced scorecard approach: A case study from a Saudi hospital," in *Proc. The 6th International Conference on Current and Future Trends of Information and Communication Technologies in Healthcare*, pp. 332–339, 2016.

[6] A. Ali, D. Warren and L. Mathiassen, "Cloud-based business services innovation: A risk management model," *International Journal of Information Management*, vol. 37, no. 6, pp. 639–649, 2017.

[7] M. M. Bazm e*t al.*, "Isolation in cloud computing infrastructures: new security challenges," *Annals of Telecommunications*, vol. 74, 2019.

[8] A. Benharref and M. A. Serhani, "Novel cloud and SOA-based framework for E-health monitoring using wireless biosensors," *IEEE Journal of Biomedical and Health Informatics*, vol. 18, no. 1, 2014.

[9] L. Dai *et al*., "Bioinformatics clouds for big data manipulation," *Biol Direct*., vol. 28, no. 7, pp. 1–17, 2013.

[10] L. Garcia *et al*., "An m-health application for cerebral stroke detection and monitoring using cloud services," *International Journal of Information Management*, vol. 45, pp. 319–327, 2018.

[11] N. S. Godbole and J. Lamb, "Research into making healthcare green with cloud, green IT, and data science to reduce healthcare costs and combat climate change," in *Proc. 9th IEEE Annual Ubiquitous Computing, Electronics and Mobile Communication Conference*, pp. 189–195, 2018.

[12] Q. Huang *et al*., "Secure identity-based data sharing and profile matching for mobile healthcare social networks in cloud computing," *IEEE Access*, vol. 6, pp. 36584–36594, 2018.

[13] IBM. (2010). European Union Consortium Launches Advanced Cloud Computing Project with Hospital and Smart Power Grid Provider. Zurich: ZURICH. [Online]. Available: https://www.prnewswire.com/news-releases/european-union-consortium-launches-advanced-cloud-computing-project-with-hospital-and-smart-power-grid-provider-109929104.html

[14] M. Jung, K. Han, and J. Cho, "Cloud computing or u-health and automotive environment," in *Proc. Fifth International Conference on Ubiquitous and Future Networks (ICUFN)*, pp. 495–500, 2013.

[15] F. Kart, L. E. Moser, and P. M. M. Smith, "Building a distributed e-healthcare system using SOA," *IT Professional*, vol. 10, pp. 245–30, 2018.

[16] H. Kurdi *et al*, "Healthy broker: A trustworthy blockchain-based multi-cloud broker for patient-centered eHealth services," *Electronics*, vol. 8, no. 6, pp. 1–17, 2019.

[17] X. Li *et al.*, "A trust-aware service brokering scheme for multiple cloud collaborative services," *IEEE Trans. Inf. Forensics Secur*., vol. 10, pp. 1402–1415, 2015.

[18] L. Liu *et al.*, "iMAGE cloud: medical image processing as a service for regional healthcare in a hybrid cloud environment," *Environ Health Prev Med.*, vol. 21, no. 6, pp. 563–571, 2015.

[19] J. Lu *et al.*, "Optimal machine placement based on improved genetic algorithm in cloud computing," *J. Supercomput*., vol. 78, pp. 3448–3476, 2022.

[20] S. Mejahed and M. Elshrkawey, "A multi-objective algorithm for virtual machine placement in cloud environments using a hybrid of particle swarm optimization and flower pollination optimization," Peer *J. Comput. Sci*., vol. 8, pp. 1–27, 2022.

[21] K. Modi and N. Kapadia, "Securing healthcare information over cloud using hybrid approach," *Progress in Advanced Computing and Intelligent Engineering*, pp. 63–74, 2018.

[22] C. R. Panigrahi, B. Pati, P. Mohapatra, R. Buyya, and K. C. Li, "Progress in advanced computing and intelligent engineering," in *Proc. ICACIE*, 2017, pp. 63–74.

[23] V. Motoch *et al.*, "The role of virtualization towards green computing and environmental sustainability," *International Journal of Advanced Research in Computer Engineering and Technology*, vol. 6, no. 6, pp. 851–858, 2017.

[24] V. Muthurajan and B. Narayanasamy, "An elliptic curve based Schnorr cloud security model in distributed environment," *The Scientific World Journal*, 4913015, 2016.

[25] L. Ogiela, M. R. Ogiela, and H. Ko, "Intelligent data management and security in cloud computing," *Sensors*, vol. 20, no. 12, pp. 1–10, 2020.

[26] W. M. Omar and A. T. Bendiab, "E-health support services based on service-oriented architecture," *IT Professional*, vol. 8, pp. 35–41, 2006.

[27] S. V. Peddi *et al*., "An intelligent cloud-based data processing broker for mobile e-health multimedia applications," *Future Generation Computer Systems*, vol. 66, pp. 71–86, 2017.

[28] R. Pushpa and M. Siddappa, "Adaptive hybrid optimization based virtual machine placement in cloud computing," in *Proc. 2022 4th International Conference on Smart Systems and Inventive Technology*, pp. 1–9, 2022.

[29] E. Rachkidi *et al*., "Towards efficient automatic scaling and adaptive cost-optimized eHealth eHealth services in cloud," in *Proc. 2015 IEEE Global Communications Conference*, pp. 1–6, 2015.

[30] N. Roy *et al*., "Efficient autoscaling in the cloud using predictive models for workload forecasting," in *Proc. IEEE 4th International Conference on Cloud Computing*, pp. 500–507, 2011.

[31] S. Roy *et al*., "Provably secure fine-grained data access control over multiple cloud servers in mobile cloud computing based healthcare applications," *IEEE Transactions on Industrial Informatics*, vol. 15, no. 1, pp. 457–468, 2018.

[32] A. J. Ryu, D. R. Magnuson and T. C. Kingsley, "Why mayo clinic is embracing the cloud and what this means for clinicians and researchers," *Mayo Clin Proc Innov Qual Outcomes*, vol. 5, no. 6, pp. 969–973, 2021,

[33] K. A. Shakil *et al*., "BAMHealthCloud: A biometric authentication and data management system for healthcare data in cloud," *Journal of King Saud University-Computer and Information Sciences*, vol. 32, no. 1, pp. 57–64, 2020.

[34] C. P. Shen *et al*., "Bio-signal analysis system design with support vector machine based on cloud computing service architecture," *Int. Conf. IEEE Eng. Med. Biol. Soc.*, pp. 1421–1424, 2021.
[35] M. I. Tariq *et al*., "Prioritization of information security controls through fuzzy AHP for cloud computing networks and wireless sensor networks," *Sensors*, vol. 20, no. 5, pp. 1–36, 2020.
[36] The Economist Intelligence Unit, The adoption of cloud computing in five industries. The Economist Intelligence Unit (EIU), 2015.
[37] M. Thomas. (2022). Cloud-computing. [Online]. Available: https://builtin.com/cloud-computing/cloud-computing-in-healthcare.
[38] J. Wang *et al*., "Design and optimization of traffic balance broker for cloud-based telehealth platform," in *Proc. 2013 IEEE/ACM 6th International Conference on Utility and Cloud Computing*, pp. 147–154, 2013.
[39] X. Wang *et al*., "Enabling smart personalized healthcare: A hybrid mobile-cloud approach for ECG telemonitoring," *EEE Journal of Biomedical and Health Informatics*, vol. 18, no. 3, pp. 739–745, 2014.
[40] S. J. Weng *et al*., "Cloud image data center for healthcare network in Taiwan," *J Med Syst*., vol. 40, no. 4, 2016.
[41] C. S. Wu and I. Khoury, "e-Healthcare web service broker infrastructure in cloud environment," in *Proc. 2012 IEEE Eighth World Congress on Services*, pp. 24–29,2012.
[42] J. Yang *et al*., "Workload predicting-based automatic scaling in service clouds," in *Proc. 2013 IEEE Sixth International Conference on Cloud Computing*, pp. 810–815, 2013.
[43] S. Yu *et al*.," A security-awareness virtual machine management scheme based on Chinese wall policy in cloud computing," *The Scientific World Journal*, vol. 9, no. 3, 2014.