Cloud Computing and Data Science
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Review

A Review on Architectures and Applications of Medical Imaging Cloud

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Received: 8 October 2025; **Revised:** 1 December 2025; **Accepted:** 11 December 2025

Abstract: Cloud-based medical imaging stands as a crucial aspect of cloud computing, significantly impacting the medical field. By integrating cloud computing into medical imaging, we facilitate the sharing of vital information across medical institutions, consulting centers, and educational establishments. This approach allows patients to access essential medical resources with ease, irrespective of spatial limitations. Once medical images are obtained from the diagnostic devices, they can be uploaded to the cloud. This enables the rapid retrieval and sharing of these images, ensuring they are accessible for viewing and utilization by all users. In this article, we explore diverse applied architectures for implementing cloud-based medical imaging systems and discuss their applications. Additionally, we delve into crucial aspects of medical imaging cloud requirements, such as the security and privacy of medical data, Service Level Agreements (SLAs), and Quality of Service (QoS). Addressing these concerns is paramount in ensuring the seamless and secure integration of cloud-based medical imaging systems in our healthcare landscape.

***Keywords*:** cloud computing, medical imaging, cloud-based medical imaging, medical image sharing

1. Introduction

The ongoing evolution of medical information systems, driven by advancements such as fifth-Generation (5G) mobile communications and the Internet of Medical Things (IoMT), has led to an unprecedented accumulation of clinical data, ranging from patient records to surgical information [1]. Within this data ecosystem, medical imaging constitutes a significant portion, revolutionized by advanced modalities like Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Positron Emission Tomography (PET), which provide critical spatial information for diagnosis [2]. However, this progress also brings formidable challenges, including the management of rapidly expanding data volumes and the imperative to ensure robust data security, privacy, and accessibility.

In modern healthcare environments utilizing systems such as Hospital Information System (HIS), Picture Archiving and Communication System (PACS), and Electronic Medical Record (EMR), medical images constitute 80-90% of all data, reflecting their critical role in clinical decision-making, which relies on imaging for approximately 70% of diagnoses [3]. This underscores that medical images are fundamental tools for diagnosis and treatment. Consequently, efficient and accurate medical image data processing is indispensable in clinical practice, where precise interpretation is vital for the early detection of diseases [2]. The exponential growth of medical data, with its volume predicted to double every five years, necessitates robust data center development. However, the continued reliance on Local Area Networks (LANs) and isolated PACS in many hospitals exacerbates critical limitations. These include insufficient storage capacity

DOI: https://doi.org/10.37256/ccds.7120269018

for large datasets, slow transfer speeds, and a fundamental lack of data sharing capabilities. Consequently, healthcare providers face significant challenges in storing, retrieving, and fully utilizing medical data. These infrastructural deficiencies in conventional medical imaging systems create a cascade of problems for all stakeholders, as summarized in Figure 1. For patients, this manifests as costly repeated imaging, increased examinations, and higher expenses due to inaccurate diagnoses. Medical specialists contend with a heavy workload, difficulties in image sharing, and a lack of quality educational resources. Clinics and hospitals, in turn, struggle with inefficient image management, diagnostic inaccuracies, and interoperability issues between disparate PACS, ultimately hindering effective diagnosis and collaboration.

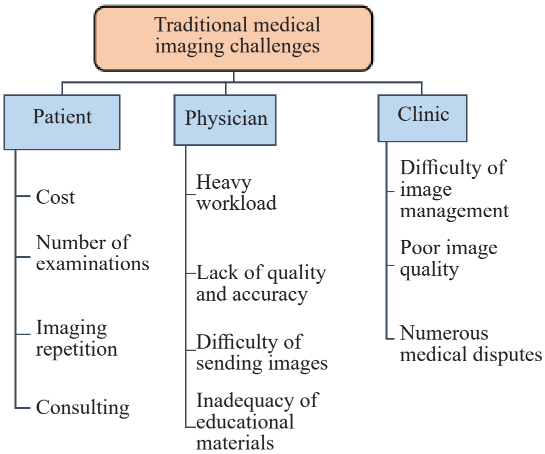

Figure 1. Challenges in traditional medical imaging systems

Cloud computing, which provides on-demand access to computing resources such as storage, processing power, and software over the Internet, offers a paradigm shift for medicine [3, 4]. This model enables the deployment of services without the burden of managing the underlying infrastructure, providing scalability and accessibility even for remote users.

Applied to medical imaging, cloud-based solutions directly address the limitations of traditional systems. In a typical cloud imaging architecture, medical images are transmitted from hospitals and imaging centers to a dedicated cloud via a local gateway or Front-End Processor (FEP). This enables authorized users, such as physicians and specialists, to access images seamlessly through the cloud. This capability facilitates remote diagnosis and consultation and is particularly transformative for multi-institutional research programs and large-scale data processing tasks in clinical medicine, overcoming previous barriers of data silos and limited computational resources.

Cloud providers deliver resources through established service models, primarily Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), and Software-as-a-Service (SaaS) [5, 6], with emerging models like Containers-as-a-Service (CaaS) also gaining relevance for medical applications [7]. It is crucial to distinguish these robust, scalable cloud paradigms from simple web-based data sharing, as their full potential is often underestimated in literature [8].

In healthcare, cloud computing is a rapidly advancing field [8, 9], with medical imaging clouds being particularly transformative. They not only enhance clinical imaging services but also serve as a foundational platform that supports the IoMT, big data analytics, and Artificial Intelligence (AI), thereby enabling a broader spectrum of medical applications. The general architecture of such a system is depicted in Figure 2. In this model, images from modalities like MRI, CT, and PET are sent to the cloud via a gateway, allowing authorized users-including physicians, patients, and students-to access and view the images from any location. This facilitates rapid retrieval and seamless sharing of medical data across institutions, consulting centers, and clinics.

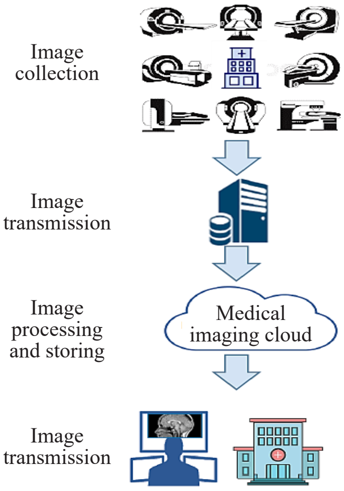

Figure 2. General concept of a cloud-based medical imaging system

The adoption of cloud services for medical data facilitates seamless sharing across medical centers, thereby expanding the resources available for patient treatment. This paradigm not only simplifies physician access to medical images but also unlocks advanced capabilities like big data analytics, IoT integration, and AI, fostering a wide spectrum of innovative medical applications. Consequently, medical image cloud services represent a critical domain within cloud computing, offering distinct benefits for all stakeholders in the healthcare ecosystem, as visualized in Figure 3.

Key advantages include enhanced inter-hospital image sharing, improved data management, access to specialized services, 3D clinical image processing, and the facilitation of scientific research. For patients, cloud services consolidate consulting, diagnosis, and treatment into a unified platform, saving time and cost while empowering them to manage their health more effectively. For physicians, these services improve diagnostic quality and accuracy, foster better patient-physician communication, and reduce medical errors, leading to increased patient satisfaction and superior care outcomes. For healthcare administrators, cloud-based systems provide a robust electronic information storage solution that enhances medical supervision, enables the study of disease patterns, and supports research initiatives.

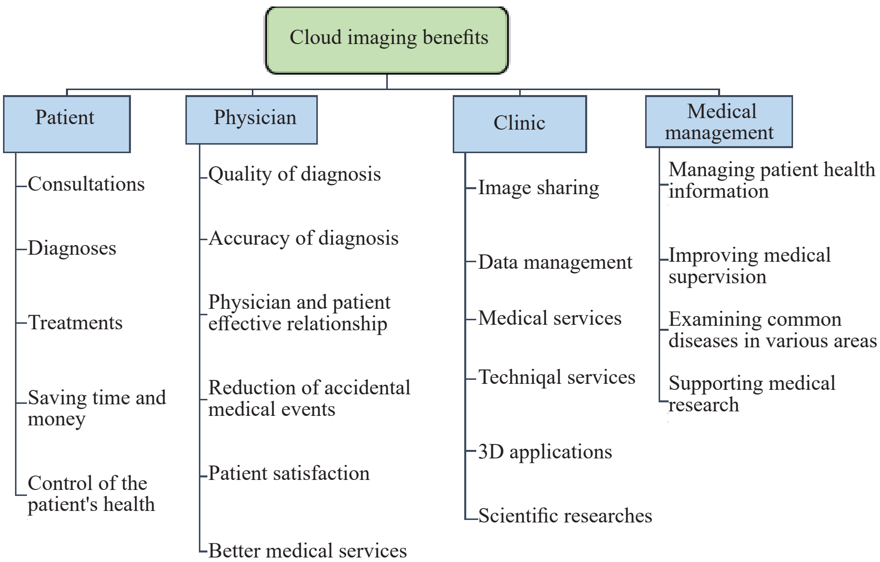

Figure 3. Benefits of medical imaging cloud for different users

A pivotal application of the medical imaging cloud is its role in enabling AI for diagnostic support. The maturation of deep learning and big data technologies allows for the development of sophisticated AI-based medical image recognition [10]. This presents a significant opportunity for automated image analysis, assisting physicians in achieving highly accurate diagnoses. As illustrated in Figure 4, this processing occurs within the cloud. This architecture offloads computational burdens from the client-side, meaning users only need to decrypt and view the processed results, thereby minimizing local hardware requirements. Furthermore, by transmitting only the essential processed data rather than entire raw datasets, this approach concurrently enhances data security.

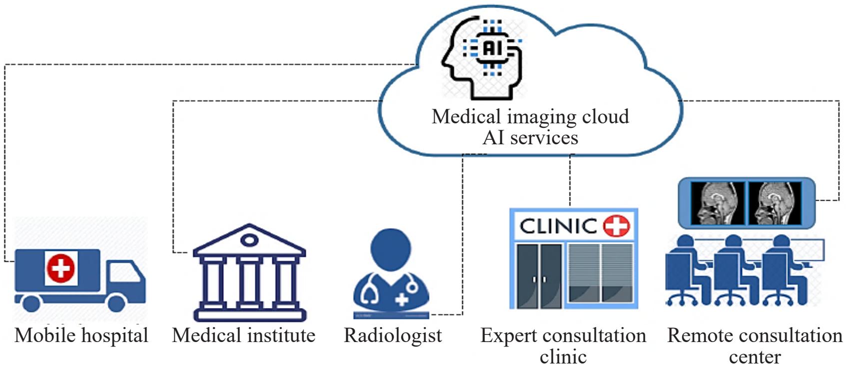

Figure 4. AI-based imaging cloud service

Furthermore, cloud-based platforms empower physicians by augmenting their diagnostic capabilities. While physicians utilize workstations for primary tasks such as image acquisition, report preparation, and consultation review, the cloud provides advanced tools that enhance image recognition accuracy. Unlike traditional methods that rely solely on a physician's expertise-a potential source of diagnostic error-cloud-based processing aids in identifying critical image features, thereby improving both the efficiency and accuracy of diagnoses.

This work presents conceptual architectures for cloud-based medical imaging and explores their applications in healthcare. The remainder of this paper is organized as follows: Section 2 reviews related work. Section 3 proposes cloud-based medical imaging architectures and services. Section 4 discusses the key requirements for implementing such a platform. Section 5 addresses future trends and research directions. Finally, Section 5 provides a summary and concluding remarks.

2. Preliminaries and related works

Information and Communication Technology (ICT) change both the world of production and services. This is especially true in the field of health, where the IoT, big data and cloud computing are revolutionizing e-health and its ecosystem, pushing it towards Healthcare 4.0 [11]. Research shows how the use of these technologies in industry 4.0 (and their integration) is changing the traditional services and products in the field of health. Therefore, many studies have been conducted in the field of e-health and the possibility of using ICT in the preservation, storage and optimal use of health data. The authors in [11] describe the main technologies and paradigms related to Healthcare 4.0 and discuss their application. In [12], the authors presented an umbrella with physical secured patient records for emergency health care sector with SaaS. The authors in [13] considered cloud-based services in the field of bioinformatics. In [8], the authors addressed the application of advanced cloud computing and bring up the main questions regarding the application of cloud computing in medical imaging. Security and ethical issues in the application of cloud computing in medical imaging were also considered. Cloud computing has significant health and research benefits that it is impossible to ignore that researchers can use the cloud to access the resources needed to conduct large-scale clinical trials involving multiple institutions. New technologies in cloud computing have aroused the interest of clinic managers, software developers and researchers to use PACS on the cloud, which aims to improve the manageability and availability of storage space. Important barriers to using the cloud pack are security, privacy, and ethics that arise from the use of cloud computing, in which the management and storage of medical information is transferred from a local organization to a publicly accessible cloud. It is also essential that appropriate measures be taken to protect the patient's private data that may be stored and processed in their systems [8]. Cloud-based hospital information service based on cloud services is discussed in [14]. In [15], the authors proposed a cloud-based medical image infrastructure consisting of compression and decompression of images with their storage and preprocessing, which were accessible through mobile imaging devices. With the proposed architecture, only one application is required on the client host, which means that the heavy burden of hardware upgrades can be reduced and the system can be made very practical for use, especially in limited resources. Authors in [16] proposed a three-layer hybrid cloud. In [17], a cloud-based system for cloud-based EMR exchange was proposed in order to share documents between the healthcare organization and the existing EMR exchange system. RESTful services were used to implement this proposed system in the Microsoft Azure cloud computing platform. In [18], cloud computing in the health care industry and the various challenges of cloud security and privacy were studied. Many security and privacy concerns for individuals and health care providers arise due to the concentration of data in the cloud. Data centralization provides information theft and data interception for attackers and transfers data ownership to cloud service providers. Therefore, there is a concern that individuals and health care providers will lose control of sensitive data [10]. Table 1 summarises the reviewed literature.

In this article, we try to propose different architectures for this topic based on the studies that have been done so far on the topics related to cloud imaging. In these architectures, all possible applications for a cloud imaging platform are considered and also important requirements in implementing a cloud imaging system are addressed.

Table 1. Summary of review literature

Reference & focus	Proposed architecture/model	Key contributions & advantages	Identified limitations & research gaps	Critical analysis & link to present work
Aceto et al. focus [11]: Introducing the "Healthcare 4.0" paradigm, exploring the convergence of Industry 4.0 technologies (IoT, Big Data, Cloud Computing) for transforming the health ecosystem.	Model: Conceptual & Survey-based. No specific architecture is proposed, but a framework for understanding technology integration is presented.	Contributions: • Provides a high-level, holistic roadmap for the future of digital healthcare. • Clearly positions cloud computing as a foundational enabler alongside IoT and big data for the next generation of health services. • Highlights the shift towards a more connected, data-driven, and intelligent healthcare model.	Limitations: • Lacks technical depth and does not propose tangible architectures or implementation details. • The discussion on medical imaging is not specific, treating it as one of many data types without addressing its unique challenges (e.g., Digital Imaging and Communications in Medicine: DICOM standards, large data volumes). • Does not address the practical barriers to adoption, such as security models or interoperability frameworks for imaging.	Synthesis & Link: This paper provides the overarching strategic context for our work. While it successfully paints the "big picture" of Healthcare 4.0, it leaves a gap in providing a concrete, implementable architecture for one of its core components: medical imaging. Our paper directly addresses this gap by proposing detailed, service-oriented architectures that translate the Healthcare 4.0 vision into a practical blueprint for the medical imaging domain.
Karthikeyan et al. focus [12]: Developing a cloud-based emergency healthcare information service for India, focusing on secure patient data access during critical care.	Model: Software-as-a-Service (SaaS) based model, described as a "physical secured umbrella" for patient records.	Contributions: • Demonstrates a practical application of cloud SaaS for a critical, time-sensitive healthcare scenario. • Emphasizes security and accessibility as non-negotiable requirements in cloud-based health data management. • Shows the potential for cloud to democratize access to vital health information in emergency settings.	Limitations: • The solution is narrowly scoped to the emergency sector and patient records, making its direct applicability to comprehensive, day-to-day medical imaging workflows limited. • The "secured umbrella" concept is described at a high level, lacking detailed architectural components for integration with imaging systems like PACS. • Does not address the scalability and storage demands of actual medical images, which are far greater than typical Electronic Health Record (EHR) data.	Synthesis & Link: This work underscores the critical importance of security and rapid access-principles that are foundational to our architectural requirements (Section 4). However, it highlights a gap in the literature: the need for cloud models that go beyond specific applications like emergencies or simple records to encompass the full spectrum of medical imaging operations. Our work generalizes and expands upon these principles to create a framework suitable for the broader and more complex domain of medical imaging.

Table 1. (cont.)

Reference & focus	Proposed architecture/model	Key contributions & advantages	Identified limitations & research gaps	Critical analysis & link to present work
Dial et al. focus [13]: Exploring the use of bioinformatics clouds for the manipulation and analysis of big data in life sciences.	Model: Survey of cloud-based platforms and tools used in bioinformatics.	Contributions: • Highlights the inherent suitability of cloud computing for handling the computational and storage challenges of big data in biomedical sciences. • Provides valuable insights into data-intensive computing paradigms that are also relevant to medical image analysis.	Limitations: • The focus is exclusively on bioinformatics (e.g., genomic, proteomic data) and does not translate findings to the field of medical imaging. • Does not discuss the DICOM standard, image-specific processing workflows, or the distinct challenges of image data management versus sequence data. • The survey does not lead to a proposed architecture for a specific domain.	Synthesis & Link: This paper reinforces the "big data" pillar of the Healthcare 4.0 paradigm mentioned in [11]. It serves as an analogous case study from a different field, validating the power of cloud computing for biomedical data. Our work leverages this validated potential but applies it specifically to the unchallenged domain of medical imaging, addressing its unique standards and workflows that [13] does not cover.
Kagadis et al. focus [8]: A foundational review addressing the application, potential, and critical questions surrounding cloud computing in medical imaging.	Model: Critical Review. It outlines conceptual challenges rather than a technical architecture.	Contributions: • One of the seminal papers to specifically and critically address cloud computing in medical imaging. • Clearly articulates the major ethical, security, and privacy concerns that arise when moving medical images from local storage to a public cloud. • Raises awareness of the need for new governance and policy models alongside technological solutions.	Limitations: • While it expertly identifies problems, it does not propose or evaluate technical solutions or architectural models to mitigate them. • The discussion remains at a conceptual level, lacking the technical depth needed to guide implementation. • The rapid evolution of cloud technology has made some of its specific technical concerns outdated, though the core ethical questions remain relevant.	Synthesis & Link: This paper is the direct intellectual precursor to our work. It effectively sets the stage by defining the problem space. We build directly upon this foundation by doing what [8] called for but did not do: proposing concrete architectures (Section 3) and detailing the implementation requirements for security, privacy, and QoS (Section 4) to address the very challenges it identified.
Yao et al. focus [14]: Proposing a Cloud-based HIS as a Service for grassroots healthcare institutions to lower the barrier to advanced IT.	Model: Service-based cloud model for delivering core HIS.	Contributions: • Demonstrates a successful model for providing complex HIS functionality to small, resource-constrained institutions via the cloud. • Highlights the economic and operational benefits of the "as-a-Service" model for democratizing access to health IT. • Proves the viability of cloud-based delivery for critical hospital operations.	Limitations: • The focus is on general hospital administration (Hospital Information System: HIS), not on the specialized and data-intensive domain of medical imaging. • It does not address the integration of PACS or other imaging modalities into its service model. • The architectural details are tailored for administrative data, not the large-file, high-throughput requirements of an imaging cloud.	Synthesis & Link: This work provides a compelling model for the service-based delivery of healthcare IT, which strongly influences our perspective on cloud services for imaging (e.g., Cloud PACS as a Service). It shows that it can be done for complex systems. Our work addresses the how, specifically for the more demanding use case of medical imaging, which was outside the scope of [14].
Arka & Chellappan focus [15]: A collaborative compressed i-cloud medical image storage system with a decompress viewer, targeting accessibility from mobile devices.	Model: Client-Server architecture with cloud storage. Focus on compression/ decompression to alleviate client-side hardware demands.	Contributions: • Directly addresses the challenge of hardware limitations on the client side, a significant barrier to adoption. • Innovates by using compression to optimize bandwidth and storage, making mobile viewing more feasible. • Presents a practical solution for remote access to medical images.	Limitations: • The architecture is relatively simplistic and does not explore broader cloud service models (PaaS, IaaS) or hybrid deployments. • Its primary focus is on storage and viewing, with less emphasis on advanced processing, multi-institutional sharing, or enterprise-grade security frameworks. • The "collaborative" aspect is not deeply explored in terms of large-scale data sharing.	Synthesis & Link: This paper offers a valuable solution to a specific part of the puzzle: client-accessibility. Our work incorporates this principle (e.g., in our discussion on mobile cloud services) but places it within a much larger and more robust architectural framework that also addresses sharing, security, AI processing, and different cloud models, going beyond a single client-server solution.

Table 1. (cont.)

Reference & focus	Proposed architecture/model	Key contributions & advantages	Identified limitations & research gaps	Critical analysis & link to present work
Liu et al. focus [16]: "iMAGE cloud": A hybrid cloud service for medical image processing to support regional healthcare.	Model: Three-Layer Hybrid Cloud (Public, Private, Data).	Contributions: • Presents a concrete, implemented example of a hybrid cloud for medical imaging, addressing real-world concerns about data locality and control. • Successfully demonstrates regional data sharing and collaboration, a key benefit of cloud-based imaging. • Moves beyond theory into practical deployment, providing valuable lessons learned.	Limitations: • The security and privacy model of the hybrid architecture is not discussed in depth. • The service model is primarily focused on processing (SaaS), with less exploration of underlying platform or infrastructure services. • The architecture is designed for a regional scale and does not explicitly scale to a national hierarchical model.	Synthesis & Link: This is one of the most directly relevant and advanced works. Our architectural proposals in Section 3 can be seen as an extension and generalization of the principles in [16]. We build upon their hybrid model by explicitly adding a hierarchical, multi-tiered structure for national sharing (Figure 17) and by providing a more thorough analysis of cross-cutting concerns like security and SLA requirements.
Wu et al. focus [17]: Implementation of a cloud-based EMR exchange system using IHE profiles on the Microsoft Azure cloud.	Model: RESTful Services on a public cloud (Azure), compliant with IHE XDS integration profile.	Contributions: • Provides a critical proof-of-concept for using international interoperability standards (Integrating the Healthcare Enterprise: IHE) within a cloud environment to ensure seamless data exchange. • Demonstrates the practical integration of healthcare standards with modern cloud API paradigms (REpresentational State Transfer: REST). • Highlights the importance of standards for achieving true interoperability in a fragmented cloud landscape.	Limitations: • The focus is on EMR documents, not on the specific handling of large-scale medical images. While images can be included as documents, the unique challenges of streaming, viewing, and processing large DICOM studies are not the primary concern. • The solution is tailored for document sharing and may not be optimized for the performance requirements of a full-fledged imaging cloud.	Synthesis & Link: This work is highly valuable for its emphasis on standards and interoperability. We adopt this critical lesson and imply its necessity for our proposed architectures. For our framework to be successful, adherence to standards like DICOM and IHE profiles is paramount. [17] proves this is feasible in the cloud, providing a methodological foundation for our work.
Al-Issa et al. focus [18]: A survey of security and privacy challenges in eHealth cloud computing.	Model: Taxonomy and Survey of security threats and challenges.	Contributions: • Offers a systematic categorization of security threats specific to the eHealth cloud domain. • Comprehensively outlines the security concerns that any cloud health implementation must address, providing a valuable checklist for developers and policymakers. • Reinforces that security is not an add-on but a core requirement.		

While the related works demonstrate the significant potential of cloud computing in medical imaging, a critical analysis reveals recurring strengths and limitations across the proposed architectures and applications. A primary strength lies in the successful proof-of-concept for specific use cases. For instance, hybrid cloud models [16] have effectively addressed regional data sharing, while SaaS-based solutions [12, 17] have demonstrated the feasibility of delivering specialized applications like EMR exchange and emergency care systems to diverse users. Furthermore, the focus on client-side efficiency through compression and mobile viewers [15] highlights a crucial strength: the cloud's ability to democratize access to advanced imaging tools by offloading computational burdens from resource-constrained endpoints. The consistent emphasis on security and privacy as foundational concerns [8, 18] is another critical strength that has shaped the discourse.

However, this analysis also exposes several overarching limitations that hinder the development of a holistic cloud-based medical imaging ecosystem. First, there is a notable tendency towards architectural siloes. Many proposals are optimized for a specific task-be it regional sharing [16], mobile viewing [15], or data exchange [17]-but lack a unified framework that integrates the full stack of cloud services (IaaS, PaaS, SaaS) with flexible deployment models (public, private, hybrid) to serve a wider range of institutional needs. Second, a significant gap exists in the quantitative justification of infrastructure. While the challenge of large data volumes is universally acknowledged, few works move beyond a qualitative description to provide a rigorous, data-driven analysis of the storage and bandwidth requirements based on real-world imaging profiles, which is essential for practical capacity planning and cost estimation. Third, non-functional requirements like Quality of Service (QoS) and Service Level Agreements (SLAs) are often underexplored. The dynamic nature of the cloud demands a more sophisticated approach to ensuring performance, availability, and reliability for clinical workflows, yet detailed discussions on KPIs and SLA negotiation for medical imaging are scarce. Finally, security is often treated as a parallel concern rather than being deeply integrated into the architectural design from the outset.

This critical synthesis underscores the need for a more comprehensive approach. It is precisely these limitations-architectural fragmentation, lack of quantitative infrastructure analysis, insufficient QoS frameworks, and a need for security-by-design principles-that the architectures and analyses presented in the subsequent sections of this paper aim to address.

3. Service based medical imaging cloud

3.1 *Cloud models*

To address the emergence of a regional health care ecosystem, physicians and surgeons in the wards and institutions of health care facilities must process medical images securely, comfortably, and efficiently, and then integrate them with EMR [16]. Three models of clouds can be considered: public, private, and hybrid. In a public cloud, cloud-computing services are provided over the Internet to a variety of users through a single service provider. In a private cloud, services are delivered by the companies to their various users via Intranet or Internet. Hybrid cloud services are provided on a hybrid infrastructure that uses both private and public clouds where the private mode is dedicated to certain aspects (e.g., data storage) and public mode is assigned for other aspects (e.g., access interfaces).

Nowadays, some hospitals and imaging centers have created a private cloud of medical imaging services in their internal networks for in-hospital applications. However, to create a public cloud system of medical images, it is necessary to complete the transition from a private cloud service to a public cloud. The process of creating a cloud service is performed by transferring from the private cloud service to the hybrid cloud service and finally to the public cloud service in three phases.

Phase 1: Hospitals and medical imaging centers create their own private clouds and transfer their systems to their own private cloud (systems such as EMR, CIS, and HIS). Then they move their PACSs to a public cloud if they wish. Figure 5 shows the connection between an in-hospital private cloud and a public cloud. However, some physicians are reluctant to do so for reasons such as the privacy of medical data, which may be overlooked, especially in scientific researches.

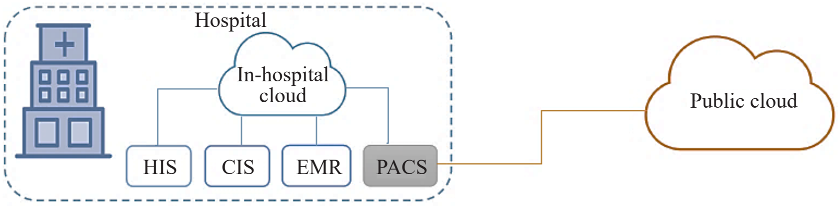

Figure 5. Connection of an in-hospital private cloud and a public cloud

Phase 2: At this phase, the private cloud is transferred to the hybrid cloud. Even large hospitals are not able to share their data with other care providers due to economic limitations or some political reasons. To overcome the limitation of sharing medical images, a hybrid cloud system is presented [19]. The hybrid cloud combines private and public systems to provide more efficient services [16]. In this case, medical collaborations are formed by sharing images between several imaging centers or hospitals. Hospitals and imaging centers hold only some sensitive medical information, and by connecting to the public cloud, they can share the rest of their information by transferring it to the public cloud. Of course, main service systems such as EMR, HIS, and CIS will be located in private clouds. Figure 6 shows the relationship between in-hospital private clouds, hybrid cloud, and public cloud. Other services such as AI and medical imaging cloud are created in the public cloud.

Phase 3: Out of hospital services, which are the main scenarios in medical applications, are gradually being transferred to the hybrid cloud and then to the public cloud. In the future, the use of the public cloud will be the main choice in medical imaging. Figure 7 shows the out of hospital services that are connected to the public cloud.

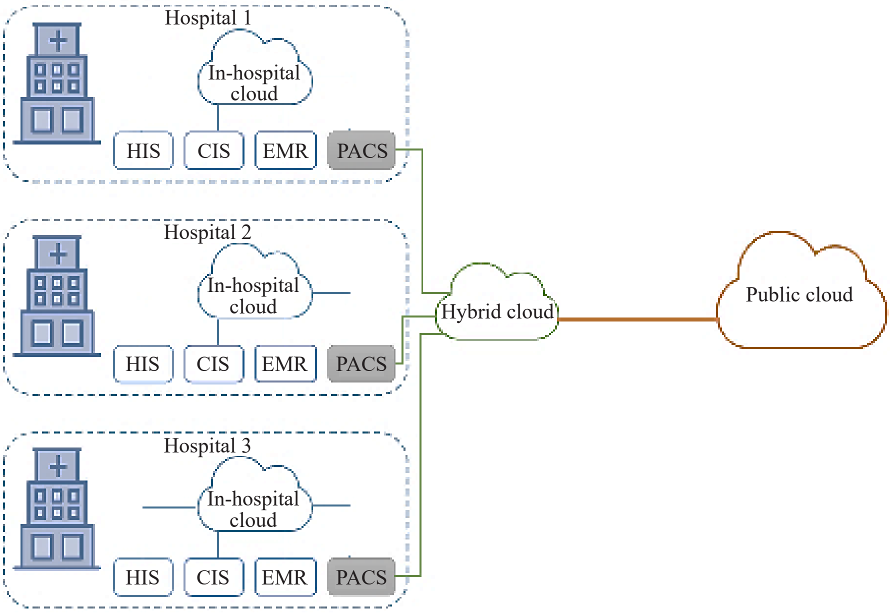

Figure 6. Relationship between in-hospital private clouds, hybrid cloud, and public cloud

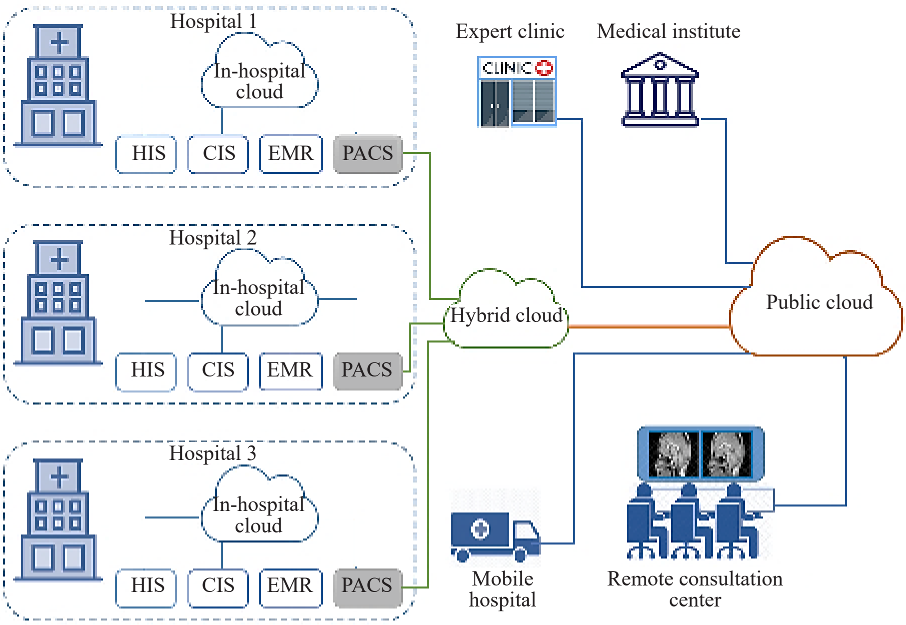

Figure 7. Providing out of hospital medical services using the public cloud

3.2 *Service based cloud architecture*

High-quality medical imaging can increase diagnostic accuracy and aid in medical decision-making and medical management guidance; however, medical imaging challenges due to resource limitations are enormous [20]. The medical imaging cloud is a perfect solution to overcome resource limitations in the medical imaging field. In this section, we will take a wide look at the medical imaging cloud benefits that are introduced as cloud services. Medical services that cloud imaging can provide in various fields of medicine are appropriate services in the field of medical imaging to hospitals, physicians, treatment control centers, and medical institutes. The users that can benefit from medical cloud services. These benefits are mentioned below:

1. Storing medical images: Storing and backing up large volumes of medical images, cloud storage and archiving of images, and emergency remote image retrieval are some of the applications of cloud imaging for storing medical images.

2. Medical imaging: Cloud imaging, cloud PACS service, 3D clinical images, mobile image viewing are some of the applications of cloud imaging in the field of medical imaging that can be used in imaging centers and hospitals, Electrocardiogram (ECG) centers, and pathology centers.

3. Medical image sharing: Cooperation between local imaging centers and imaging consulting centers is one of the applications of cloud imaging sharing.

4. Medical education: Online training of physicians, online surgery, medical tests, and a specialized pool of medical images are some of the applications of cloud imaging in the field of medical education.

5. Medical image management: Aggregation and storing of personal medical images, online consultation for medical images, and remote health monitoring, including cloud imaging applications in the field of health management.

In general, the services provided by the cloud imaging can be divided into five general categories as follows:

A. Medical image storage

Processing of large medical imaging data is profoundly challenging due to computational complexity, size of data, security, and privacy issues. In the traditional PACS disk, storage arrays are used in practical solutions. This type of storage solution is not recommended for the huge medical imaging data that requires reliable storage and timely access. An economical and technical solution is cloud computing that provides better scalability, flexibility, performance, and management. Cloud-based storage architecture for huge medical imaging data has attracted more attention in the field of health [21]. In hospitals, where the PACS do not have sufficient storage memory, the use of a cloud storage system is recommended. In this case, frequently used images are stored internally in the hospital and other images are stored in the hospital cloud system or a secondary cloud system. Two or three cloud image centers are needed to achieve a safer system. In some cases, the hospital can also deploy its cloud storage in a secondary cloud system, or in other words, a medical imaging cloud system. These modes are shown in Figure 8.

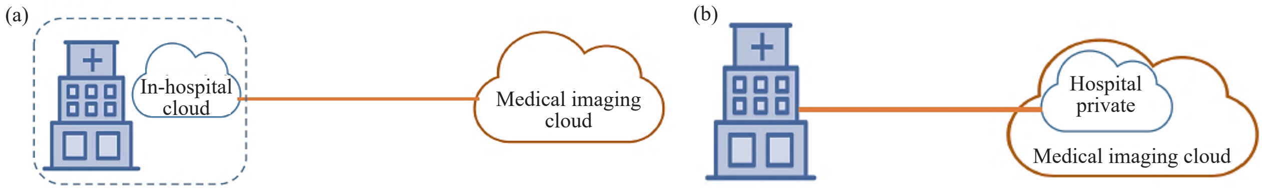

Figure 8. Relationship between hospital cloud and medical imaging cloud; (a) Connecting the in-hospital cloud to the medical imaging cloud, (b) Merging the hospital private cloud to the medical imaging cloud

Figure 8 elucidates two distinct architectural paradigms for the integration of core hospital IT infrastructure with a specialized medical imaging cloud platform. These models represent different strategic approaches to data management, accessibility, and scalability in modern healthcare IT. The first model, depicted in Figure 8a, illustrates a 'federated' or 'connected' architecture. In this approach, the in-hospital cloud and the medical imaging cloud operate as separate, independent entities. They are connected through secure Application Programming Interfaces (APIs) and robust interoperability frameworks. This connection facilitates the seamless exchange of medical images and associated data, such as DICOM files and radiology reports, between the two environments. The primary advantage of this model is that it allows the hospital to maintain direct sovereignty over its internal data and systems while still leveraging the extensive storage and computational capabilities of an external imaging cloud. It is a model that prioritizes modularity and clear boundaries between systems.

In contrast, the second model, shown in Figure 8b, represents a 'unified' or 'merged' architecture. Here, the hospital's private cloud is fully integrated and subsumed within the broader medical imaging cloud infrastructure. Rather than being two connected systems, they become a single, consolidated platform. This merger creates a holistic ecosystem where all medical data, including Electronic Health Records (EHR), Laboratory Information Systems (LIS), and medical imaging archives, can be managed from a centralized environment. The key benefits of this approach include potentially superior operational efficiency, streamlined data governance, reduced infrastructure redundancy, and enhanced capabilities for hospital-wide analytics and artificial intelligence applications, as all data resides in a unified repository. The choice between these models depends on institutional priorities regarding data control, security policy, and long-term digital transformation strategy.

However, hospitals that have developed their PACSs will increase the reliability of their data storage by storing their images in an external Disaster Recovery (DR). The data is backed up to the cloud so that it can be recovered if the hospital images are lost. External DR ensures data access and service continuity. This mode is shown in Figure 9.

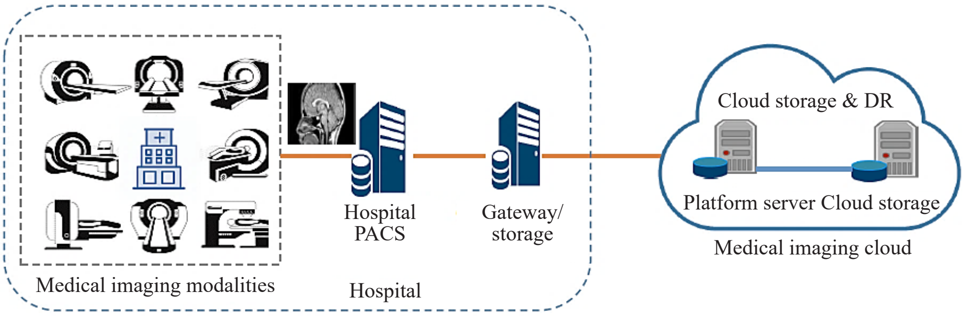

Figure 9. DR backup architecture of medical images in cloud imaging storage

In this case, users will be able to view images inside the hospital through the hospital's local network (i.e., a wired or wireless network). These images will be stored for a long time in the external DR system and through the cloud system. Figure 10 shows this concept. In general, to back up medical images, it is necessary to transfer these images from the data center of the hospitals (where the images were taken to another cloud service) to a DR or to the permanent memory provided for their storage. In addition, the PACS can be backed up. In general, backup of medical images in DR is done at two levels of data and application, and backup of the PACS is done at the application level:

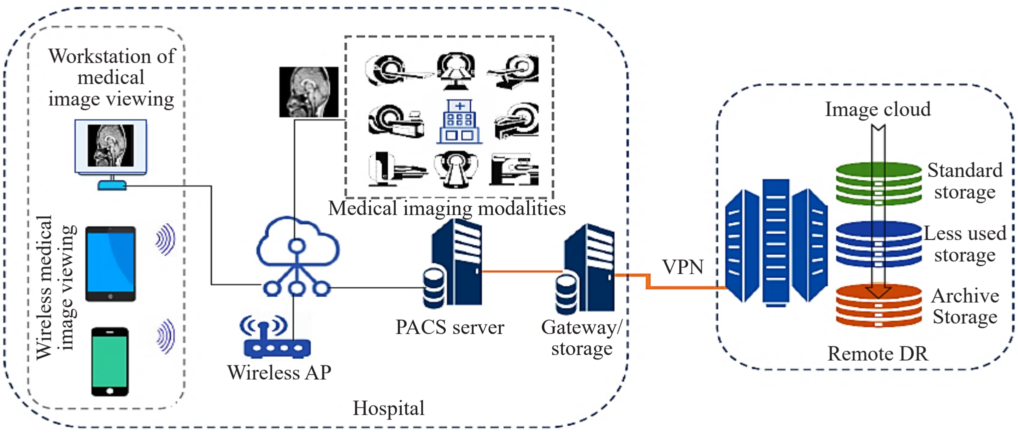

Figure 10. External DR and backup of medical images

DICOM standard defines how to store medical images onto removable media such as CD/DVD. These media replaced film printers as the primary way to store and exchange medical images between medical users. In addition, DICOM images can be loaded into PACS to be viewed, compared, interpreted, or have additional image processing. In the emergency transfer case, the CD/DVDs were sometimes taped to the patient for transport, and in some cases, the transport itself was delayed.

Medical images and diagnostic reports are in the form of electronic copies that can be shared with patients. Physicians can receive, analyze, and archive normal copies of images and diagnostic reports. So, patients do not need to print medical images or save copies of them. By the cloud imaging, patients can view and share their images anywhere and anytime.

B. Medical imaging cloud PACS

Cloud PACS is a suitable option for imaging in hospitals and imaging centers that do not have a local PACS. Also, the cloud PACS can replace local PACS and all users of local PACS can benefit from it. Cloud PACS can also allow images to be pre-processed and managed. In the cloud system, hospitals and imaging centers can share their medical images with other organizations. If an imaging center does not have a local PACS or is looking to upgrade or change it, using a cloud PACS would be a better option. Cloud PACS can be one of the most common services in health systems. When a hospital that does not have a local PACS intends to use cloud PACS, a gateway or an FEP is needed in the hospital's local network. Imaging devices such as MRI and CT send images to FEP through Digital Imaging and Communications in Medicine (DICOM) ports. DICOM protocols are used for viewing medical images and medical diagnoses using PACS [22]. Medical images are compressed and sent to the cloud by FEP. Two dedicated lines or Virtual Private Network (VPN) connections of different carriers in active / standby redundancy are used to ensure the reliability of medical image transferring. FEP is only used for uploading medical images to the cloud. To meet high-reliability, medical images should be uploaded and backed up in real-time. The architecture of the cloud PACS is shown in Figure 11.

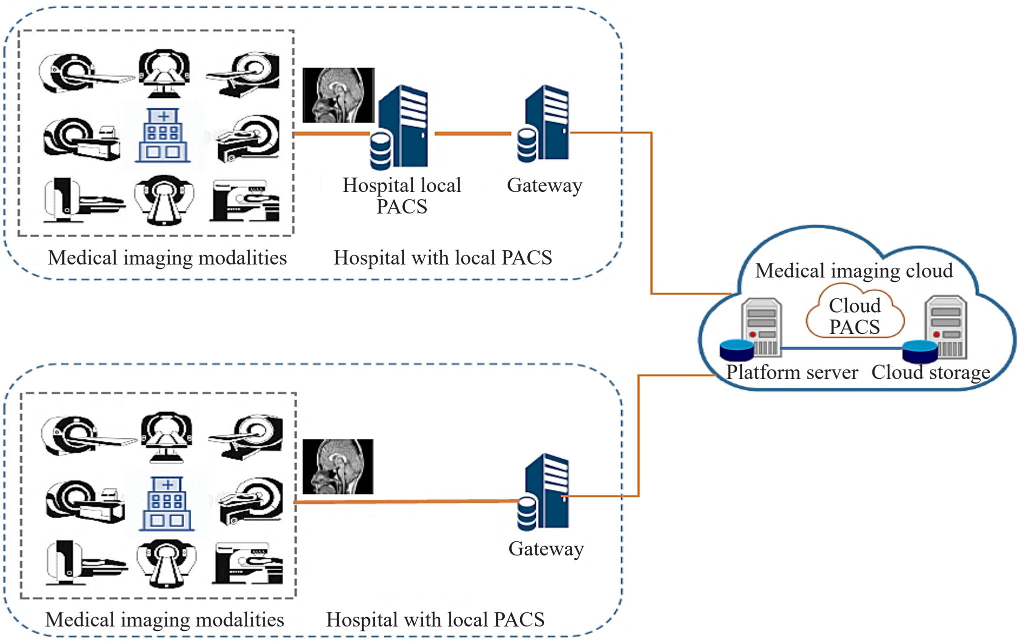

Figure 11. Cloud PACS architecture in hospitals with local PACS and hospitals without local PACS

1) Provision of imaging processing services

Second- and third-tier hospitals spend large sums of money on their local PACSs. However, some small hospitals may not prefer to spend much on their local PACSs. Therefore, such centers are very interested in using cloud-imaging services. In addition to reducing costs, payments can be made for each imaging. Moreover, all users in local systems can use the cloud PACS. The cloud system also provides pre-processing and image management services. Rural physicians may not have sufficient training to diagnose some complex medical images. General medical centers may also have imaging devices, but do not have a physician who can read the images. Therefore, it is necessary that by forming medical associations, low-level hospitals upload their images on the cloud platform so that the physicians of high-level hospitals can view them and submit their medical reports. In this case, the expertise of physicians can be widely shared in large hospitals. The medical imaging cloud can be a collaborative workspace for third-party hospitals. This service is supported by a paid charge and allows medical organizations to make progress. Operational efficiency, optimizing physician allocation, providing innovative medical services through global data analysis and monitoring services, reducing Operational Expenditure (OPEX) costs, and expanding their jobs are the benefits of this service.

2) Backup of the PACS

In addition to storing and backing up medical images, PACS can also be backed up. This application is shown in Figure 12.

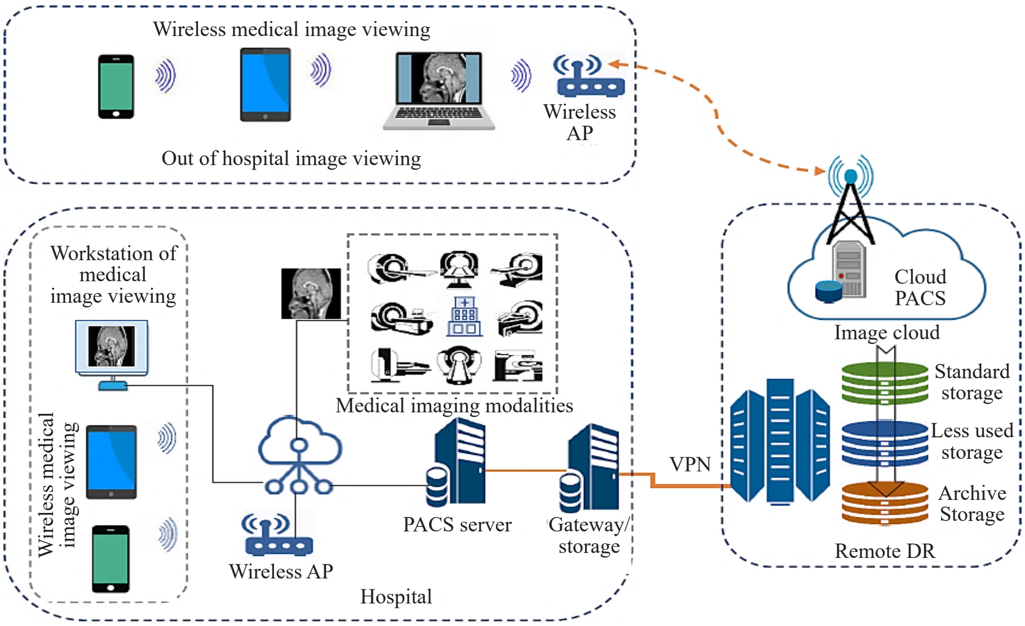

Figure 12. PACS level backup in active-active mode

3) Mobile cloud service

Physicians can view medical images or diagnostic reports anytime, anywhere, whether in hospitals (whether in the wards, operating rooms, or emergency rooms), at home, or being on the move. This is a very important issue and will be the basis for hierarchical diagnosis and remote treatment and consulting. Mobile cloud service has the following applications:

• Viewing medical images on a mobile smartphone is possible at any terminal, any place, and any time.

• Physicians can view medical images in real-time and provide treatment recommendations remotely.

• In emergency conditions, physicians may need to consult a physician who is not in the hospital. It should be noted that emergency guidance for low-level hospitals, which can be done via the Internet and the cloud platform, could reduce patient mortality.

C. Medical image sharing

The geographical scope of medical information exchange activities points to some of the following limitations: 91% of organizations stated that local exchange of medical data is somewhat active, but at the regional level, the rate of medical information exchange reaches 79%. At the national level, the rate of medical information exchange includes only 7% of organizations that can have a full exchange (47% have minor capabilities). At the interstate level (i.e. at cross-country level), unsurprisingly, no organization reports that it has strong capabilities for exchanging images with other organizations; however, a small number (19%) indicate having at least such abilities. Only 36% of participating organizations make a diagnosis [23]. Today, cloud-supported IoT is widely deployed in intelligent medical systems. In this way, the limitations of IoT-related medical devices in terms of data access, storage, scalability, and computing are solved using cloud computing architecture. However, with the rapid development of medical equipment and the increasing amount of medical equipment, it will be very difficult to plan or manage such an extensive IoT system in conventional single cloud systems [3].

By creating a pyramidal structure, medical image data can be shared at different levels, from local hospitals in cities, provinces, regions to the national centers. Briefly, a hierarchical structure of medical imaging clouds can be created from city/town centers, province centers, regional centers, to national centers with the goal of publicly sharing medical images, such as those shown in Figure 13.

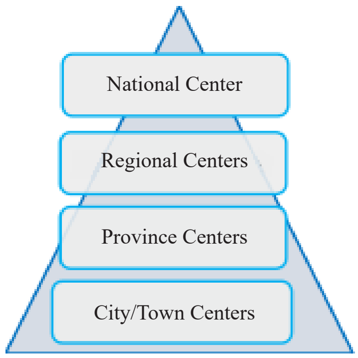

Figure 13. Hierarchical structure for sharing medical images

Figure 13 illustrates the proposed multi-tiered hierarchical architecture for efficient and scalable sharing of medical images across a national healthcare system. This model is designed to optimize data flow, reduce latency, and manage network load by distributing storage and access responsibilities across different administrative levels.

At the apex of the hierarchy is the National Center, which acts as the central repository and governance body. It stores a master index of all studies conducted nationwide and is responsible for setting overarching data standards, security protocols, and interoperability frameworks. Beneath it, Regional Centers serve as major hubs, aggregating and managing image data from multiple provinces within a large geographic area. This tier facilitates large-scale regional collaboration and data analytics. The Province Centers form the core operational level, handling the image data generated by major hospitals and healthcare facilities within a specific province. This localization ensures that most data requests within a province are served quickly without relying on national-level infrastructure. Finally, City/Town Centers represent the edge of the network, providing low-latency access to medical images for local clinics, diagnostic centers, and general practitioners. This hierarchical structure ensures that a patient's medical images are accessible to authorized providers at any level while ensuring that data requests are routed to the nearest available copy, thereby enhancing the speed and reliability of clinical decision-making, especially in time-sensitive situations like teleradiology or emergency care.

According to the requirements and technical specifications for the construction of remote information systems, the architecture of the remote network should consist of the following layers: urban medical centers, provincial centers, regional centers, and national centers. The pyramid structure for public access to cloud imaging services can be defined based on the geographical division into four layers. Based on the structure, different hospitals in cities are connected to local urban imaging clouds and medical images are shared between them. In the next layer, the cloud imaging system of the cities of a province is connected to the imaging cloud of that province, and in the third layer, the imaging clouds of several provinces, which are covered by a region in the form of a regional division, are connected to the regional imaging cloud. Finally, in the last layer of the cloud imaging structure, the regional imaging clouds are connected to the central cloud, or in other words, the national cloud, and thus the sharing of medical images at the national level will be hierarchically realized.

1) Regional imaging centers

Medical Imaging centers are mainly in the category of health care regulators and medical groups. Based on cloud computing, cloud centers implement the following functionalities: regional medical imaging, high-resolution medical image processing, centralized medical image storage, image analysis and sharing, fast data retrieval, and medical images search for big data. Imaging centers use the information and imaging services of all medical equipment to ensure the participation and cooperation of imaging modalities and specialists in the region and to support remote image reading and diagnostic reports. They also achieve a balance in the allocation of medical resources, improve diagnostics in public hospitals, improve the use of imaging modalities, and efficiency of medical services.

2) Remote imaging centers

Remote imaging centers perform medical image viewing and diagnosis in public hospitals. In this way, medical images information can be shared and managed between hospitals. There are three modes for these services:

a) With remote diagnosis for public hospitals, internal medicine institutes, and specialists can participate in remote diagnosis.

b) Medical institutes upload low-level imaging data on a cloud system so that it can be read through the remote imaging center in the central hospital.

c) Imaging and centralized diagnosis in-group hospitals, which are designed to avoid double costs and improve the use of medical resources to perform centrally.

3) Third-party imaging centers

In third-party imaging centers for small hospitals that may not have enough physicians and resources, a medical diagnosis of images can be done remotely.

4) Remote imaging consulting centers

Telemedicine imaging consulting refers to an IT-based telephony face-to-face consulting between specialists, patients, and medical staff. A telemedicine consulting center can provide interregional health cooperation and specialist consulting by improving the quality of diagnosis in public hospitals.

Multidisciplinary Treatment (MDT) is a process for discussing, performing, and diagnosing patients performed by the senior multidisciplinary specialists. The MDT patient information is included in the medical imaging data especially for the diagnosis of complex diseases. Prior to treatment, specialists in the relevant departments conduct an evaluation through the cloud-imaging platform to come up with a common, scientific, sensible, and logical treatment solution. Remote medical centers are connected to secondary and tertiary hospitals, health care centers, and ambulances through private digital lines, Multiprotocol Label Switching (MPLS) VPN, Internet, and satellite.

D. Medical image training and researching

Medical imaging training facilities (hardware and software) in most colleges have not progressed with rapid medical imaging developments, while PACS technology is evolving. Therefore, the use of PACS for medical training still has some limitations, such as medical information compatibility, and collaboration with the hospital. Universities can teach in this field by creating a cloud-imaging platform. This implementation of online education and clinical applications in real-time ensures data consistency and a variety of new information. Moreover, professors, medical students, and hospitals can directly communicate with each other.

E. Medical image remote services

With the creation of the cloud system, health care and consultation can be established through communication with physicians. With the help of physicians, people can manage and improve their health information about diseases, medical images, and medical experiments that are managed over the cloud by health consultation, medical planning and also follow-up prescribed medical instructions. Cloud-based remote imaging services are shown in Figure 14.

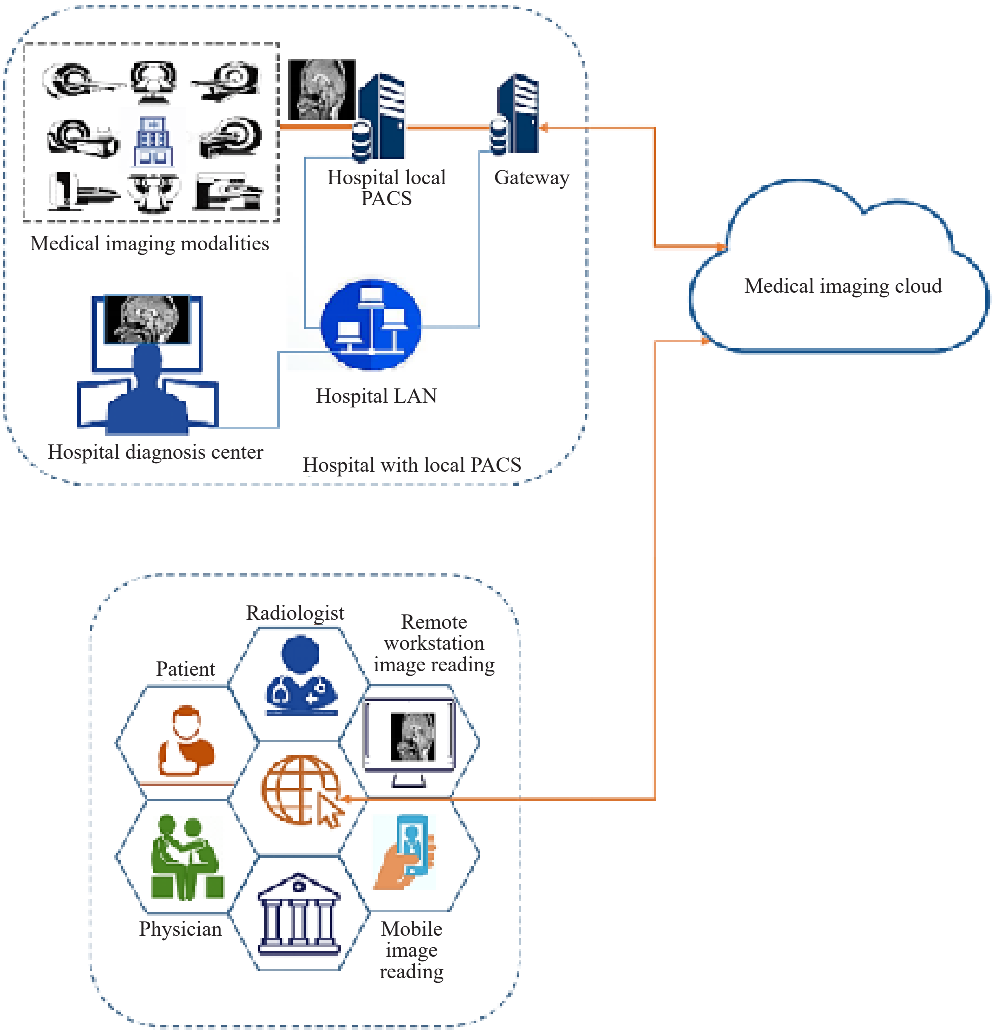

Figure 14. Cloud-based remote imaging services

Medical imaging data can be presented to physicians, nurses, and medical students. Medical image processing researchers with live or televised training, as well as attending medical conferences can deliver medical courses, give lectures, exchange academic views, view surgery, and simulate them. This will promote medical image sharing as medical education resources, reduce national medical education costs, and improve medical skills across the country. Currently, colleges are moving from traditional screen-based to online course teaching, PACS training, and the establishment of digital simulation centers for medical imaging. Some colleges have attached their PACS to hospitals or medical imaging centers. So, medical college online exams can be attached to the hospital PACS. The education system of hospitals in such a way allows students to experience the hospital work environment. Remote consulting in cloud-based medical imaging is shown in Figure 15.

Of course, it should be noted that mobile devices can not have high-performance hardware like workstations and desktops, so that mobile subscribers can make full use of PACS resources. In addition, the increase in CPU and memory power in PCs usually has little effect on their performance for medical cloud imaging because web browsers have a limited license to allocate computing resources and low performance of client script code. Therefore, research has been done in this field to increase the efficiency of customer software so that users with low-performance devices are more efficient and appropriate [24].

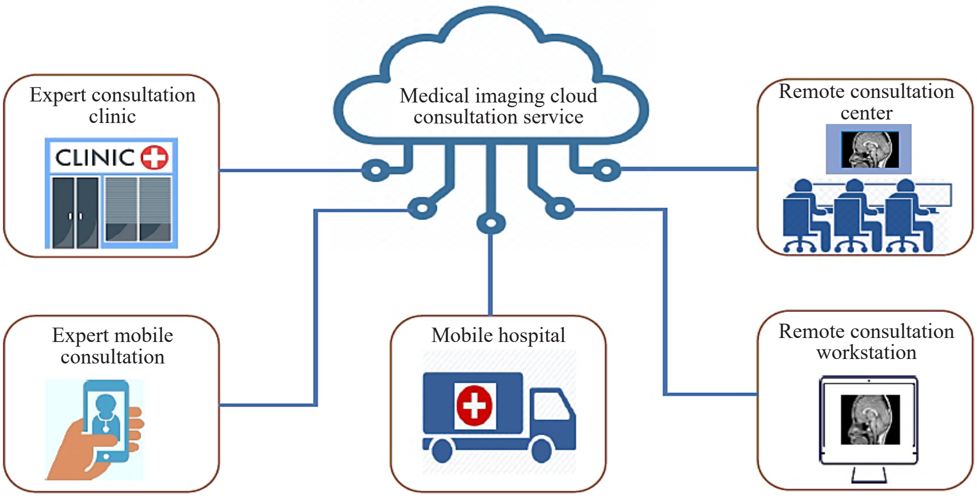

Figure 15. Remote consulting in cloud-based medical imaging

4. Requirements for implementing medical imaging cloud

The medical imaging industry is expected to evolve with the cloud technology. Cloud computing has many benefits, perhaps the most important of which is sharing medical images and retrieving them quickly. However, it should be born in mind that data centralization allows attacking data to steal and intercept data, as well as transferring data ownership to cloud service providers. As a result, individuals and health care providers lose control of sensitive data. As a result, security, privacy, efficiency, and scalability concerns preclude widespread adoption of cloud technology [25]. Some frameworks for the secure encryption of healthcare images are presented by researchers [26].

4.1 *Security requirements*

The use of low-reliability clouds creates security problems for medical data. Medical records and medical images include the medical privacy of patients who may be exposed to data security threats. Therefore, a safe approach to patient privacy is needed [27]. The security requirements for implementing a medical imaging cloud system can be classified into four layers: a) network security, b) host security, c) application security, and d) data security. These classification and security requirements are shown in Figure 16. In general, the security requirements in a medical imaging cloud include all the essential requirements of a cloud system.

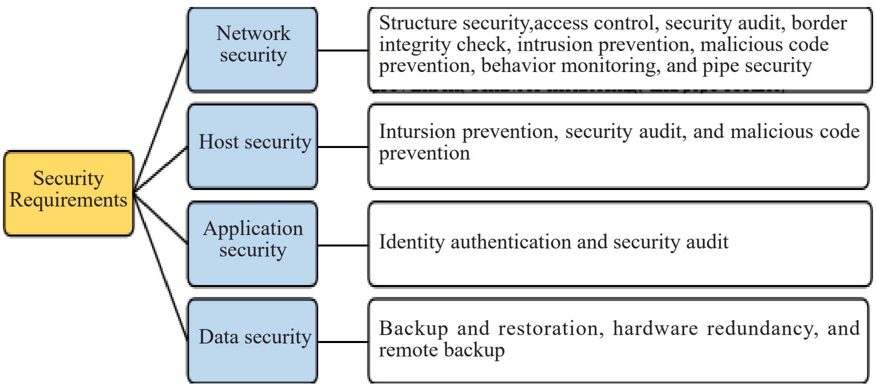

Figure 16. Security requirements for creating a medical imaging cloud

While the foundational security requirements for a medical imaging cloud can be classified into the four layers of network, host, application, and data security (as shown in Figure 16), a deeper analysis of specific threats and modern countermeasures is warranted given the sensitive nature of medical data.

Potential threats and threat models: Beyond generic cloud security concerns, medical imaging clouds face unique threats. These include:

Insider threats: Malicious or negligent actions by employees of the Cloud Service Provider (CSP), who may have privileged access to the infrastructure housing sensitive patient data.

Data interception in transit: Eavesdropping on data as it moves from hospital networks to the cloud, especially over public internet links, despite the use of VPNs.

Multi-tenancy Risks: The architectural model of cloud computing, where resources are shared among multiple hospitals (tenants), creates a potential attack surface for data cross-contamination or leakage if isolation mechanisms fail.

API vulnerabilities: Many cloud services are accessed via APIs. Insecure APIs can be exploited to gain unauthorized access, manipulate data, or launch denial-of-service attacks.

Data remanence: The lingering presence of sensitive data on storage media even after it has been supposedly deleted, posing a risk when storage resources are reallocated to a new tenant.

Existing solutions and advanced countermeasures: To mitigate these threats, a layered security approach is necessary, building upon the foundational layers:

Data security: Encryption is non-negotiable. Data must be encrypted using strong standards like AES-256, both at rest and in transit (e.g., using TLS 1.3). For more advanced use cases, Format-Preserving Encryption (FPE) can be employed to allow certain operations, like routing based on DICOM tags, to be performed directly on encrypted data without decryption. Homomorphic Encryption (HE), which enables computation on encrypted data, represents a promising future direction for allowing third-party researchers to analyze data without ever seeing it in plaintext, thus preserving patient confidentiality.

Access control and audit: Moving beyond simple role-based access, Attribute-Based Access Control (ABAC) provides fine-grained policies based on user attributes, resource properties, and environmental context (e.g., "A radiologist can only access MRI studies from the hospital they are affiliated with, during their shift hours, and from a registered workstation"). Furthermore, leveraging blockchain technology or immutable logs for access auditing creates a tamper-proof record of every data access event, providing full transparency and enabling forensic analysis in case of a security incident.

Infrastructure and application hardening: The principle of Zero-Trust Architecture (ZTA)-"never trust, always verify"-should be adopted. This involves implementing mutual TLS (mTLS) for service-to-service authentication within the cloud and mandating regular, independent security penetration testing and vulnerability scanning of all cloud-facing applications and interfaces.

Future directions and challenges: The evolving landscape presents new security challenges. As AI becomes integral to diagnosis, securing the AI models themselves-protecting them from poisoning, extraction, or inversion attacks-is crucial. Furthermore, the tension between data utility for large-scale research and the imperative of patient privacy requires continued innovation in Privacy-Enhancing Technologies (PETs) like differential privacy and secure multi-party computation. Finally, the adoption of formal certifications like Health Insurance Portability and Accountability Act (HIPAA), General Data Protection Regulation (GDPR) compliance, and Health Information TRUST Common Security Framework (HITRUST CSF) can provide a structured framework for managing security and privacy risks, building trust among healthcare providers and patients alike.

4.2 *Network communication infrastructure requirements*

A. Required bandwidth and storage

Although different modalities such as MRI and CT-Scan used in medical imaging centers produce images with different specifications, all of them are produced according to the DICOM protocol. The profile of medical images in some modalities is listed in Table 2.

Table 2. Profile of medical images of different modalities

Modality	Typical image matrix			Image size (MB)	Study count	Study size (MB)
	Height	Width	bit/Pixel			
Magnetic Resonance (MR)	256	256	16	0.131	60-3,000	7.86-393
Computed Tomography (CT)	512	512	16	0.524	40-3,000	20.96-1,572
Digital Mammography (MG)	4,608	5,200	14	45.7	1	45.7
Ultrasound (US)	512	512	8	0.262	20-240	5.24-62.88
Computed Radiography (CR)	3,520	4,280	12	30	2	60

Table 2 provides a critical profile of medical images across common diagnostic modalities, highlighting the significant variations in data characteristics that directly impact storage and network infrastructure requirements. The table details the typical image matrix (height and width in pixels), bit depth, the resulting single-image size, and the extrapolated size for an entire study. For instance, the data reveals a stark contrast between the relatively modest sizes of single MR and CT images (0.131 MB and 0.524 MB, respectively) and the substantial size of a single Digital MG image (45.7 MB). This disparity is primarily driven by the high spatial resolution required for Digital MG, as evidenced by its large 4,608 × 5,200 pixel matrix. However, the most critical factor for system design is the total study size. While a CT image is only 0.524 MB, a study comprising 3,000 slices resulted in a massive 1.57 GB dataset. Similarly, an MR study can reach up to 393 MB. This underscores that modalities like CT and MR, which generate numerous images per examination, present a 'volume challenge,' whereas modalities like MG and CR present a 'density challenge' due to the large size of each individual image. Understanding this profile is fundamental for designing cloud-based archives, calculating network bandwidth for telemedicine, and planning the computational resources needed for large-scale data processing and artificial intelligence applications.

To send medical images on the network, due to the large size of medical images in different modalities, it is necessary to have a suitable bandwidth to minimize the time taken for sending images from hospitals to the PACS server in the imaging cloud so that the images are uninterruptedly accessible. By compressing medical images, important resources such as bandwidth and memory can be used optimally. The compression of medical images must be in accordance with the Diocese protocol. Todays, some common compression formats are presented for medical images using the DICOM standard [28]. Private line bandwidth should be calculated based on hospital statistics such as working hours a day and the peak traffic volume. Table 3 shows the transmission time of medical images on the network based on the network bandwidth.

Table 3. Required time for sending images in the network based on the type of medical images and network bandwidth

Modality	Study upload time taken (sec) for different BWs					Study size (MB)
	1 Mbps	2 Mbps	4 Mbps	8 Mbps	10 Mbps	
MR	62.88-3,144	31.44-1,572	15.72-786	7.86-393	6.29-314.4	7.86-393
CT	167.68-12,576	83.84-6,288	41.92-3,144	20.96-1,572	16.77-1,257.6	20.96-1,572
Digital MG	365.6	182.8	91.4	45.7	36.56	45.7
US	41.92-503.04	20.96-251.52	10.48-125.76	5.24-62.88	4.19-50.30	5.24-62.88
CR	480	240	120	60	48	60

An important point to consider when implementing a network infrastructure is the storage required to store images on the cloud PACS server. The amount of storage required depends on the number of medical images taken per day by different modalities. If we classify hospitals based on the number of hospital beds into three categories (small, medium and large) , assuming the average number of images taken per day by different modalities, the amount of storage required in the imaging cloud server per day and per year can be estimated based on Tables 4 and 5, respectively.

Table 4. Storage required for daily storage of medical images

Modality	Range of study sizes (MB)	Average study size (MB)	Small hospital (50 Study per day)	Medium hospital (100 Study per day)	Large hospital (150 Study per day)
			Average required storage per day (GB)	Average required storage per day (GB)	Average required storage per day (GB)
MR	7.86-393	200	10	20	30
CT	20.96-1,572	796	40	80	120
Digital MG	45.7	45.7	2.3	4.6	6.9
US	5.24-62.88	34	1.7	3.4	5.1
CR	60	60	3	6	9

Table 5. Storage required for annual storage of medical images

Modality	Average study Size (MB)	Small hospital (50 study per day)	Medium hospital (100 study per day)	Large hospital (150 study per day)
		Average required storage per year (TB)	Average required storage per year (TB)	Average required storage per year (TB)
MR	200	3.6	7.2	10.8
CT	796	14.4	28.8	43.2
Digital MG	45.7	0.8	1.7	2.5
US	34	0.61	1.2	1.8
CR	60	1.1	2.2	3.2

Table 5 provides a critical projection of the annual storage capacity required to archive medical images, quantifying the infrastructure burden based on hospital scale and imaging modality. The calculations are derived from the average study sizes detailed in previous analyses and model three distinct hospital tiers based on daily study volume. The data reveals a striking disparity in storage demands across different modalities. CT emerges as the most storage-intensive modality, requiring a substantial 14.4 to 43.2 Terabytes (TB) per year, directly resulting from its large average study size of 796 MB compounded by high daily volumes. Similarly, MR studies, with a 200 MB average size, necessitate significant storage, ranging from 3.6 to 10.8 TB annually. In contrast, modalities like Digital MG, US, and CR, while often producing large individual images, generate less data annually due to fewer studies performed per day and smaller average study sizes, as seen with MG (45.7 MB). The table powerfully illustrates how scaling from a small to a large hospital can more than triple the storage requirements for high-volume modalities like CT and MR. These figures have profound implications for IT budgeting, the selection of on-premise storage solutions versus cloud-based archives, and long-term data retention strategies. Furthermore, this analysis underscores the necessity for scalable, cost-effective, and robust storage architectures in modern healthcare, where the accumulation of imaging data is relentless and critical for patient care, legal compliance, and secondary use in research.

B) Acceptable level of service in the medical imaging cloud

Currently, most cloud computing service providers only offer public Service-Level Agreement (SLA) to best guarantee QoS features such as bandwidth and data backup. SLA is a very significant factor for using cloud services and customers need it completely to avoid risks and get the QoS as they want. Due to significant changes in customer needs, a negotiation process must determine SLAs separately. Because medical images are recovered frequently, they must be recovered within a short time without any significant delay to meet the needs of reading medical images in the cloud. The required bandwidth should be determined based on the number and type of medical image reading terminals and the average size of medical images. For example, if a typical hospital has 50 medical image reading terminals and the average medical image loading speed is 8 Mbps with 25% reserved bandwidth margin, then the required bandwidth is 500 Mbps. Also in mobile systems, mobile imaging improves the performance of physicians and ensures on-time and effective consultation. This requires a reliable and stable network that covers all work areas to prevent interruptions. Approved SLAs serve as a basis for QoS compliance. Due to the dynamic nature of the cloud, QoS features must be constantly monitored and managed. Key Performance Indicators (KPIs) are used to describe QoS [29]. The purpose of this section is to provide different KPIs for cloud SLAs to facilitate cloud services. Although much research has been done on SLA formats, the content of SLAs leaves another field for research. Due to the fact that SLAs always contain specific scenarios, it is difficult to generalize about their content. KPIs as the main components of Service Level Objectives (SLOs) are increasingly presented in KPI libraries. Extensive knowledge of the service and how to use it is necessary to select the right KPIs for a service. To provide more insights into specific cloud KPIs, the most common ones are summarized in Figure 17 without elaborating further. Since specific service requirements do not differ much from other public services, therefore medical imaging cloud KPIs may overlap with some conventional KPIs.

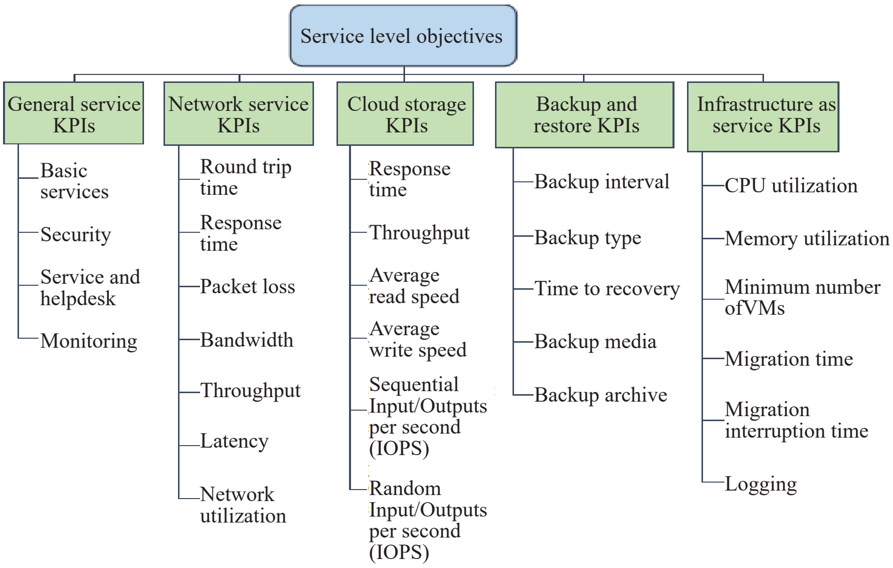

Figure 17. KPIs used in the cloud systems

4.3 *Discussion*

The landscape of cloud-based PACS is rapidly evolving, driven by technological advancements and emerging clinical needs. Several promising research directions can be identified that build upon current architectures while addressing their limitations.

The standardization of diverse imaging formats represents a critical foundation for future systems. As demonstrated by Gupta et al. [30], the “DICOMization” of proprietary files from advanced imaging modalities like confocal, whole-slide, and Focused Ion Beam-Scanning Electron Microscope (FIB-SEM) microscope scanners enables seamless integration into unified archives. This approach facilitates the consolidation of imaging data across specialties, from pathology to materials science, creating comprehensive patient records and research datasets. Future research should focus on developing automated, real-time DICOM conversion pipelines that can handle increasingly complex multi-modal data while preserving essential metadata.

Building upon this standardized data foundation, cloud architecture design continues to evolve toward more sophisticated implementations. Kawa et al. [31] highlighted key considerations in designing and implementing cloud PACS architectures, emphasizing the importance of scalability and interoperability. Future research should explore dynamic resource allocation algorithms that can automatically adjust computing resources based on real-time workload patterns, particularly for handling large-volume studies from modalities like CT and MRI. The integration of serverless computing paradigms could further optimize resource utilization while maintaining performance guarantees.

The management of application state in distributed environments presents another crucial research direction. Szalay et al. [32] investigated state management for cloud-native applications, addressing challenges related to consistency, availability, and partition tolerance. Future cloud PACS architectures must develop sophisticated state synchronization mechanisms that maintain consistency across distributed components while ensuring high availability for clinical users. Research into conflict resolution strategies for concurrent access and editing of medical images would be particularly valuable for supporting collaborative diagnostic workflows.

Artificial intelligence is revolutionizing medical imaging modernization, with Duvvur [33] demonstrating AI-driven approaches for data migration that intelligently categorize, prioritize, and transfer imaging studies. Future research should extend these concepts to develop self-optimizing storage systems that automatically tire data based on access patterns, clinical importance, and regulatory requirements. Machine learning algorithms could predict which studies will likely be accessed soon, pre-fetching them to faster storage tiers while archiving less critical data to cost-effective solutions.

The integration of AI into clinical workflows represents perhaps the most transformative trend. Pérez-Sanpablo et al. [34] comprehensively analyzed how AI integration in PACS enhances diagnostic accuracy and workflow efficiency. Future research should focus on developing context-aware AI systems that adapt their analysis based on clinical context, patient history, and specific diagnostic questions. The creation of feedback mechanisms that allow radiologists to easily correct AI inferences and thereby continuously improve model performance would represent a significant advancement.

Streamlining AI development and deployment remains challenging. Jesus et al. [35] addressed this by creating frameworks for streamlined AI tool generation on cloud medical imaging platforms. Future work should develop standardized interfaces and abstraction layers that allow healthcare institutions to integrate AI models from multiple vendors seamlessly. Research into automated model validation and monitoring systems would ensure consistent performance as clinical conditions and imaging protocols evolve.

Decentralization offers promising alternatives to traditional centralized archives. Lebre et al. [36] explored decentralizing the storage of DICOM-compliant PACS, potentially improving resilience and reducing vendor lock-in. Future research should investigate hybrid architectures that intelligently distribute data across centralized clouds and edge devices based on access patterns, legal jurisdictions, and clinical needs. The development of secure peer-to-peer sharing protocols would enable direct institution-to-institution collaboration while maintaining patient privacy.

Educational and research applications continue to expand, with Lebre et al. [37] demonstrating the Dicoogle framework's utility for medical imaging teaching and research. Future platforms should incorporate sophisticated simulation environments that allow trainees to practice interpretation skills across diverse pathology libraries. The development of adaptive learning systems that personalize educational content based on individual performance metrics could significantly accelerate radiology education.

Privacy-preserving technologies are increasingly crucial, particularly for research applications. Jesus et al. [38] developed a DICOM Gateway Anonymizer architecture for scalable research PACS, enabling the creation of anonymized datasets while preserving clinical utility. Future research should focus on developing more sophisticated de-identification techniques that maintain data relationships necessary for AI training while ensuring patient privacy. The integration of differential privacy and synthetic data generation could enable broader data sharing for research purposes.

Finally, comprehensive cloud-enabled diagnostic systems represent the culmination of these advancements. Gafar et al. [39] demonstrated a system leveraging PACS and AI for enhanced remote carotid atherosclerosis management, showcasing the potential for integrated diagnostic platforms. Future research should develop holistic patient management systems that seamlessly integrate imaging data with electronic health records, genomics, and clinical outcomes. The creation of predictive analytics platforms that identify patients at risk for specific conditions based on multi-modal data would represent a significant advancement toward precision medicine. The future of cloud-based medical imaging lies in intelligent, adaptive systems that seamlessly integrate advanced technologies while addressing practical clinical needs. These research directions, building systematically upon current foundations, promise to enhance diagnostic capabilities, improve workflow efficiency, and ultimately advance patient care through more personalized and precise imaging services.

5. Future trends and research directions

The evolution of cloud-based medical imaging is intrinsically linked to advancements in adjacent technological fields. While current architectures provide robust solutions for storage and sharing, several emerging trends are poised to redefine their capabilities and applications. This section outlines key future directions that promise to shape the next generation of medical imaging clouds.

A. The proliferation of Federated Learning (FL) and AI-as-a-Service (AIaaS)

The integration of AI and Machine Learning (ML) is moving beyond simple model deployment. A major future trend is the adoption of FL. FL enables the training of AI models across multiple decentralized hospitals or imaging centers without sharing the raw patient data itself. Instead of centralizing data in one cloud, model updates (e.g., gradients) are sent to a central aggregator. This paradigm directly addresses critical data privacy and regulatory concerns, allowing institutions to collaboratively build powerful, generalized AI models while keeping sensitive data within their own firewalls. Furthermore, cloud platforms will increasingly offer AIaaS, providing curated marketplaces of validated algorithms for tasks like automated detection, segmentation, and quantification, which clinicians can access on a pay-per-use basis, democratizing access to advanced diagnostic tools.

B. Advanced data compression and streaming for real-time telemedicine

As medical imaging resolutions increase and real-time applications like teleradiology and intraoperative guidance become more common, efficient data handling is paramount. Future advancements will focus on intelligent, context-aware compression techniques that go beyond standard DICOM compression. This includes using AI to identify diagnostically critical regions of an image for lossless compression while applying higher compression to less critical areas, optimizing the trade-off between bandwidth and clinical fidelity. Moreover, adaptive streaming protocols, similar to those used in video streaming, will be adopted. These protocols will dynamically adjust the quality and resolution of transmitted images based on the available network bandwidth and the user's immediate task (e.g., preliminary review vs. final diagnosis), ensuring seamless access even in bandwidth-constrained environments.

C. The impact of evolving privacy regulations and PETs

The global regulatory landscape, with frameworks like GDPR in Europe and HIPAA in the US, is continuously evolving, demanding more stringent data governance. Future cloud architectures must be designed for "Privacy by Design." This will involve the wider implementation of PETs. Key among these are:

1) Differential privacy

Adding calibrated statistical noise to query results from large datasets to prevent the re-identification of individuals while preserving the utility of the data for population-level research.

2) HE

As mentioned in Section 4.1, HE allows computations to be performed directly on encrypted data. While currently computationally intensive, advances in HE and specialized hardware will make it a viable option for secure outsourcing of medical image analysis.

3) Zero-Knowledge Proofs (ZKPs)

This technology could allow a cloud service to prove it has performed a task correctly (e.g., running a specific AI model) without revealing the underlying data or the model's internal parameters, enabling new forms of audit and verification.

The convergence of these trends-decentralized AI, intelligent data pipelines, and robust privacy frameworks-will create a more intelligent, efficient, and trustworthy cloud ecosystem for medical imaging, ultimately accelerating personalized medicine and collaborative care.

6. Conclusion

One of the most important methods in clinical diagnoses is medical imaging. The large volume of imaging data has caused medical service providers to face challenges such as data storage, data recovery, and full data utilization. Also, in conventional medical imaging in clinics, there are some problems such as lack of accurate medical diagnosis, re-imaging for a referral to a physician, defects in imaging records data, poor quality and accuracy in image recognition, and existence problems sending and sharing data to medical centers. The medical imaging cloud is one of the most important areas in cloud computing that can be used in the field of medical imaging. In the cloud, medical images can be shared in medical institutions, consulting centers, and educational institutes. The medical imaging cloud allows patients to access the medical images easily and without spatial restrictions. In addition, cloud computing not only provides better clinical imaging services to physicians, but also supports IoT, big data, and AI, providing more valuable applications. Medical data in cloud services can be shared between medical centers and organizations. Cloud imaging services can also provide a wide range of applications and economic activities in this area. In the medical image cloud, sharing images between hospitals, medical data management, specialized medical services, and medical researches are some of the benefits of cloud services in medical imaging. The medical imaging cloud service for patients can integrate patient-related consulting, diagnoses, and treatments, thus saving time and money and making it easier to control the patient's health. The medical image cloud services improve the quality and accuracy of the diagnosis, creates an effective connection between physicians and patients, and reduces medical accident incidents. As a result, it increases patient satisfaction and ultimately provides better medical services. On the other hand, the cloud medical imaging service for management units can provide an electronic information storage system and manage patients' health information to improve medical supervision, examine common diseases in different areas, and support medical researches. In this study, we have dealt with different models of providing cloud services in the field of medical imaging and examined the possibility of providing this service in different situations. We also reviewed the requirements for implementing a medical imaging cloud service in a network, and related issues such as storage, bandwidth, and SLA requirements for achieving better QoS in the medical imaging cloud.

Data availability

All data generated or analyzed during this study are included in this published article.

Funding

No funding was received to assist with the preparation of this manuscript.

Ethical

This material is the authors' own original work, which has not been previously published elsewhere. The paper is not currently being considered for publication elsewhere. The paper reflects the authors' own research and analysis in a truthful and complete manner.

Author contribution

All authors contributed to the study conception and design. All authors read and approved the final manuscript.

Informed consent

This study does not involve any human beings and the subject of the study is quite a technical subject.

Conflict of interest

The author declares that they have no conflict of interest.

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