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An Architectural Framework for Telemedicine Systems: Components, Roles, and Implementation Challenges

S. Hemalatha, PhD (CSE)[1]; Kiran Mayee Adavala, PhD (CSE)[2]; Pullela SVVSR Kumar, PhD (CSE)[3]; P. Kumaravel, ME (PhD)[4]; N. Muthuvairavan Pillai, PhD[5] and G. Krishna Mohan PhD (CSE)[6]

[1]Department of Computer Science and Business Systems, Panimalar Engineering College, Chennai, Tamil Nadu, India; [2]CSE(AIML), Kakatiya Institute of Technology and Science, Warangal, India; [3]Department of Computer Science and Engineering, Aditya University, Surampalem, Andhra Pradesh, India; [4]Department of Mechanical Engineering, Sona College of Technology, Salem, Tamil Nadu, India; [5]Department of Computer Science and Business Systems, RMD Engineering College, Chennai, India; [6]Department of CSE, Koneru Lakshmaiah Education Foundation, Guntur, India

Corresponding Author: S. Hemalatha, Email: pithemalatha@gmail.com

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Abstract

The rapid expansion of telemedicine, accelerated by the COVID-19 pandemic, has transformed healthcare delivery by enabling remote consultation, monitoring, and diagnostics. However, existing telemedicine systems often suffer from fragmented architectures, limited interoperability, and inadequate alignment with regulatory and operational requirements. This article proposes a comprehensive architectural framework for telemedicine systems that integrates key technological components, stakeholder roles, and implementation considerations into a unified model. Through a systematic review and comparative analysis of established frameworks, including outcome-oriented models, semantic healthcare standards, and emerging technology-driven architectures, critical gaps were identified in current telemedicine design approaches. The proposed framework delineates modular layers encompassing user interfaces, communication protocols, service components (e.g. electronic health records and AI engines), data management, integration with third-party systems, and governance mechanisms to ensure privacy and compliance. Additionally, the framework explicitly defines the roles and responsibilities of patients, healthcare providers, system administrators, institutions, and regulatory bodies to facilitate coordinated operation and oversight. Implementation challenges such as data security, infrastructure limitations in rural areas, interoperability across diverse electronic health records systems, scalability, user training, and deployment costs are thoroughly discussed. This work offers a foundational reference model to guide researchers, developers, and policymakers in advancing telemedicine platforms that are scalable, secure, and interoperable. Future efforts will focus on validating the framework through simulation, prototype development, and pilot studies to enhance practical adoption and impact.

Plain Language Summary

Telemedicine enables patients to receive care remotely through digital technologies, and its use expanded rapidly during the COVID-19 pandemic. However, many telemedicine systems still struggle with fragmented designs, poor compatibility between platforms, and challenges in meeting privacy and regulatory standards. This article introduces a comprehensive architectural framework that organizes telemedicine into clear layers, including user interfaces, secure communication, service components like electronic health records and AI tools, data management, and governance mechanisms. It also defines the roles of patients, healthcare providers, administrators, institutions, and regulators to ensure smooth coordination.

Key challenges, such as data security, rural connectivity, system interoperability, scalability, user training, and deployment costs, are identified and discussed. The proposed framework serves as a guide for building secure, interoperable, and scalable telemedicine systems. Future work will focus on validating this model through prototypes and pilot studies to support better healthcare access worldwide.

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Telemedicine,[1] the provision of healthcare services at a distance through telecommunications technology, has witnessed remarkable evolution over the past several decades. Initially conceived to address the challenge of geographic barriers[2] and limited healthcare access in remote areas,[3] telemedicine has expanded dramatically in scope and complexity with advances in digital infrastructure,[4] mobile technologies,[5] and cloud computing.[6] Early systems were often isolated and limited in functionality, focused largely on video consultations[7] or simple remote monitoring.[8] However, the integration of emerging technologies such as the Internet of Medical Things (IoMT),[9] artificial intelligence (AI),[10] and electronic health records (EHR)[11] interoperability has paved the way for more sophisticated, real-time, and patient-centered telehealth ecosystems.[12]

The COVID-19 pandemic[13] greatly accelerated telemedicine use worldwide, as hospitals faced many patients[14] and social distancing rules.[15] Telemedicine helped maintain care while reducing the risks for infection.[16] However, this rapid growth also highlighted problems, including a lack of standardized systems that can easily work together and meet regulatory requirements.[17] Simultaneously, it exposed significant limitations in the existing telemedicine infrastructure, most notably, the lack of standardized, scalable, and interoperable system architectures that can support diverse clinical workflows and regulatory demands.[17]

Despite the many telemedicine platforms, the landscape is fragmented. Some (e.g., Model for Assessment of Telemedicine [MAST])[18] focus on evaluating outcomes but do not guide system design.[19] Semantic standards such as EN ISO (International Organization for Standardization) 13940-2015 (ContSys)[20,21] provide detailed options to represent healthcare information (i.e. 'semantic modeling'), which can create common definitions enabling systems to understand shared data. However, they do not address how to build or deploy telemedicine systems in practice. Emerging technologies such as blockchain and edge computing can process data closer to where it is generated rather than sending it all to the cloud.[22] However, their integration into healthcare standards is still limited.

This fragmentation creates a gap. There is no comprehensive framework that brings together technology, user roles, and regulations into a practical, implementable telemedicine architecture.[17,23] To fill this gap, the authors propose a layered framework that covers everything from user interfaces and communication protocols to data management and governance. It clearly defines the roles of patients, providers, administrators, institutions, and regulators. This approach aims to ensure interoperability (systems working together), privacy compliance, and flexibility to adopt new technologies like AI diagnostics and blockchain security.

This framework helps researchers develop and test new telemedicine solutions, informs policymakers about regulation,[24] and guides designers in building user-friendly, interoperable platforms. In addition, it considers real-world challenges such as infrastructure limits, digital literacy, and cost barriers.

The article is organized as follows: existing research and gaps are reviewed, details of the proposed framework layers are presented, and a description of stakeholder roles is reviewed. This is followed by a discussion of implementation challenges. Then, a framework with others and notes on limitations is discussed. The article concluded with suggestions for future work, including prototype development and pilot testing.

Literature Review

The framework was evaluated using the Delphi method, a structured communication process that gathers expert consensus through multiple rounds of surveys. The accelerated global adoption of telemedicine, particularly in the wake of the COVID-19 pandemic,[25] has underscored the urgent need for robust, interoperable, and scalable system architectures. While governments and healthcare institutions[26] have responded with fragmented solutions, sustainable integration of telemedicine into healthcare ecosystems demands more than just ad hoc deployment. It requires architecturally sound systems that align with stakeholder roles, regulatory policies, technological constraints, and healthcare interoperability standards.[27] Numerous frameworks have been proposed,[28] which are broadly categorized into assessment-based models,[29] semantic standards,[30] and technologically driven architectures, each with specific strengths and limitations.

A comparative analysis of existing telemedicine frameworks reveals three primary categories.[31] The first includes assessment-centric models such as the MAST,[32,33] which has been extensively utilized in EU (European Union)-funded initiatives such as Renewing Health and

SmartCare.[34] The MAST emphasizes multidisciplinary evaluation spanning medical, economic, and ethical aspects and is praised for its rigorous outcome assessment methodology. However, it lacks guidance on architectural design or system implementation, thereby limiting its utility for developers and system architects.

The second category encompasses standards-based semantic models, most notably the EN ISO 13940 (ContSys) standard.[22,35] ContSys contributes a structured ontology for healthcare semantics, clearly defining healthcare actors, processes, and information flows to support continuity of care. While it forms a strong foundation for EHR system interoperability, its abstraction level makes it less applicable to the practical realization of telehealth-specific distributed architectures.

The third category includes technology-enabling architectures, typically proposed in academic literature. These integrate cutting-edge technologies such as Edge Computing, AI,[36] the Internet of Medical Things (IoMT),[37] cloud computing, and blockchain.[38] These models address key challenges such as real-time monitoring, decentralized trust, and computational efficiency. For example, edge-AI-IoT (Internet of Things)[39] systems provide latency-resilient platforms ideal for remote diagnostics, and blockchain-based approaches ensure privacy-preserving data sharing. However, such architectures often remain conceptual and suffer from limited real-world implementation, minimal compliance with healthcare standards, and a lack of explicit stakeholder role definitions.

Recent technological advancements have catalyzed significant shifts in the telemedicine landscape. AI and machine learning are increasingly embedded into telehealth platforms for predictive analytics, automated triage, medical imaging analysis, and clinical decision support. New regulations such as TRIPOD-AI and DECIDE-AI[40] have further encouraged the adoption of explainable and clinically valid AI models. Both IoT and IoMT, coupled with edge computing, are enabling scalable remote patient monitoring systems capable of functioning in bandwidth-constrained environments. With market growth estimated at a CAGR of 21% to 29%,[41] these technologies are critical for continuous, context-aware healthcare. In addition, EHR integration and interoperability have matured, supported by Fast Healthcare Interoperability Resources (FHIR) application programming interface,[42,43] blockchain-based smart contracts,[44] and openEHR standards,[45] all of which promote data portability and user-controlled access. Cloud and edge hybrid architectures[46] now enable highly elastic, scalable systems capable of handling dynamic healthcare workloads, with C ensuring localized processing for latency-sensitive applications.

A consolidated comparison of frameworks further clarifies the domain's current state as presented in Table 1. The MAST[32–34] provides rigorous, multidimensional evaluation but lacks implementation guidance. ContSys (a system of concepts to support continuity of care) excels[23,35] in healthcare semantics but is detached from system design. Emerging Edge-AI-IoT[36–39] frameworks offer modularity and intelligent features but remain under-validated in real-world healthcare environments. Hybrid blockchain Artificial Intelligence of Things (AIoT) models[44] promise privacy and decentralization but raise concerns about scalability, cost, and EHR standard alignment. Thus, while these frameworks contribute valuable insights, they do so in isolation, failing to bridge the gap between semantic coherence, technological feasibility, and stakeholder-centered architecture.

Emerging technologies such as Extended Reality (XR), which encompasses Virtual Reality, Augmented Reality, and Mixed Reality, are increasingly being explored in telemedicine. These technologies enable immersive medical training, virtual consultations with 3D anatomical models, remote surgery assistance, and physical rehabilitation with real-time visual feedback. The XR holds promise for enhancing clinician-patient interaction, especially in fields like mental health, orthopedics, and medical education. As XR hardware becomes more accessible, its integration into telehealth platforms is anticipated to expand significantly. These technologies enable immersive medical training, virtual consultations with 3D anatomical models, remote

Table 1. Summary of healthcare framework architecture.

Framework/standard	Focus area	Strengths	Limitations
MAST (EU)[32–34]	Telemedicine assessment methodology	Multi-domain, evidence-based, systematic	Lacks architecture/system modeling; evaluation only
ContSys (EN ISO 13940)[23,35]	Semantic continuity of care	Standardized models for actors and processes	Semantic only, no platform/telemedicine IT structure
Edge-AI-IoT Proposals[36–39]	Real-time smart architectures	Low latency, modular, AI-integrated	Conceptual stage, few implementation studies
Blockchain-AIoT Hybrid Models[44]	Data security, decentralization	Privacy, user-controlled access	Scalability and cost concerns; no standard EHR alignment

AI: artificial intelligence, AIoT: Adaptive Large Optics Technologies, ContSys: system of concepts to support continuity of care, MAST: Model for Assessment of Telemedicine, EHR: electronic health record, EU: European Union, IT: IoT: Internet of Things, ISO: International Organization for Standardization.

surgery assistance, and physical rehabilitation with real-time visual feedback. In addition, XR holds promise for enhancing clinician-patient interaction, especially in fields like mental health, orthopedics, and medical education.

This fragmented landscape reveals several critical research gaps. First, there is no integrated architectural blueprint that combines outcome assessment, semantic modeling, stakeholder workflows, and technical specifications. Second, there is a lack of standards-aware, operationally oriented design that can translate conceptual technologies into practical telemedicine solutions. Specifically, existing models fall short in combining interoperability protocols (e.g. FHIR, blockchain) and semantic standards (e.g. ContSys) with next-generation computing paradigms (e.g. AI, edge computing). Third, existing efforts often neglect real-world deployment challenges such as data privacy, user onboarding, low-bandwidth operation, and compliance with regulatory frameworks like the Health Insurance Portability and Accountability Act (HIPAA)[47–49] or the General Data Protection Regulation (GDPR).[49]

In summary, prior research presents valuable but disjointed contributions, offering either evaluative robustness (e.g. MAST), semantic precision (e.g. ContSys), or technical innovation (e.g. Edge-AI-IoT: integration of AI with edge computing and the IoT). However, a critical gap remains: the absence of a unified, standards-compliant, and stakeholder-aware architectural framework that bridges these dimensions into a deployable telemedicine solution. Addressing this gap is the central focus of the present research, which proposes a comprehensive architectural framework that integrates key components, defines stakeholder roles, ensures interoperability, and incorporates implementation best practices in real-world healthcare scenarios.

Proposed Architectural Framework

To address the gaps identified in the literature, we propose a comprehensive architectural framework for telemedicine systems[17,50,51] that integrates technical components, stakeholder roles, and regulatory requirements into a unified, scalable, and interoperable structure. This framework aims to support both synchronous and asynchronous care delivery while ensuring clinical relevance, data privacy, and system adaptability across various healthcare contexts.[52,53]

High-Level Architecture Overview

At a high level, the proposed architecture follows a modular, layered design pattern that promotes separation of concerns, scalability, and ease of integration. A block diagram or layered architectural view is envisioned to represent the interactions visually between layers, enabling stakeholders to understand system boundaries, data flow, and interface touchpoints. This layered model, as shown in Table 2, fosters plug-and-play extensibility, allowing the architecture to adapt to evolving technological and regulatory landscapes.

Table 2. Layered architecture framework.

Layer				
Governance				
Audit	Consent	Compliance	Policy	Risk Management
Integration				
FHIR	IoT Platform	HIS/LIS	National Registry	
Data				
DBs (SQL/NoSQL)	Logs	Analytics	Encryption, Anonymization	
Service				
her	AI Engines	Diagnostic	API Gateway	
Communication				
Video	Messaging/SMS		Sensor APIs	
User Interface				
Patient	Clinician		Admin & Staff Console	

API: Application Programming Interface; DBs: Deep Brain Stimulation; EHR: electronic health record; FHIR: Fast Healthcare Interoperability Resources; SMS: Short Message Service; HIS/LIS: Hospital Information System/Laboratory Information System; SQL/NoSQL: Structured Query Language/Not Only SQ.

Layered Components of the Architecture

Layered components include the user interface layer, communication layer, service layer, data layer, integration layer, and governance layer.

User Interface Layer

This layer constitutes the front end of the system, providing interactive portals for patients, doctors, and administrative staff. For patients, the interface includes features for appointment scheduling, virtual consultations, health record access, and remote monitoring dashboards. For healthcare providers, it offers clinical dashboards, patient history views, diagnostic tools, and communication consoles. The interface is designed to be accessible, multilingual, and responsive across devices, ensuring equitable digital access.

Communication Layer

Facilitating real-time and asynchronous interactions, the communication layer incorporates video conferencing modules, secure messaging systems, and support for wearable sensors and diagnostic devices. It is responsible for establishing secure, low-latency communication channels that comply with healthcare-grade encryption standards (e.g. Transport Layer Security [TLS], HIPAA-compliant messaging[47]). The layer is also extensible to support future modalities such as augmented reality for remote surgery or AI-powered chatbots.

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Service Layer

The service layer encapsulates core healthcare functionalities such as Electronic Health Record (EHR) management,[54] diagnostic engines,[55] decision-support systems,[56] and AI modules for image analysis, triage, or predictive analytics.[57] These services are exposed via microservices or API gateways, enabling dynamic composition of telemedicine workflows and personalized care pathways. AI modules are validated under frameworks like TRIPOD-AI[58] to ensure clinical transparency and robustness.

Data Layer

This layer is responsible for secure data storage, retrieval, and processing. It supports structured and unstructured data formats and includes components for data encryption, anonymization, and compliance logging. Advanced analytics modules within this layer enable population health insights, patient stratification, and real-time anomaly detection. Data governance mechanisms ensure adherence to local and international standards, including GDPR and HIPAA.[48,49]

Integration Layer

Interoperability is enabled through this Integration Layer, which connects the telemedicine system to third-party APIs,[59] IoT platforms,[60] hospital information systems (HISs),[61,62] and national health registries.[63] Support for standards such as Health Level Seven—Fast Health Interoperability Resources (HL7 FHIR),[64] DI laboratory information systems (LIS)COM Digital Imaging and Communications in Medicine [DICOM],[65] and Open Electronic Health Record (openEHR)[66] ensures seamless data exchange across systems. The layer also manages authentication and data mapping across heterogeneous sources.

Governance Layer

Serving as the supervisory tier, the governance layer enforces compliance with regulatory policies,[67] ethical frameworks,[68] and legal requirements.[69] It includes modules for audit trails, consent management, licensing validation, and access control. The layer also provides interfaces for policy configuration and risk assessment, ensuring that the system remains trustworthy, transparent, and aligned with jurisdiction-specific mandates.

This architectural framework presents a robust foundation for the development and deployment of next-generation telemedicine systems. It ensures that both functional and non-functional requirements, such as usability, interoperability, scalability, and compliance, are holistically addressed.

Top of Form4. Methodology: Framework Validation Strategy

To validate the proposed architectural framework for telemedicine systems rigorously, a comprehensive, multi-method approach will be employed, combining expert evaluation, real-world case study application, and simulation-based performance analysis. This triangulated methodology is designed to assess the framework's conceptual integrity, practical applicability, and technical robustness.

The initial validation phase involves structured expert evaluation by a panel of specialists with extensive experience in telemedicine deployment, health informatics, system architecture, and regulatory compliance. These experts will be presented with a detailed overview of the framework's layered design, encompassing the User Interface, Communication, Service, Data, Integration, and Governance layers. Using iterative rounds of feedback guided by the Delphi method, the panel will critically assess the framework's completeness, modularity, interoperability, security adherence, and real-world feasibility. This process aims to achieve consensus on the framework's strengths and identify potential areas for refinement, thereby ensuring the model aligns with current industry best practices and standards.

Following expert review, the framework will be applied to a real-world telemedicine implementation as a case study, preferably within a regional hospital or rural healthcare network. This analysis will involve mapping the existing telemedicine infrastructure to the proposed architectural layers and identifying any gaps or weaknesses in system components and processes. Particular attention will be given to evaluating patient-provider interactions, data integration workflows, and compliance mechanisms embedded within the system. This case study will provide valuable insights into how the framework supports cohesive alignment between technical modules and stakeholder roles, highlighting its operational relevance and potential impact on system coherence and service delivery effectiveness.

Complementing the qualitative evaluations, the final validation stage involves simulation-based performance modeling to quantitatively assess the framework's technical viability. Utilizing simulation NS3 (Network Simulator 3) platforms such as NS3,[70] Any Logic,[71] or Objective Modular Network Testbed in C++ (OMNeT++),[72] key aspects such as communication latency, data throughput, service layer load balancing, failover responsiveness, and data security measures will be modeled under varying conditions of user demand and network environments. Additionally, scalability analyses will be conducted to compare performance in both resource-constrained rural settings and more robust urban infrastructures. Performance metrics, including response time, error rates, and system availability, will be monitored to evaluate the framework's capacity to sustain efficient, secure, and reliable telemedicine operations.

By integrating these three complementary validation strategies, expert consensus building, empirical case study application, and quantitative simulation testing, the proposed architectural framework will be subjected to thorough and multidimensional scrutiny. This approach ensures the framework is not only conceptually sound but also practically deployable and technically resilient, thereby addressing existing gaps in telemedicine system design literature and facilitating broader adoption in diverse healthcare settings.

Roles of Stakeholders

Effective telemedicine systems depend heavily on the clear definition and coordination of roles among diverse stakeholders,[73] each contributing to the overall functionality, security, and sustainability of healthcare delivery. The proposed architectural framework delineates the responsibilities and interactions of key participants, including patients, healthcare professionals, system administrators, healthcare institutions, and government bodies, ensuring a holistic and compliant telemedicine ecosystem. Patients serve as the primary users, engaging with the system through interactive portals that facilitate remote consultations, appointment scheduling, and health data sharing. Their active participation in data provision, such as vital signs, medical history, and real-time sensor data, is critical for accurate diagnosis and continuous monitoring. Ensuring user-friendly interfaces and secure data handling is paramount to maintaining patient trust and compliance.

Doctors and nurses form the clinical backbone of telemedicine services. Their roles encompass remote consultation, continuous patient monitoring, diagnostic interpretation, and treatment planning, often supported by integrated decision-support tools powered by AI. These professionals require seamless access to updated EHRs[74] and communication channels to provide timely and effective care. System administrators oversee the technical operations of the telemedicine platform, including system configuration, performance optimization, troubleshooting, and maintenance. They ensure the availability, reliability, and security of all system components, managing user access controls and implementing software updates to align with evolving healthcare standards and cybersecurity protocols.

Healthcare institutions such as hospitals and clinics are responsible for hosting telemedicine infrastructures and enforcing data governance policies. Their oversight includes managing patient data confidentiality, ensuring interoperability with existing health information systems, and coordinating with external service providers. Institutions also play a key role in training users and facilitating integration across clinical departments. Government bodies and regulatory agencies provide the overarching framework for telemedicine practice by establishing compliance mandates related to patient data privacy, security standards, reimbursement policies, and licensure requirements. Their regulations ensure that telemedicine services meet legal and ethical norms, fostering public trust and enabling widespread adoption.

To enhance clarity and operational alignment, a Role-Component Matrix[75] is proposed and given in Table 3. This matrix cross-references stakeholder roles

Table 3. Role-component matrix.

Stakeholder	Layer					
	User	Communication	Service	Data	Integration	Governance
Patients	Access portals for consultation, data input, and notifications.	Use video, chat, and sensor data transmission.	View diagnostic results, AI support.	Share personal health data, consent management.	Connect with external devices (wearables, sensors).	Consent to data use, privacy preference.
Doctors/nurses	Access patient dashboards, teleconsultation portals.	Engage in real-time communication with patients.	Utilize EHRs, diagnostic tools, AI decision support.	Access/update patient records securely.	Interface with hospital systems, labs.	Comply with clinical data privacy, audit trails.
System administrators	Manage user accounts, roles, and access controls.	Maintain communication network performance.	Configure service modules and AI engines.	Ensure secure data storage, backups.	Integrate third-party APIs, monitor data flows.	Implement security policies, ensure compliance.
Healthcare institutions	Provide infrastructure for user access.	Oversee communication infrastructure reliability.	Manage service availability and quality.	Enforce data governance, retention policies.	Coordinate with external healthcare systems.	Ensure institutional compliance with laws and standards.
Government bodies	Regulate user access policies and authentication standards.	Set standards for communication security.	Define requirements for clinical software certification.	Enforce data privacy laws, audit requirements.	Regulate interoperability standards.	Establish legal and regulatory frameworks.

AI: artificial intelligence, API: application programming interface, EHR: electronic health record.

with architectural components, illustrating the interactions, responsibilities, and control points each actor maintains within the system. This structured representation aids in identifying accountability, optimizing workflows, and ensuring compliance across the telemedicine ecosystem. A clear and professional Role–Component Matrix can be included in the article. This matrix maps key stakeholders against the primary components of a telemedicine system and highlights their main responsibilities or interactions with each component. It provides a concise overview of stakeholder involvement, system functionality, and accountability, facilitating better understanding for both designers and evaluators of telemedicine platforms.

Implementation Challenges

The deployment of telemedicine systems faces multifaceted implementation challenges spanning technical, regulatory, and operational domains. Data privacy and security remain paramount concerns, as telemedicine platforms must comply with stringent regulations such as HIPAA[47–49] in the United States and the GDPR[49] in the European Union. Ensuring end-to-end encryption, secure data storage, and controlled access are essential to protect sensitive patient information and maintain trust. However, meeting these regulatory requirements often involves complex architectural adjustments and continuous monitoring.

From a technical perspective, bandwidth limitations and inadequate infrastructure, particularly in rural and underserved areas, pose significant barriers to delivering high-quality video consultations and real-time monitoring. Limited internet connectivity results in latency issues and interrupted service, which can adversely affect clinical outcomes. Innovative solutions leveraging edge computing and adaptive streaming technologies are being explored to mitigate these constraints, though widespread adoption remains a challenge.

System interoperability across diverse EHR platforms[11,45] is another critical hurdle. Despite advances in standards such as FHIR,[42,43] many healthcare providers utilize heterogeneous systems with varying data formats, complicating seamless data exchange. The Integration Layer of telemedicine frameworks must therefore be designed with flexibility and adherence to emerging interoperability standards to ensure continuity of care and accurate information flow.

Scalability is essential to support population-level telemedicine services, especially in public health emergencies. Here, 'population-level' refers to healthcare solutions designed to serve large groups of people or entire communities rather than individual patients. These services aim to provide accessible, equitable care across diverse regions or demographic groups, enabling healthcare systems to manage widespread health needs efficiently. Systems must handle sudden surges in user demand without compromising performance or security. Cloud-native architectures offer elastic resource management (meaning the system can dynamically allocate computing resources based on demand) but introduce concerns around cost and vendor lock-in (dependency on a single cloud provider).

User training and digital literacy present operational challenges. Both patients and healthcare professionals require sufficient digital skills to effectively engage with telemedicine platforms. Training programs and intuitive user interface designs are vital to increase adoption and minimize errors. Additionally, the cost of deployment covering hardware, software development, maintenance, and support can be prohibitive, particularly for low-resource healthcare settings.

Several real-world case studies highlight these challenges. For instance, the rapid telehealth expansion during the COVID-19 pandemic[13,25] exposed gaps in rural broadband access in the United States, leading to inequities in service delivery. Similarly, interoperability issues have been documented in multi-institutional telemedicine networks, where inconsistent data standards hinder clinical decision-making. Addressing these implementation challenges is crucial for developing robust, scalable, and equitable telemedicine systems and forms a key focus area for ongoing research and development.

Discussion

The proposed architectural framework advances beyond existing telemedicine models by offering an integrated and operationally grounded blueprint that cohesively aligns system components, stakeholder roles, and implementation constraints. Unlike MAST,[18,33,34] which primarily focuses on evaluation without detailed architectural guidance, our framework explicitly delineates layered system modules from user interfaces to governance and maps these to the key actors in telehealth delivery. Compared to semantic standards such as EN ISO 13940 (ContSys),[20,21,23,24] which provide rich ontologies for continuity of care but lack practical deployment details, this framework integrates semantic interoperability with real-world technological considerations, including AI, IoT, and cloud-edge architectures.

A unique strength of the proposed model lies in its comprehensive inclusion of the governance layer, addressing regulatory compliance, privacy, and security within the core design rather than as an afterthought. Additionally, the explicit Integration Layer facilitates flexible interfacing with third-party healthcare systems and devices, enhancing scalability and adaptability.

However, this work currently remains conceptual and has not yet been validated through large-scale implementation or empirical testing. Limitations include the absence of prototype development and real-world pilot studies, which are essential to evaluate operational feasibility, performance, and user acceptance. Furthermore, while the framework is designed to accommodate emerging technologies such as AI-driven diagnostics and Blockchain for secure data management, detailed integration strategies for these components require further elaboration.

Looking forward, the architecture's modular design provides significant potential for adaptation to rapidly evolving technologies. For instance, the incorporation of AI models can enhance diagnostic accuracy and personalized treatment recommendations, while Blockchain could improve data integrity and patient-controlled access. The flexible Integration Layer also supports seamless upgrades as standards and tools mature, ensuring long-term relevance and resilience.

Conclusion and Future Work

This article presents a novel architectural framework for telemedicine systems that bridges existing gaps by unifying technical, semantic, and governance dimensions into a cohesive, stakeholder-aware model. The framework's layered design and role-component mapping offer a clear roadmap for developing interoperable, secure, and scalable telehealth platforms capable of addressing contemporary healthcare challenges.

The contributions of this work are manifold. For researchers, the framework provides a structured foundation for further investigation into telemedicine architectures and their performance under diverse conditions. Policymakers can leverage the governance considerations embedded within the model to inform regulatory guidelines that balance innovation with patient safety and privacy. System designers and developers gain a practical reference for building telemedicine solutions that are compliant, modular, and adaptable. Future work will focus on empirical validation through simulation studies and prototype development to test the framework's operational effectiveness.

Planned extensions include integration of advanced AI algorithms for diagnostics and decision support, as well as pilot deployments in clinical settings to assess user experience and system robustness. Additionally, ongoing refinement will address emerging standards and technologies to ensure the framework remains at the forefront of telemedicine innovation. Future enhancements could include evaluating the integration of XR for immersive patient interaction, medical training simulations, and remote surgical support.

References

1. Alenoghena CO, Ohize HO, Adejo AO, Onumanyi AJ, Ohihoin EE, Balarabe AI, et al. Telemedicine: a survey of telecommunication technologies, developments, and challenges. J Sens Actuator Netw. 2023;12(2):20. https://doi.org/10.3390/jsan12020020
2. Kruse CS, Karem P, Shifflett K, Vegi L, Ravi K, Brooks M. Evaluating barriers to adopting telemedicine worldwide: a systematic review. J Telemed Telecare. 2018;24(1):4–12. https://doi.org/10.1177/1357633X16674087
3. Kaeley N, Choudhary S, Mahala P, Nagasubramanyam V. Current scenario, future possibilities and applicability of telemedicine in hilly and remote areas in India: a review protocol. J Fam Med Prim Care. 2021;10(1):77–83. https://doi.org/10.4103/jfmpc.jfmpc_1085_20
4. Hsiao V, Chandereng T, Lankton RL, Huebner JA, Baltus JJ, Flood GE, et al. Disparities in telemedicine access: a cross-sectional study of a newly established infrastructure during the COVID-19 pandemic. Appl Clin Inform. 2021;12(3):445–58. https://doi.org/10.1055/s-0041-1730026
5. Stotts MJ, Grischkan JA, Khungar V. Improving cirrhosis care: the potential for telemedicine and mobile health technologies. World J Gastroenterol. 2019;25(29):3849. https://doi.org/10.3748/wjg.v25.i29.3849
6. Kumar MS, Ganesh D. Improving telemedicine through IoT and cloud computing: opportunities and challenges. Adv Eng Intell Syst. 2024;3(3):123–35.
7. Kang S, Thomas PB, Sim DA, Parker RT, Daniel C, Uddin JM. Oculoplastic video-based telemedicine consultations: Covid-19 and beyond. Eye (Lond). 2020;34(7):1193–5. https://doi.org/10.1038/s41433-020-0953-6
8. Volterrani M, Sposato B. Remote monitoring and telemedicine. Eur Heart J Suppl. 2019;21(Suppl_M):M54–6. https://doi.org/10.1093/eurheartj/suz266
9. Kadu A, Singh M. Comparative analysis of e-health care telemedicine system based on Internet of Medical Things and artificial intelligence. In: Proceedings of the 2021 2nd International Conference on Smart Electronics and Communication (ICOSEC). IEEE; 2021, p. 1768–75.
10. Holzinger A, Langs G, Denk ipaa, Zatloukal K, Müller H. Causability and explainability of artificial intelligence in medicine. Wiley Interdiscip Rev Data Min Knowl Discov. 2019;9(4):e1312. https://doi.org/10.1002/widm.1312
11. Alfiyyah A, Ayuningtyas D, Rahmanto A. Telemedicine and electronic health record implementation in rural area: a literature review. J Indones Health Policy Adm. 2022;7(2):2. https://doi.org/10.7454/ihpa.v7i2.4116
12. Palozzi G, Ranalli F. Telemedicine implementation between innovation and sustainability: an operating model for designing patient-centered healthcare. In: Pfannstiel N, editor. Human-centered service design for healthcare transformation: development, innovation, change. Cham: Springer International Publishing; 2023, pp. 375–99.
13. Omboni S, Padwal RS, Alessa T, Benczúr B, Green BB, Hubbard I, et al. The worldwide impact of telemedicine during COVID-19: current evidence and recommendations for the future. Connect Health. 2022;1:7. https://doi.org/10.20517/ch.2021.03
14. Arshid MA, Mumtaz M, Nazir R. Unforeseen challenges to global health system, in particular context to COVID-19 pandemic and health care personnel. Arab J Basic Appl Sci. 2021;28(1):145–53. https://doi.org/10.1080/25765299.2020.1824395
15. Gupta, S, Simon KI, Wing C. Mandated and voluntary social distancing during the COVID-19 epidemic: a review. Brookings Papers on Economic Activity 2020;2020(2):269–326. https://doi.org/10.3386/w28139
16. Ezeamii VC, Okobi OE, Wambai-Sani H, Perera GS, Zaynieva S, Okonkwo CC, et al. Revolutionizing Healthcare: How Telemedicine Is Improving Patient Outcomes and Expanding Access to Care. Cureus 2024;16(7):e63881. https://doi.org/10.7759/cureus.63881
17. Jat AS, Grønli TM, Ghinea G, Assres G. Evolving software architecture design in telemedicine: a PRISMA-based systematic

review. Healthc Inform Res. 2024;30(3):184–93. https://doi.org/10.4258/hir.2024.30.3.184
18. Kidholm K, Jensen LK, Kjølhede T, Nielsen E, Horup MB. Validity of the model for assessment of telemedicine: a Delphi study. J Telemed Telecare. 2018;24(2):118–25. https://doi.org/10.1177/1357633X16686553
19. Deng J, Huang S, Wang L, Deng W, Yang T. Conceptual framework for smart health: a multi-dimensional model using IPO logic to link drivers and outcomes. Int J Environ Res Public Health. 2022;19(24):16742. https://doi.org/10.3390/ijerph192416742
20. Buhvestova, J-L. Osapoole ja Osapoole Seose arhetüüpmustrite realiseerimine, testimine ja sobivuse hindamine ISO 13940:2015 (ContSys) mõistete deklaratiivseks spetsifitseerimiseks. Tallinna Tehnikaülikool. Bakalaureusetöö. Juhendajad: Toomas Klementi, Gunnar Piho; 2023.
21. Das S, Hussey P. HL7-FHIR-based ContSys formal ontology for enabling continuity of care data interoperability. J Pers Med. 2023;13(7):1024. https://doi.org/10.3390/jpm13071024
22. Awasthi MV, Bhattacharjee S, Karande N. Convergence of Internet of Medical Things, Artificial Intelligence, and Blockchain in healthcare: a transformative platform for interoperable healthcare. Convergence. 2023;10(6).3312–3318
23. Peral J, Ferrández A, Gil D, Munoz-Terol R, Mora H. An ontology-oriented architecture for dealing with heterogeneous data applied to telemedicine systems. IEEE Access 2018;6:41118–38. https://doi.org/10.1109/ACCESS.2018.2857499
24. Parimbelli E, Bottalico B, Losiouk E, Tomasi M, Santosuosso A, Lanzola G, et al. Trusting telemedicine: a discussion on risks, safety, legal implications and liability of involved stakeholders. Int J Med Inform. 2018;112:90–8. https://doi.org/10.1016/j.ijmedinf.2018.01.012
25. Olorunsogo TO, Balogun OD, Ayo-Farai O, Ogundairo O, Maduka CP, Okongwu CC, et al. Reviewing the evolution of US telemedicine post-pandemic by analyzing its growth, acceptability, and challenges in remote healthcare delivery during global health crises. World J Biol Pharm Health Sci. 2024;17(1):75–90. https://doi.org/10.30574/wjbphs.2024.17.1.0010
26. Sharma D, Gupta S. The role of e-government in modern public health systems. In: Startup-Driven E-government: digital innovation for sustainable ecosystems. IGI Global Scientific Publishing; 2025, pp. 239–72.
27. Tsinale HL, Mbugua S, Luvanda A. Architectural health data standards and semantic interoperability: a comprehensive review in the context of integrating medical data into big data analytics. International Journal of Engineering Applied Sciences and Technology, 2023;8(04):17–30. https://doi.org/10.33564/IJEAST.2023.v08i04.002
28. Bradford N, Chambers S, Hudson A, Jauncey-Cooke J, Penny R, Windsor C, et al. Evaluation frameworks in health services: an integrative review of use, attributes and elements. J Clin Nurs. 2019;28(13–14):2486–98. https://doi.org/10.1111/jocn.14842
29. Kolukısa Tarhan A, Garousi V, Turetken O, Söylemez M, Garossi S. Maturity assessment and maturity models in health care: a multivocal literature review. Digit Health. 2020;6:2055207620914772. https://doi.org/10.1177/2055207620914772
30. de Mello BH, Rigo SJ, da Costa CA, da Rosa Righi R, Donida B, Bez MR, et al. Semantic interoperability in health records standards: a systematic literature review. Health Technol (Berl). 2022;12(2):255–72. https://doi.org/10.1007/s12553-022-00639-w
31. Vis C, Bührmann L, Riper H, Ossebaard HC. Health technology assessment frameworks for eHealth: a systematic review. Int J Technol Assess Health Care. 2020;36(3):204–16. https://doi.org/10.1017/S026646232000015X
32. Morelli S, D'Avenio G, Daniele C, Grigioni M, Giansanti D. Under the tech umbrella: assessing the landscape of telemedicine innovations (Telemechron Study). Healthcare. 2024;12(6):615. https://doi.org/10.3390/healthcare12060615
33. Parvez A, Saleem J, Bhatti MA, Hasan A, Mahmood A, Ali Z, et al. Aligning practitioner's perception: empowering MAST framework for evaluating telemedicine services. Digit Health. 2024;10:20552076241297317. https://doi.org/10.1177/20552076241297317
34. Paleari L, Malini V, Paoli G, Scillieri S, Bighin C, Blobel B, et al. EU-Funded Telemedicine projects – assessment of, and lessons learned from, in the light of the SARS-CoV-2 pandemic. Front Med (Lausanne). 2022;9:849998. https://doi.org/10.3389/fmed.2022.849998
35. RossiMori A. Extend the ContSys standard to support the continuity of care across health and social care contexts. Int J Integr Care. 2020;21(S1):198. https://doi.org/10.5334/ijic.ICIC20519
36. Sun L, Jiang X, Ren H, Guo Y. Edge-cloud computing and artificial intelligence in internet of medical things: architecture, technology and application. IEEE Access. 2020;8:101079–92. https://doi.org/10.1109/ACCESS.2020.2997831
37. Goel A, Neduncheliyan S. With the convergence of Blockchain, AI, and the Internet of Medical Things (IoMT). In: Khurana M, Thakur A, Kantha A, Shieh C-S, Shukla RK, editors. Machine Learning Algorithms: First International Conference, ICMLA 2024. Himachal Pradesh, India, February 23–24, 2024, Proceedings. Cham: Springer Nature; 2024, Vol. 2238, p. 194.
38. Gupta S, Sharma HK, Kapoor M. Blockchain for secure healthcare using Internet of Medical Things (IoMT). Cham: Springer; 2023, p. 1–197.
39. Diop F, Faye BM, Niang I. Edge-AI and Internet of Things for intelligent systems: architectures, applications, and future perspectives. In: Saeed editor. International conference on e-infrastructure and e-services for developing countries. Cham: Springer Nature Switzerland; 2023, pp. 111–22.
40. Vasey B, Collins GS. Invited Commentary: transparent reporting of artificial intelligence models development and evaluation in surgery: the TRIPOD and DECIDE-AI checklists. Surgery. 2023;174(3):727–9. https://doi.org/10.1016/j.surg.2023.04.037
41. Jakovljevic M, Lamnisos D, Westerman R, Chattu VK, Cerda A. Future health spending forecast in leading emerging BRICS markets in 2030: health policy implications. Health Res Policy Syst. 2022;20(1):23. https://doi.org/10.1186/s12961-022-00822-5
42. Nan J, Xu LQ. Designing interoperable health care services based on fast healthcare interoperability resources: literature review. JMIR Med Inform. 2023;11(1):e44842. https://doi.org/10.2196/44842
43. Vorisek CN, Lehne M, Klopfenstein SAI, Mayer PJ, Bartschke A, Haese T, et al. Fast healthcare interoperability resources (FHIR) for interoperability in health research: systematic review. JMIR Med Inform. 2022;10(7):e35724. https://doi.org/10.2196/35724
44. Khatoon A. A blockchain-based smart contract system for healthcare management. Electronics. 2020;9(1):94.
45. Pedrera-Jiménez M, García-Barrio N, Frid S, Moner D, Boscá-Tomás D, Lozano-Rubí R, et al. Can OpenEHR, ISO 13606, and HL7 FHIR work together? An agnostic approach for the selection and application of electronic health record standards to the next-generation health data spaces. J Med Internet Res. 2023;25:e48702. https://doi.org/10.2196/48702
46. Yu J, Fu B, Cao A, He Z, Wu D. EdgeCNN: a hybrid architecture for agile learning of healthcare data from IoT devices.

In: 2018 IEEE 24th International Conference on Parallel and Distributed Systems (ICPADS). IEEE; 2018, p. 852–9.
47. Eisenberg JM, Rhee JM. Implications of telemedicine. Semin Spine Surg. 2024;36(3):101121.
48. Kurzweil C. Telemental health care and data privacy: current HIPAA privacy pitfalls and a proposed solution. Ann Adv Direct. 2021;31:155.
49. Schmidt A. Regulatory challenges in healthcare IT: ensuring compliance with HIPAA and GDPR. Acad J Sci Technol. 2020;3(1):1–7.
50. Al Omari H, Alkhateeb, A, Hammo B. Applying Togaf-Based Enterprise Architecture in the Healthcare Sector: A Case Study of the National Center for Diabetes In Jordan. Jordanian Journal of Computers & Information Technology 2024:10(2).
51. Kanimetta DK. AI and Predictive Analytics in Epic on Azure: A Technical Review of Population Health Management Innovation. Journal Of Engineering And Computer Sciences 2025;4(6):181–90.
52. Mukhopadhyay J. Telemedicine technology. chapter Telemedicine Technology by Jayanta Mukhopadhyay. In: Gupta R, Biswas D, editors. Health Monitoring Systems: An Enabling Technology for Patient Care. Boca Raton, Florida: CRC Press; 2019, pp. 121–46.
53. Abd Ghani MK, Mohamed MA, Mostafa SA, Mustapha A, Aman H, Jaber MM. The design of flexible telemedicine framework for healthcare big data. Int J Eng Technol. 2018;7(3.20):461–8.
54. Gochhait S, Singh T, Bende A, Thapliyal M, Vemulapalli H, Shukla G, et al. Implementation of EHR using digital transformation: a study on telemedicine. In: 2020 Int Conf for Emerging Technology (INCET). IEEE; 2020, p. 1–4.
55. Al Barazanchi I, Hamid SA, Abdulrahman RA, Rasheed H. Automated telemedicine and diagnosis system (ATDS) in diagnosing ailments and prescribing drugs. Period Eng Nat Sci. 2019;7(2):888–94. https://doi.org/10.21533/pen.v7i2.486
56. Kumar NS, Nirmalkumar P. An intelligent decision-support system for telemedicine. Appl Math Inf Sci. 2018;5(12):983–93.
57. Villafuerte N, Manzano S, Ayala P, García MV. Artificial intelligence in virtual telemedicine triage: a respiratory infection diagnosis tool with electronic measuring device. Future Internet. 2023;15(7):227. https://doi.org/10.3390/fi15070227
58. Collins GS, Moons KGM, Dhiman P, Riley RD, Beam AL, Van Calster B, et al. TRIPOD+ AI statement: updated guidance for reporting clinical prediction models that use regression or machine learning methods. BMJ 2024;385:1-14. https://doi.org/10.1136/bmj-2023-078378
59. Baker J, Stanley A. Telemedicine technology: a review of services, equipment, and other aspects. Curr Allergy Asthma Rep. 2018;18:1–8. https://doi.org/10.1007/s11882-018-0814-6
60. Mohamed W, Abdellatif MM. Telemedicine: an IoT application for healthcare systems. In: Proc 8th Int Conf Softw Inf Eng; 2019 Apr, p. 173–7.
61. Handayani PW, Hidayanto AN, Budi I. User acceptance factors of hospital information systems and related technologies: systematic review. Inform Health Soc Care. 2018;43(4):401–26. https://doi.org/10.1080/17538157.2017.1353999
62. Kondakov A, Kulik S. Intelligent information system for telemedicine. Procedia Comput Sci 2020;169:240–3.
63. Jin MX, Kim SY, Miller LJ, Behari G, Correa R. Telemedicine: current impact on the future. Cureus. 2020;12(8). Page number 1–5. https://doi.org/10.7759/cureus.9891
64. Gøeg KR, Rasmussen RK, Jensen L, Wollesen CM, Larsen S, Pape-Haugaard LB. A future-proof architecture for telemedicine using loose-coupled modules and HL7 FHIR. Comput Methods Programs Biomed. 2018;160:95–101. https://doi.org/10.1016/j.cmpb.2018.03.010
65. Singh KU, Abu-Hamatta HS, Kumar A, Singhal A, Rashid M, Bashir AK. Secure watermarking scheme for color DICOM images in telemedicine applications. Comput Mater Contin. 2021;70(2):2525–42. https://doi.org/10.32604/cmc.2022.019302
66. Delussu G, Mascia C, Sulis A, Meloni V, Del Rio M, Lianas L, et al. A survey of openEHR clinical data repositories. Int J Med Inform 2024;191:1386–5056. https://doi.org/10.1016/j.ijmedinf.2024.105591.
67. Fields BG. Regulatory, legal, and ethical considerations of telemedicine. Sleep Med Clin. 2020;15(3):409. https://doi.org/10.1016/j.jsmc.2020.06.004
68. Nittari G, Khuman R, Baldoni S, Pallotta G, Battineni G, Sirignano A, et al. Telemedicine practice: review of the current ethical and legal challenges. Telemed J E Health. 2020;26(12):1427–37.
69. Tedeschi C. Ethical, legal, and social challenges in the development and implementation of disaster telemedicine. Disaster Med Public Health Prep. 2021;15(5):649–56. https://doi.org/10.1017/dmp.2020.118
70. Kumar AA, Rao SV, Goswami D. NS3 simulator for a study of data center networks. In: 2013 IEEE 12th international symposium on parallel and distributed computing. IEEE; 2013, pp. 224–31.
71. Borshchev A. Multi-method modelling: AnyLogic. In: Brailsford S, Churilov L, Dangerfield B, editors. Discrete-Event Simulation and System Dynamics for Management Decision Making. John Wiley & Sons; 2014.
72. Varga A, Hornig R. An overview of the OMNeT++ simulation environment. In: Proc 1st Int Conf Simulation Tools Tech Commun Netw Syst Workshops; 2008 Mar. p. 1–10.
73. Jones E, Cross-Barnet C. Telehealth as a tool to transform pediatric care: views from stakeholders. Telemed J E Health. 2023;29(12):1843–52. https://doi.org/10.1089/tmj.2022.0496
74. Silow-Carroll S, Edwards JN, Rodin D. Using electronic health records to improve quality and efficiency: the experiences of leading hospitals. Issue Brief (Commonw Fund). 2012;17(1):40.
75. Lockledge JC, Salustri FA. Design communication using a variation of the design structure matrix. In: Design management: process and information issues. 2001;2:27.