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A Service-Oriented, API-Driven Framework for Interoperability of Health Information Systems in the Democratic Republic of Congo

Kalema Josue (1), Vincent Havyarimana (2), Businge Mbabazi Phelix (3), and Julius Niyongabo (4)

(1) PhD student at Doctoral school, University of Burundi, Bujumbura;

(2) Full Professor, Department of Computer Engineering, Ecole Normale Superieur, Bujumbura;

(3) Professor, Department of Information System, University of Kabale, Uganda;

(4) Professor, Department of Information System, University of Burundi, Bujumbura;

Abstract: **Interoperability among health information systems remains a major challenge in the Democratic Republic of Congo (DRC) due to fragmented infrastructures, heterogeneous software platforms, limited connectivity, and lack of standardized data exchange mechanisms. These challenges hinder effective data sharing between hospitals, laboratories, and national health systems, ultimately affecting healthcare delivery and public health decision-making. This paper proposes an API-driven interoperability framework based on Service-Oriented Architecture (SOA) and the Service-Oriented Analysis and Design (SOAD) methodology to address these issues .The proposed approach follows a structured methodology organized into three abstraction levels: Conceptual View (CV), Logical View (LV), and Physical View (PV). At the conceptual level, healthcare business processes are analyzed and decomposed into reusable business services, consolidated into a service portfolio. At the logical level, Enterprise Architecture and SOA principles are applied to map business services into interoperable software services exposed through RESTful APIs. At the physical level, the solution is implemented using a layered and microservices-based architecture, incorporating an API Gateway, domain-specific microservices, MySQL and MongoDB for transactional data storage, and Hadoop for large-scale health data analytics .The architecture is designed to operate under the infrastructural constraints of the DRC by supporting modular deployment, loose coupling, and resilience to network instability. Scenario-based evaluation demonstrates that the proposed solution enables secure, scalable, and flexible data exchange without requiring major modifications to existing systems. The results indicate that an SOAD-guided, API-driven interoperability framework is a viable and sustainable approach for strengthening digital health ecosystems in low-resource environments such as the DRC.**

Keywords: Health Information Systems; Interoperability; Service-Oriented Architecture (SOA); Service-Oriented Analysis and Design (SOAD); RESTful APIs;Microservices Architecture; Digital Health; Enterprise Architecture; Health Data Integration; Democratic Republic of Congo (DRC);

1. INTRODUCTION

The rate of application of information and communication technology (ICT) has now become a significant indication of economic success. Several developing countries have prioritized technical innovation in their national growth objectives and have made large expenditures in ICT. The healthcare system has changed in the twenty-first century due to the usage of information and communication technology (ICT) in healthcare services and patients' desire to pay more attention to their health [1]. The application of ICTs in healthcare is known as electronic health (e-Health), and the researcher chose the abbreviated term in most sections of this study [2]. eHealth is a relatively recent topic of research [3], and it is typically multidisciplinary. "The application of information, communication, computing, and sensing technologies across the entire range of functions and processes forming the practice and delivery of health care services" is the definition of "eHealth" [3]. Effective eHealth implementation, according to this definition, involves much more than simply technology [4] [5]. and involves stakeholders and procedures from a wide variety of health care duties [6]. Because of this, many researchers and organizations have different definitions and justifications for eHealth.

E-health is made up of a number of applications that support patient care and administration. Applications include EMRs, Telemedicine, Health Knowledge Management, M-Health, Consumer Health Informatics (CHI), and Healthcare Information Systems (HIS). The exchange of medical information via a media transmission link between two groups located at different geological sites is known as telemedicine [7]. Telemedicine includes video conferencing, where data exchange between health workers and patients is done via a video link [8].In the same context the author [9] says that Telemedicine refers to the use of ICT technologies to overcome barriers such as time constraints in the treatment of certain illnesses. When used properly, telemedicine can be a cost-effective method of gaining proficiency in the health care systems of different nations, according to [10]. Systems that gather, examine, store, retrieve, and assess health data are referred to as health information systems, or health management information systems (HMIS).

A health management information system integrates data and offers access to support and protect population health, according to [11].According to [12], the purpose of the Health Management Information System is to regularly assess service quality by comparing specified requirements to perceived service delivery. the author [13] defines mobile health as the use of mobile communications to enhance healthcare service delivery. According to the author [14], mobile devices and the internet present new possibilities for managing and promoting health. Additionally, patients, healthcare professionals, and the general public can all benefit from better access to a variety of knowledge sources thanks to these tools.

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Electronic Medical Records (EMR) also generally referred to as Electronic Health Records (EHR) are apps that are used to preserve patient's clinical history and support medical actions by healthcare specialists. They provide details about the patient's general medical history, treatment, and test results. As a result, electronic health records store patient data and make it easier for various medical professionals to communicate with one another. Moreover the care givers can access the patient information electronically through usage of certain authorization [15].

Digital health systems are increasingly utilized in the Democratic Republic of Congo (DRC) to improve illness surveillance, reporting, clinical management, and health logistics. Platforms that function independently across provinces include DHIS2 (for national health reporting), OpenMRS (for electronic medical records), iHRIS (for human resource information), and different laboratory or supply-chain systems [16] [17]. Despite the fact that these tools play a major role in data collecting and service delivery, their fragmentation has led to an ecosystem of health information where data are isolated, making it unable to make comprehensive decisions. Health facilities frequently use incompatible tools, duplicate inputs, and manual data transfers, which causes delays, mistakes, and decreased reliability of national health indicators [16].

A variety of healthcare applications are developed by different vendors and operate on different platforms in e-health system development. Interoperability, which is crucial for data and information interchange, is one of the difficulties in the context of app development [18]. Over time, healthcare applications start to transition from paper-based to computer-based paperless. Population data, health insurance data, and electronic medical records are examples of pertinent information that healthcare organizations, including hospitals, need for their e-health. In order to give their citizens better public services, many nations have been actively working to promote interoperability for data sharing and electronic transactions among government institutions [19].

In an e-health system, patient data is maintained in a distributed data source [20], which is an organization of healthcare providers like physicians, hospitals, labs, and others.

Because these healthcare providers are independent, the organization manages the data on its own. As a result, each company has committed to sharing data while taking goals, plans, and agreed-upon data into account.

The capacity of two or more systems or components to communicate information and use that information is often referred to as interoperability [21]. Interoperability is facilitated in large part by data sharing and information format. It is crucial to standardize information formats and data interchange [22]. Collaboration between various organizations and information systems is made possible via interoperability. Figure 1 illustrates the four levels of interoperability. An interface that is published in accordance with a particular standard is necessary for the development of data interoperability. Such an interface is not necessary for a system that does not need to be able to share data and information [23]. The organizational interoperability level permits both internal and external interoperability, as seen in Figure 1.

Internal interoperability can occur in some data/information sources from an organization, while external interoperability allows the exchange of data perfom by different organizations.

Tab 1. Levels of Interoperability.

Organizational Interoperability	Business process integration beyond the boundaries of a single organization
Semantic Interoperability	Ensuring the same meaning of exchanged data through predefined and shared meaning of terms and expressions
Syntactic Interoperability	Exchange of information through predefined data format and structure
Technical Interoperability	Technical end-to-end exchange of data among systems

Interoperability is necessary for the exchange of patient data in e-health systems. Minimal interoperability is implemented with two distinct systems or applications. While other systems or applications operate as data consumers, one system or application acts as a data provider [24].

The syntactic interoperability level, as shown in Table 1, that are developed using various programming languages and operating on different platforms. Semantic interoperability enables a document to be translated and read on the receiving data/information side, whereas syntactic interoperability concentrates on data interchange mechanisms [25].

The Service Oriented Architecture (SOA) paradigm can be used to implement interoperability. One strategy to satisfy the requirements for the quality and necessity of software development is SOA. SOA divides a system's functionality into services [26]. Then, separate apps running on different platforms can communicate and share information without being directly connected to one another (loosely coupled). SOA is a type of architectural technology that divides major functionality into smaller services with defined goals in accordance with the concepts of service orientation [27]. CORBA (Common Object Request Broker Architecture), DCOM (Distributed Component Object Model), RMI (Remote Method Invocation), and Web Services are just a few of the technologies that can be utilized to achieve SOA architecture [28]. On the other hand, several of these technologies have flaws. For instance, CORBA, DCOM, and RMI are closed (proprietary), meaning that development is limited to specific platforms. Although the online service is web-based and open (non-proprietary),

Two electronic devices connected to a computer network can communicate with each other using the Web service [29]. The software module supplied by the service provider is the service that is owned by the web service [30]. Web services are founded on the idea of service-oriented architecture (SOA) as a different approach to distributed system development. Before the introduction of the REST protocol, web services were developed using the SOAP protocol [31]. The distinctions between the SOAP and REST protocols are seen in Figure 1. The SOAP Protocol specifies web services as three entities: service provider, service registry, and service consumer Figure 1(a). The service provider fulfills the customer's requests.

Generally speaking, an application that uses web services is the service consumer. The service register serves as a directory, offering a variety of services along with descriptions of those services.

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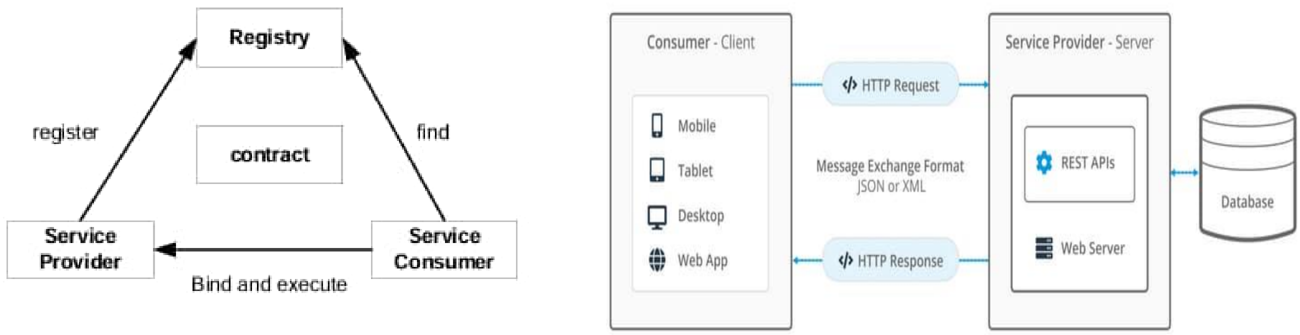
Service consumers can locate a service and communicate with the service provider based on the description and documentation supplied by this service registry. XML notation is used for communication between each entity.
The representational State Transfer (REST) protocol was introduced by Fielding [32] , as seen in Figure 1(b). According to Fielding, REST is a client-server exchange in which the client makes a request and the server responds. The resource, known as a URI, is the basis for communication between this client and server.
CRUD (Create, Read, Update, and Delete) database operations can be combined with RESTful Web Services' use of HTTP methods like GET, PUT, POST, and DELETE [33]. There are procedures that must be followed for system analysis and design in any software engineering approach. Conceptual View (CV), Logical View (LV), and Physical View (PV) are the three stages of the Service Oriented Architecture (SOA) design process. Developers employ an approach known as Service Oriented Analysis and Design (SOAD) to guide design implementation of the SOA concept [34]. A service portfolio will be created from the outcomes of these three processes [35].

Fig1. [33] SOAP and REST protocol, (a) SOAP protocol , (b) REST protocol

(a)

(b)



Health Information Systems (HIS) in the Democratic Republic of Congo (DRC) are characterized by heterogeneity, fragmentation, and limited interoperability [16]. Hospitals, laboratories, non-governmental organizations, and national health programs often use independent and heterogeneous information systems, developed using different technologies, data models, and standards. As a result, health data are stored in isolated silos, leading to inefficient data sharing, duplication of information, delayed clinical decision-making, and challenges in national health reporting and surveillance.
Existing interoperability efforts in the DRC are often ad hoc, relying on manual data exchange or tightly coupled system integrations that are difficult to scale, maintain, and adapt to evolving health system requirements [30]. Furthermore, the absence of a standardized interoperability framework based on Service-Oriented Architecture (SOA) and Application Programming Interfaces (APIs) limits the ability of health systems to securely exchange data in real time while preserving system autonomy.
Given the increasing need for integrated healthcare services, timely health reporting, and evidence-based decision-making, there is a critical need for a flexible, scalable, and standards-based interoperability framework that enables seamless communication among heterogeneous health information systems in the DRC without requiring extensive modifications to existing systems [36].
The main objective of this paper is to design and validate a service-oriented, API-driven interoperability framework that enables secure, scalable, and efficient data exchange among heterogeneous health information systems in the Democratic Republic of Congo

2. METHODOLOGY

This study adopts the **Service-Oriented Analysis and Design (SOAD) framework** as a logical and systematic approach to analyze, classify, and organize information related to health system interoperability in the Democratic Republic of Congo (DRC). SOAD is selected because it provides a structured methodology for transforming complex business processes into interoperable services through Service-Oriented Architecture (SOA). The methodology is structured into three main abstraction levels: **Conceptual View (CV)**, **Logical View (LV)**, and **Physical View (PV)** [37].

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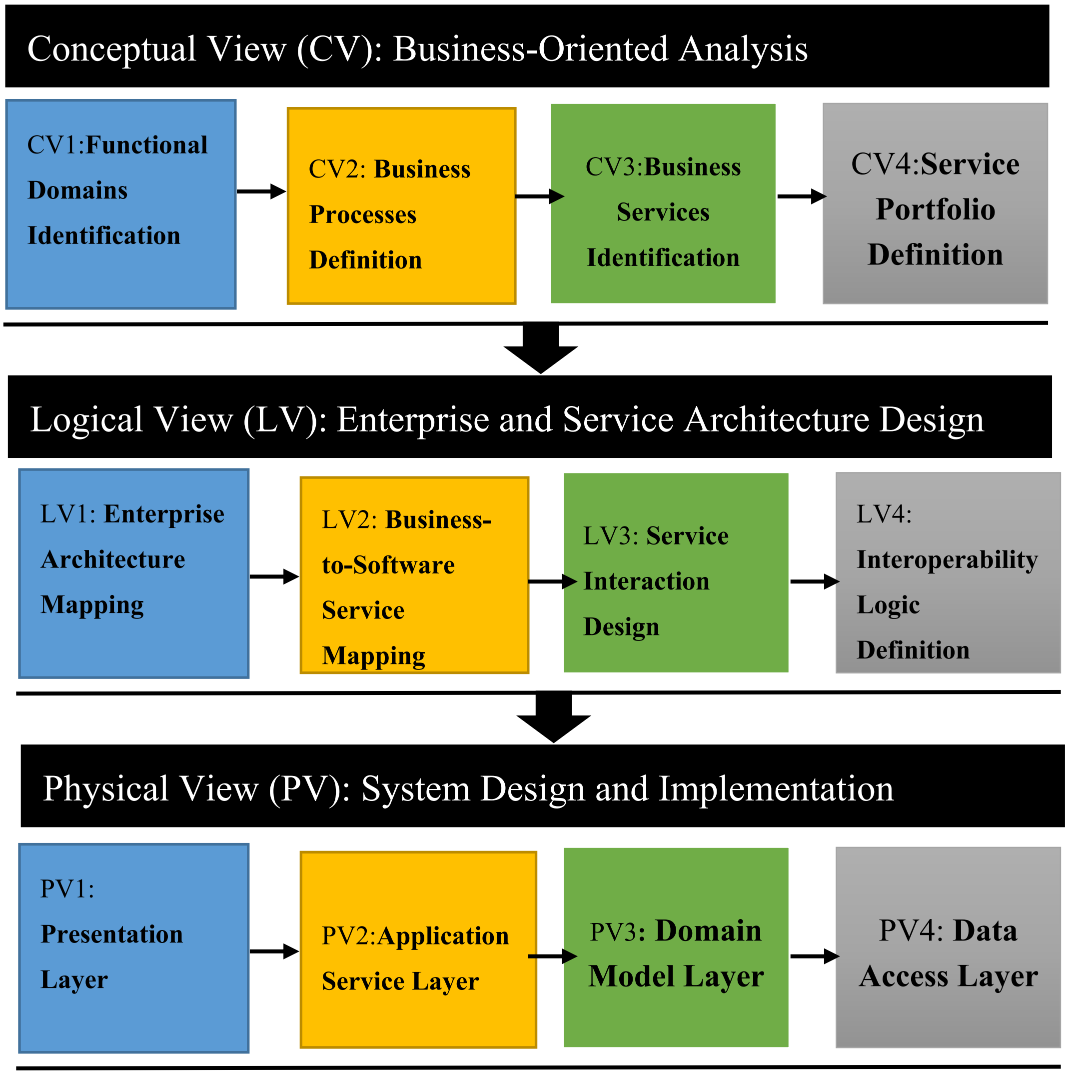
Fig2. SOAD-based methodology framework for health systems interoperability in the DRC



Tab 2. SOAD-Based Methodology Mapping for Health Systems Interoperability

SOAD View Description	Step Identifier	Analysis and Design Activities
The Conceptual View (CV) focuses on understanding the healthcare interoperability problem from a business and functional perspective. In this step, the existing health information ecosystem in the DRC is analyzed to identify fragmentation among hospital systems, laboratory systems, and national health platforms	CV1	Key functional domains are identified, including patient management, clinical encounters, laboratory services, reporting, and national health surveillance
	CV2	Core business processes such as patient registration, laboratory test requests, results reporting, and health data aggregation are modeled
	CV3	Each business process is decomposed into business services, for example: *Patient Information Service*, *Laboratory Result Service*, and *Health Reporting Service*.
	CV4	The identified business services are consolidated into a Service Portfolio, which serves as a repository of reusable and interoperable services. This portfolio represents the foundation for service consolidation and reuse in the proposed interoperability framework
The Logical View (LV) translates business services into logical system components using principles of Enterprise Architecture (EA) and Service-Oriented Architecture (SOA)	LV1	Mapping organizational objectives, business processes, data entities, applications, and IT infrastructure within the DRC health system context
	LV2	Business services identified in CV are mapped into **software services**, implemented as interoperable Web services and RESTful APIs
	LV3	Service interactions are defined using logical service contracts, message formats (JSON/FHIR), and communication protocols (HTTP/HTTPS).
	LV4	The interoperability layer is logically designed to mediate between heterogeneous systems without modifying legacy applications

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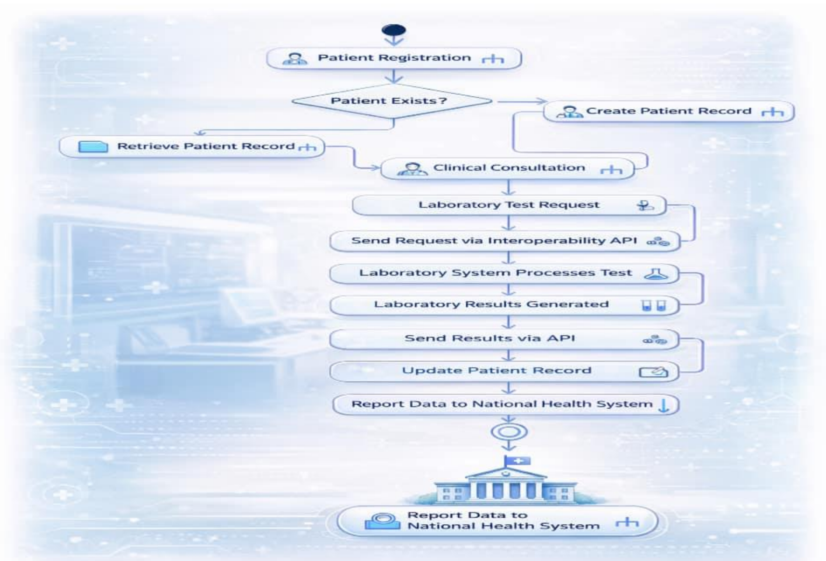
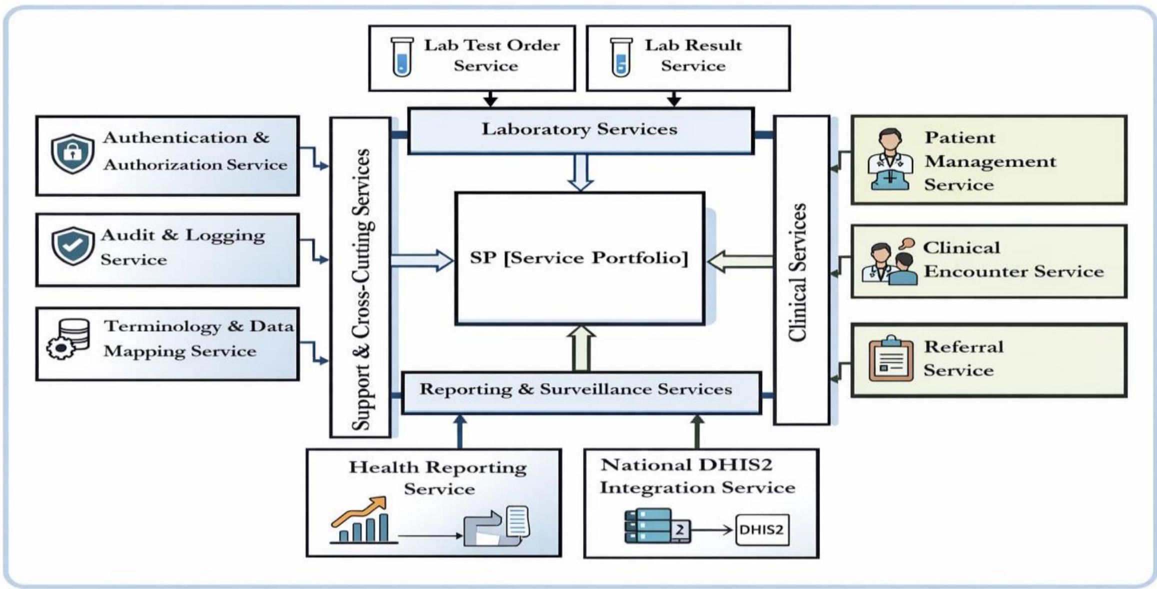
The Physical View (PV) represents the implementation-level design of the proposed solution. This step adopts a layered architecture consistent with SOAD literature	PV1	Describes the Graphical User Interface (GUI) or client systems (hospital systems, laboratory systems, dashboards) used to access interoperability services via APIs
	PV2	Contains RESTful Web services developed using **Spring Boot**, responsible for handling business logic, validation, and orchestration of interoperability services.
	PV3	Defines the data models and class diagrams representing health entities such as Patient, Encounter, Observation, and Organization. This layer also includes activity and sequence diagrams derived from SBPADs in the CV step
	PV4	Manages database operations using **Create, Read, Update, and Delete (CRUD)** mechanisms. This layer ensures persistent storage and retrieval of standardized health data.

Fig 3: illustrates the Business Process Activity Diagram (BPAD) describing the main healthcare workflow, from patient registration to laboratory result exchange and reporting to the national health system. This diagram supports the identification of business services in the Conceptual View of the SOAD framework.



This BPAD represents a high-level business process, exactly as required in the CV step of SOAD.It shows end-to-end healthcare data flow: Patient registration → clinical care → laboratory services → interoperability API → national reporting.
It clearly separates decision points, activities, and service interactions, which justifies the identification of business services and the service portfolio in the next step.
Fig 4: presents the proposed service portfolio resulting from the Conceptual View analysis. The portfolio groups healthcare business services into clinical, laboratory, reporting, and support domains, providing a foundation for service consolidation and reuse in the SOA-based interoperability framework



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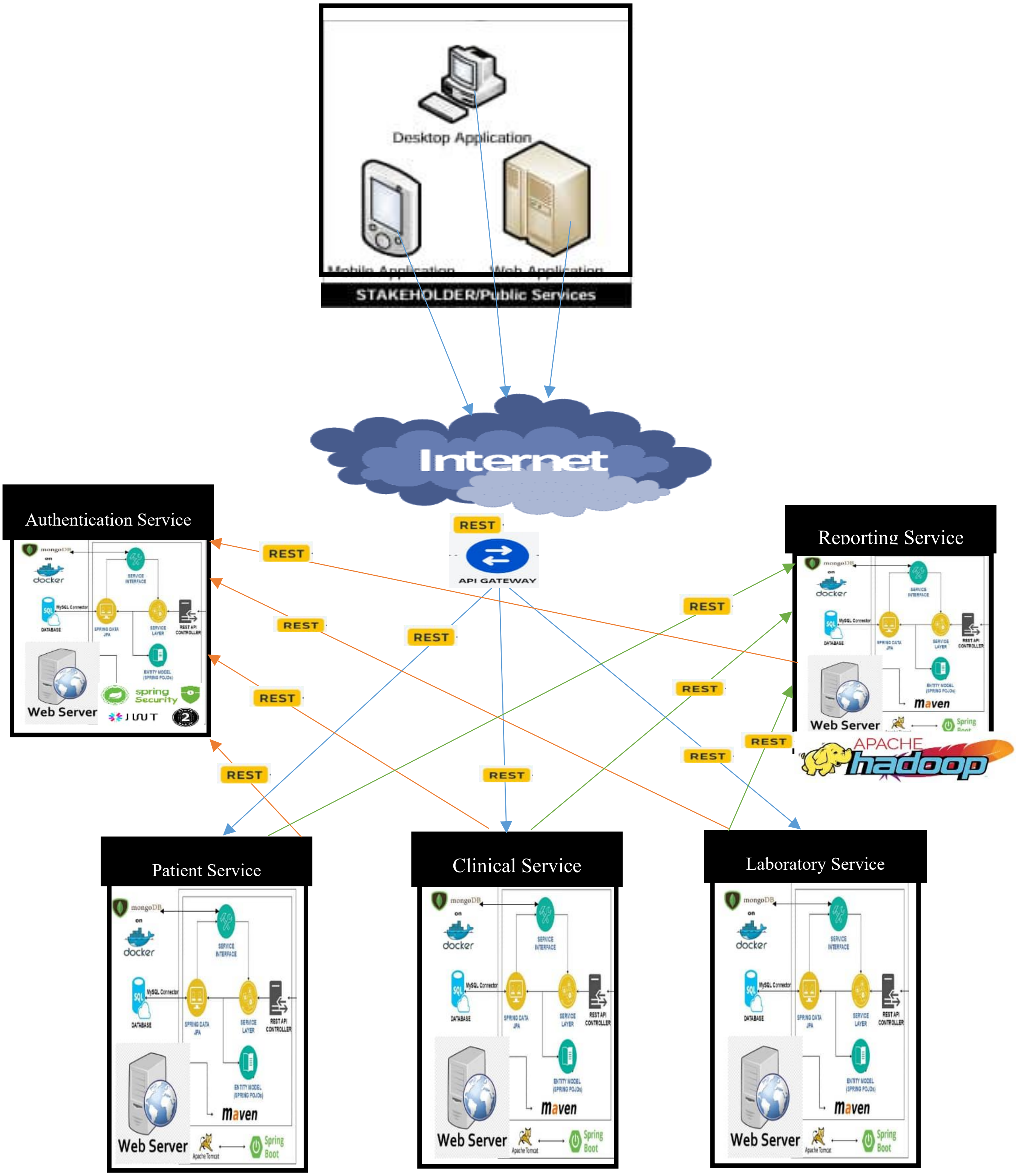
3. RESULTS

3.1. Proposed API-Driven Interoperability Architecture

The architecture introduces a central interoperability layer acting as a mediator between isolated systems. It exposes standardized REST APIs and implements FHIR data models.

Fig 5: illustrates the deployment view of the proposed interoperability platform. Client health systems communicate securely with the centralized API server, which manages authentication, service orchestration, and persistent storage in the health database.



The proposed interoperability platform is designed to operate effectively within the infrastructural realities of the Democratic Republic of Congo (DRC), where health information systems are highly heterogeneous and network connectivity is often limited or unstable. To address these constraints, the system adopts a lightweight, REST API–based microservices architecture that minimizes bandwidth usage while ensuring reliable data exchange.

Health facilities such as hospitals and laboratories interact with the platform through a REST API Gateway, which serves as a secure and centralized access point. The gateway simplifies integration for legacy systems commonly used in the DRC by exposing standardized interfaces and supporting asynchronous communication patterns, reducing dependency on continuous internet connectivity. When connectivity is interrupted, client systems can queue requests and synchronize data once the network is restored.

Domain-specific microservices handle healthcare functionalities independently, including patient registration, clinical encounters, laboratory services, and reporting. This modular design allows services to be deployed incrementally, which is essential in a context where technical capacity and infrastructure vary across regions. Failures in one service do not disrupt the entire system, improving resilience in resource-constrained environments.

Transactional health data are stored using MySQL and MongoDB to accommodate both structured and semi-structured data commonly produced by diverse health facilities. Local instances or regional servers can be used to reduce latency and dependence on central infrastructure. Periodic synchronization ensures data consistency at the national level.

For public health surveillance and decision-making, aggregated data are transferred to a Hadoop-based analytics platform. Hadoop supports large-scale processing of historical health data, enabling epidemiological analysis, disease monitoring, and reporting to national authorities without impacting daily clinical operations.

In a typical scenario, a rural hospital registers a patient and submits clinical or laboratory data through the API Gateway. Microservices process and store the data locally or regionally, and once connectivity permits, summarized information is transmitted to national analytics systems. This approach ensures interoperability, scalability, and sustainability within the operational constraints of the DRC health system.

4. DISCUSSION

4.1. Infrastructure and Connectivity Constraints in the DRC

The Democratic Republic of Congo faces significant infrastructural challenges that directly affect health systems interoperability. These include limited and unstable internet connectivity, especially in rural and remote areas, unreliable electricity supply, heterogeneous legacy systems, and limited technical capacity at health facility level [38] [39]. Unlike high-income settings, many health facilities in the DRC still rely on semi-digital or fragmented systems, making real-time data exchange difficult. These constraints necessitate interoperability solutions that are lightweight, resilient to network disruptions, and compatible with legacy applications [40].

The proposed API-driven, microservices-based architecture addresses these challenges by supporting asynchronous communication, modular deployment, and incremental integration. The separation between transactional systems (MySQL/MongoDB) and analytical platforms (Hadoop) further ensures that daily clinical operations are not affected by large-scale data processing tasks, which is critical in resource-constrained environments [1].

4.2. Comparison with Other Countries

In high-income countries such as the United States and members of the European Union, health interoperability solutions often rely on highly standardized infrastructures, widespread broadband connectivity, and strict regulatory frameworks [41]. Platforms based on HL7 FHIR are deployed with near real-time data exchange, cloud-native infrastructures [42], and centralized national health data exchanges. These environments allow for complex interoperability mechanisms that may not be immediately feasible in the DRC.

In contrast, middle-income countries such as Rwanda, Kenya, and India have adopted pragmatic and scalable approaches tailored to limited resources [43]. Rwanda's national health information exchange leverages OpenHIE and DHIS2 with gradual integration of facility-level systems [44]. Kenya has implemented API-based interoperability layers to connect county health systems with national platforms [45]. India's National Digital Health Mission adopts microservices and APIs while allowing phased onboarding of health providers.

Compared to these countries, the proposed DRC approach aligns more closely with low- and middle-income country (LMIC) best practices by prioritizing flexibility, service reuse, and offline tolerance rather than full real-time integration. The use of open standards, REST APIs, and modular services reflects successful strategies observed in similar contexts [46].

4.3. Implications for the DRC

This comparison demonstrates that while the DRC faces more severe infrastructural constraints than many countries, these challenges do not preclude effective interoperability. Instead, they require context-aware architectural choices. By adopting an SOAD-based, API-driven interoperability framework inspired by successful LMIC experiences, the DRC can progressively achieve scalable, secure, and sustainable health information exchange while laying a foundation for future digital health transformation

5. CONCLUSION

This study demonstrates that effective interoperability of health information systems in the DRC is achievable through a structured SOAD-based methodology and an API-driven SOA architecture. By aligning business processes with modular, reusable services and deploying them through microservices and standardized APIs, the proposed solution addresses key infrastructural and organizational constraints. The approach supports

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scalability, resilience, and gradual system integration, making it suitable for low-resource healthcare environments. Future work will focus on real-world deployment, performance optimization, and alignment with international interoperability frameworks such as OpenHIE and HL7 FHIR.

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AUTHOR CONTRIBUTIONS

KALEMA JOSUE DJAMBA

is currently a PhD Candidate at University of Burundi.

Kalema received his Masters of Information System (2017) and Bachelor's Degree in Computer Engineering (2015) from Institut Superieur d'informatique et de Gestion(DRC/Goma), and a second Master's Degree in Internet System (2021) from Kigali Independent University in Rwanda, with professional experience in web and mobile projects in the environment of Java/JEE,.Net, PHP, cartography.

Vincent Havyarimana ,PhD

received the B.S. degree in mathematics from the University of Burundi, Bujumbura, Burundi, in 2007, and the M.E. and Ph.D. degrees in computer science and electronic engineering from Hunan University, Changsha, China, in 2011 and 2016, respectively. He is currently a Full Professor and the Head of Section of Computer Engineering and a Coordinator of Pedagogical Training Project with Ecole Normale Superieure, Bujumbura. His research interests include wireless communication and mobile bioadjust computing.

Businge Phelix Mbabazi, PhD

is currently Dean/Associate Professor of Information Technology, Kabale University with PhD in Management Information System (2017), Masters of Information System (2010) and Bachelor's Degree in Computer Engineering (2007) of Kampala International University.

Dr.Businge has over Fifteen(15) years' experience in University Teaching since 2008 such as Kampala International University and Muni University.

Julius NIYONGABO , PhD

received the B.S. degree of Polytechnic Sciences in Mathematics from University of Burundi in 2006, the M.S. degree of Engineering in computer science and technology from Hunan University, Changsha, China, in 2011 and the Ph.D. in computer science and technology from University of Burundi in partnership with Hunan University in 2023. He is currently an expert at National Geomatic Center of Burundi. He is also a part-time Professor at University of Burundi, Hope Africa University and Olivia University of Bujumbura in Departments of Computer Science and Engineering.