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Architecture Design of Healthcare Software-as-a-Service Platform for Cloud-Based Clinical Decision Support Service

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Objectives: To design a cloud computing-based Healthcare Software-as-a-Service (SaaS) Platform (HSP) for delivering healthcare information services with low cost, high clinical value, and high usability. **Methods:** We analyzed the architecture requirements of an HSP, including the interface, business services, cloud SaaS, quality attributes, privacy and security, and multi-lingual capacity. For cloud-based SaaS services, we focused on Clinical Decision Service (CDS) content services, basic functional services, and mobile services. Microsoft's Azure cloud computing for Infrastructure-as-a-Service (IaaS) and Platform-as-a-Service (PaaS) was used. **Results:** The functional and software views of an HSP were designed in a layered architecture. External systems can be interfaced with the HSP using SOAP and REST/JSON. The multi-tenancy model of the HSP was designed as a shared database, with a separate schema for each tenant through a single application, although healthcare data can be physically located on a cloud or in a hospital, depending on regulations. The CDS services were categorized into rule-based services for medications, alert registration services, and knowledge services. **Conclusions:** We expect that cloud-based HSPs will allow small and mid-sized hospitals, in addition to large-sized hospitals, to adopt information infrastructures and health information technology with low system operation and maintenance costs.

Keywords: Clinical Decision Support Systems, Electronic Health Records, Computer Systems, Medical Order Entry Systems

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I. Introduction

Most hospitals have adopted an Electronic Health Record (EHR) system, also known as a hospital information system (HIS). Such systems are generally installed and operated as standalone systems in each hospital site, leading to the adoption of many systems and high maintenance costs. However, many small- and mid-sized hospitals as well as rural hospitals can no longer afford to invest in EHR systems or advanced healthcare information services, such as clinical decision support (CDS), which improve the quality of care and patient safety [1,2]. According to a survey on the adoption of EHR systems in South Korea in 2010 [3], the adoption rates of EHR systems in Korean tertiary teaching and general hospitals were 50.2% and 35.0%, respectively, due to barriers such as capital requirements and high maintenance costs.

As one of the emerging strategic information technologies, cloud computing is promising for its cost efficiency and its potential to provide quality information services in the healthcare industry [4]. Cloud computing is the use of computing resources (hardware and software) that are delivered as a service over a network. Also, cloud computing features three main types of service: Infrastructure-as-a- Service (IaaS), which uses virtualization technology; Platform-as-a-Service (PaaS), which includes an OS, development tools, and runtime tools; and Software-as-a-Service (SaaS), which provides software applications and data [5]. SaaS allows cloud providers to install, manage, and operate software applications, leading to lower operation cost and high provisioning to the end-user [5].

There are various aspects of cloud-based medical healthcare systems, such as infrastructure and dynamic scalability, information sharing, availability, and cloud monitoring tools [6]. Kuo [7] summarized the uses of adopting cloud computing in healthcare, which range from the cloud-based monitoring of patient's vital data, emergency medical systems, and home healthcare services, to bioinformatics research, such as colorectal cancer imaging analyses, and genetic testing models, highlighting the opportunities and challenges of cloud computing in healthcare regarding its management, technology, security, and legality.

This study sought to design a cloud computing-based Healthcare SaaS Platform (HSP) to deliver healthcare information services with low cost, high clinical value, and high usability. Regarding SaaS-based healthcare services, we focused on the sharing of Clinical Decision Service (CDS) content services, basic order entry services, and mobile services for multi-platform and multi-device support in an EHR system.

II. Methods

We defined HSP as a healthcare SaaS platform to provide a mobile, cloud-based modular EHR system. Figure 1 shows an overview of an HSP that utilizes cloud technology and infrastructures. We analyzed the architecture requirements of HSPs, including the interface, business services, cloud SaaS, quality attributes, privacy and security, as well as multilingual capacity. The requirements for a cloud SaaS platform include operational support services (OSS), business support services (BSS), a service consumer portal, a service provider portal, a service development portal, and a cross platform framework for implementing cloud SaaS. The required quality attributes include availability, performance, standardization, productivity, maintainability, and flexibility.

From the requirements, we selected the following factors that affect the system configuration, performance, and quality as the major architecture drivers for HSP.

- It should support multi-tenant SaaS.

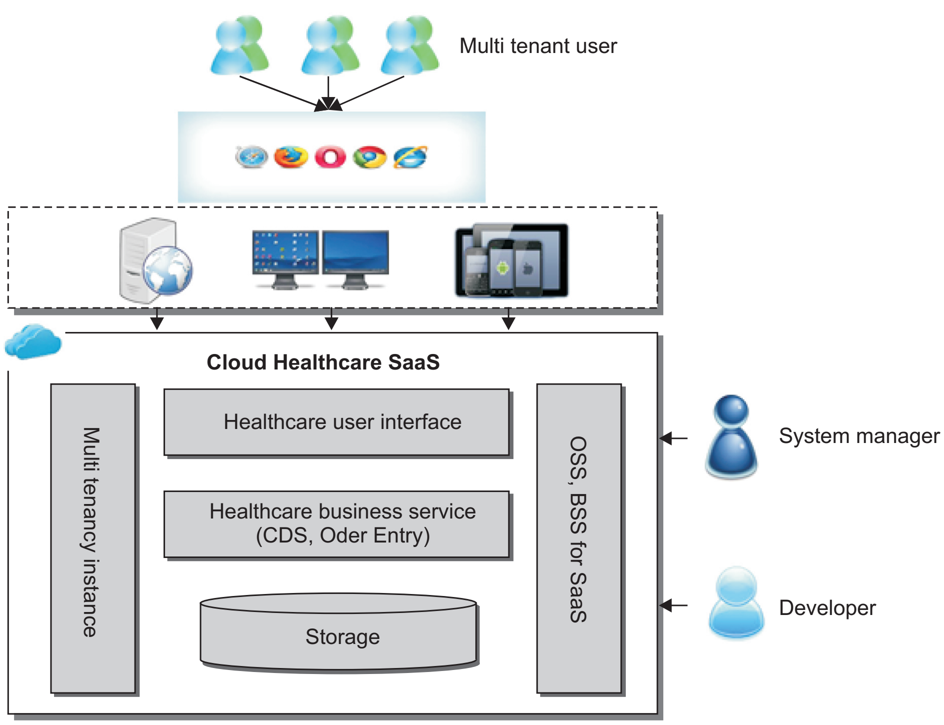

Figure 1. Overview of cloud computing-based Healthcare Software-as-a-Service (SaaS). CDS: Clinical Decision Support, OSS: operational support service, BSS: business support service.

- Only authorized users should be able to access the SaaS service.
- It should support accessibility by over three different mobile devices and platforms.
- It should support resource sharing based on cloud computing.
- It should provide functions to quickly catch errors and identify the causes of the errors.
- It should protect against system errors with comprehensive logging and monitoring.
- It should be easy to use.
- It should provide a stable service environment.

The user requirements of HSP include CDS services, order entry and display, immunization management, service availability checking, host manger account, tenant account, host account, CDA master management, patient information management, and appointments/admission scheduling for small- and mid-sized hospitals.

1. Scope of Cloud-Based SaaS Healthcare Services

For cloud-based SaaS services, we aimed to provide CDS content services, basic functional services, and mobile services as a cloud service to improve patient safety and quality of care in a hospital setting.

The CDS content service included tools and knowledge to aid medical staff in making clinical decisions and preventing medication-related errors, such as preventing the administration of duplicate medications, preventing drug-allergy interactions, adhering to clinical guidelines, providing standard order sets, and linking to clinical knowledge resources. For the collecting and driving requirements of the CDS content services, we analyzed required CDS functionalities of the HIMSS Analytics Electronic Medical Record Adoption Model (EMRAM) [8], Stage 2 Meaningful Use [9], and a Korean tertiary general university hospital. Figure 2 shows how a Clinical Decision Support Service (CDSS) can be provided as a cloud-based SaaS. The system was designed to integrate the patient management or order entry legacy systems with the CDSS in the form of an SaaS that includes modules of knowledge authoring tools, knowledge and content databases, interface servers for advanced CDS, and interface servers for retrieving knowledge and contents.

Regarding basic functional services, we also incorporated fundamental services for patient management, appointment management, and physician order entry into our cloud service for hospitals that do not have an electronic ordering system. These services are needed by non-digitalized hospitals to bring them up to date with CDS content services with low-cost maintenance.

Regarding mobile services, the CDS content services and basic functional services must be accessible via smart mobile devices, such as tablet PCs, smart phones, and PCs.

We considered international standards in the architecture design of the cloud-based HSP to achieve interoperability with heterogeneous legacy systems. We adopted the Health Level 7 (HL7) Infobutton standard and decision support service standard to provide context-aware knowledge retrieval services [10,11].

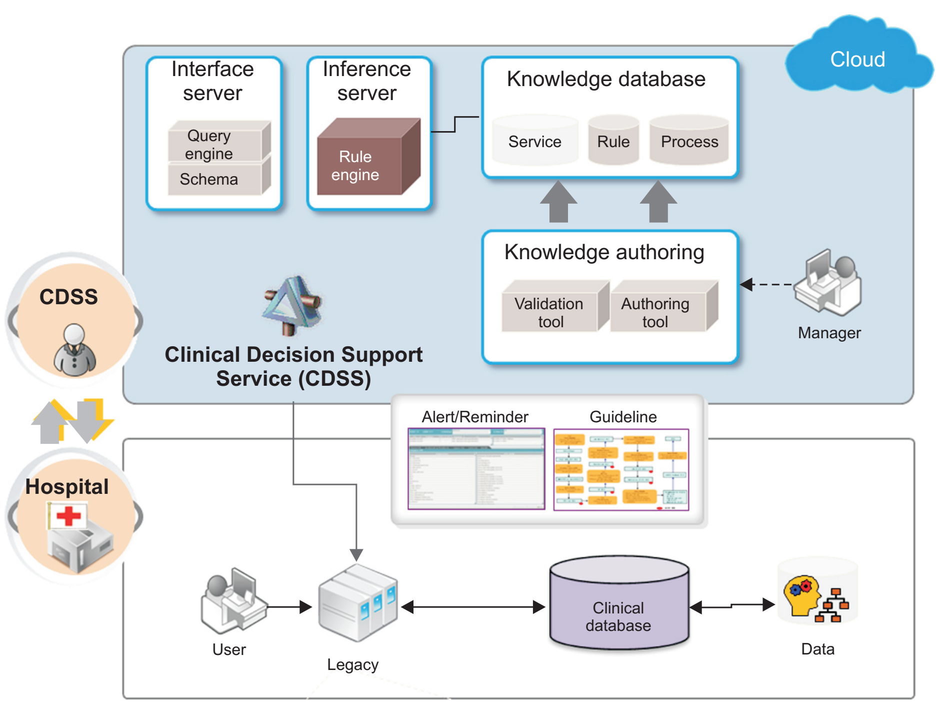

Figure 2. Overview of a cloud-based Clinical Decision Support Service (CDSS).

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2. Cloud Computing Platform

Because we focused on SaaS cloud computing, we used Microsoft's Azure cloud computing for IaaS and PaaS. Microsoft's Azure was adopted because it has been evaluated as a leading cloud computing solution in terms of its comprehensive features for application development and delivery and strategies [12]. We utilized platform & framework, management, and SDK for PaaS, and we utilized virtualization, server, networking, and storage for IaaS. The Azure services that we utilized were the following: BLOB storage, Queue storage, Table storage, Database service, Cloud service-web role, Cloud service-worker role, Visual studio online, and Traffic manager. Thus, the HSP consisted of healthcare services for CDS and for basic functional services; data services for multi-tenancy and healthcare areas; cloud management services for cloud SaaS, such as OSS and BSS; and technical services for a cloud SaaS application development framework.

Mobile services were designed to provide high usability and availability of healthcare information services to medical staff through interactive web technology based on the Mobile Enterprise Application Platform (MEAP). This platform enables one source and multiple services for various mobile operating systems, such as iOS, Android, and Windows Mobile. The cross platform open-source .Net development framework MonoCross was utilized to develop a multi-platform application.

3. Privacy and Security for Cloud-based Healthcare Services

To provide reliable and secure access services to sensitive healthcare data, we reviewed governmental security and privacy regulations and security threats on cloud computing services, such as privileged user access, data location, data segregation, data sharing, account hijacking, and abuse of cloud services [13-16].

We then defined the security requirements for the development of a healthcare SaaS in terms of technical, administrative, and physical aspects, as shown in Table 1.

III. Results

1. Architecture of the Healthcare SaaS Platform (HSP)

Figure 3 shows the architecture of the HSP based on the functional view of Microsoft's Azure cloud computing service. It consists of a cloud service consumer (hospital), a cloud service provider, and a cloud service creator. The service consumer/provider portal and the API provide portals and APIs for the consumers, providers, and developers. Regarding technical services, we incorporated a cross-platform UI framework for mobile applications, security for cloud computing services, a base framework for the development of business service, and a service-oriented architecture (SOA)

Table 1. Overview of technical security requirements

	PC	Network	Application	System & DB
Authentication/ authorization	Security USB, Prevention of data breach	Diagnosis of harmful websites, Separated network	Identification, Account control, Digital-rights management, Secure coding	DB access control, Secure OS
Access control	Security USB, Prevention of data breach, PC firewall	Diagnosis of harmful websites, Separated network, Firewall, Intrusion prevention system, Intrusion detection system, DMZ, Access control to network VPN/Private line,	Identification, Account control, Digital-rights management, Secure coding, PC firewall	DB access control, Secure OS
Encryption	Encryption of personal information	Encrypted transmission segment	Digital-rights management, Personal information masking	DB encryption
Backup/vaccine	PC Vaccine		Backup	Server vaccine, Backup
Common	Password management, Multi-factor authentication, Patch management system, Vulnerability diagnosis and simulation hacking, Integrated log management, Security control			

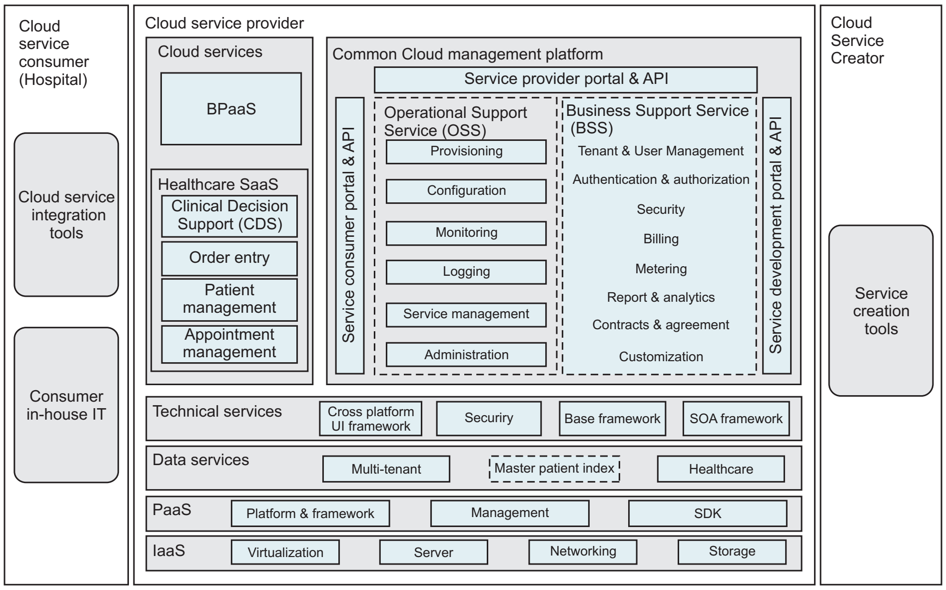

Figure 3. Architecture of the Healthcare SaaS Platform (HSP): functional view.

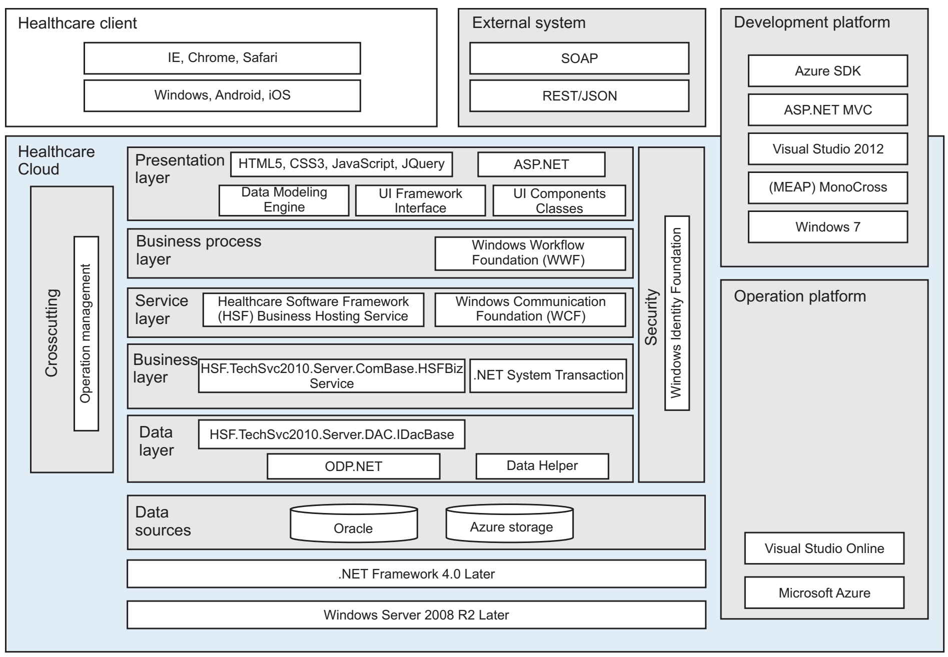

Figure 4. Architecture of the Healthcare SaaS Platform (HSP): software view.

framework for exposing business services to web services.

Figure 4 shows the software view of the implemented HSP. The HSP was designed with a layered architecture consisting of a data source, a data layer, a business layer, a service layer, a business process layer, and a presentation layer. External systems can be interfaced with the HSP using SOAP and REST/JSON.

2. Healthcare Services based on HSP

The healthcare services for the SaaS that we selected are listed in Table 2. The CDS services were categorized into rule-based services for medications, alert registration services, and knowledge services. These services can be integrated with the legacy systems of each hospital, or they can be provided with basic functional services on a cloud.

3. Cloud Configuration and Service Model

Because there are regulatory issues regarding the physical location of patients' medical data, for example, patients' medical data cannot be stored outside hospitals in South Korea, the multi-tenancy model of the HSP was designed as a shared database with separate schema for each tenant though a single application. Healthcare data can be physically located on a cloud or in a hospital, depending on the

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Table 2. Healthcare services based on the Healthcare SaaS Platform (HSP)

Categorization	Service
Clinical Decision Support services	Rule-based services for medications
	Overlapping prescriptions
	Drug-drug interactions
	Renal dosing guidelines
	Overdose prevention
	Age contraindications (child, elderly)
	Pregnancy contraindications
	Breast feeding contraindications
	Drug-disease interactions
	Alert registration service
	Drug allergies
	Age
	Pregnancy
	Breast feeding
	Knowledge service
	Drug information
	Order sets
	Clinical pathway order sets
	Antibiotics guidelines
	Transfusion guidelines
	Link to external knowledge resources
	Medication dose calculator
Basic functional services	Order entry
	Patient management
	Appointment management
	Order set management
Mobile services	Access to all of the above healthcare services via various smart devices

SaaS: Software-as-a-Service.

regulations. Figure 5 shows the HSP multi-tenancy model. It incorporates a single application and a shared database. Healthcare data can be managed by each tenant. A multi-tenant database is used to manage the tenant IDs for all tables and views, with a shared database and a shared schema.

Figure 6 shows the difference between the system usage environments of normal EHR and cloud-based EHR, indicating that users and hospitals do not need to have knowledge and control of the underlying infrastructure when adopting cloud-based computing platform and CDS services. Cloud-based EHR allows self-provisioning and pay-as-you-use as the HSP provides the functions of provisioning, configuration, logging, service management, tenant & user management, metering, and billing.

The cloud configuration of the HSP using the infrastructure and Microsoft's Azure cloud computing platform are shown in Figure 7.

IV. Discussion

In light of the increasing demands for low-cost health information technologies and mobile accessibility in the healthcare industry, in this study a cloud computing-based HSP was designed to support the development and integration of basic order entry functions, CDS services, and mobile services in a scalable and self-provisioning manner.

Regarding cloud-based healthcare information services, previous studies have reported the utilization of cloud computing, such as the development of a palm vein pattern recognition-based medical record system and medical imaging processing tools for emergency healthcare treatment in India [17], the development of an ECG tele-monitoring and tele-consultation system with ECG beat analysis [18-20], and the development of a CDS service and healthcare service for the diagnosis and management of chronic diseases [21]. In addition, a cloud-based HIS for exchanging information and medical images among hospitals and for the effective use of resources has been suggested [1,4]. Fernandez-Cardenosa et al. [22] proposed scenarios for the deployment of a cloud computing system for a large hospital and a network of primary care health centers. They proposed a hybrid EHR system that hosts images on hospital servers and the rest of the EHR system in the cloud, with the aim of sharing patient history and imaging processing tools among medical practitioners.

These studies have shown various uses of mobile and cloud computing technologies in the healthcare industry in terms of cost reduction and resource utilization, although data security is one of the challenging issues pertaining to cloud computing. This study addressed the technical architecture for a Microsoft Azure cloud computing-based HSP to implement healthcare services as an SaaS, considering the integration of legacy healthcare systems and cloud security issues. We sought to provide various CDS services, such as rule-based services for medications, alert registration services, and knowledge services. Dixon et al. [23] performed a pilot test of a cloud-based CDS for preventive care reminders, which exchanged CDS knowledge between two healthcare providers, reporting issues regarding governance, semantic interoperability, and usability.

Our study is an ongoing project, and the HSP is in the stage of implementation. However, the HSP would be useful for small and mid-sized hospitals to adopt an information

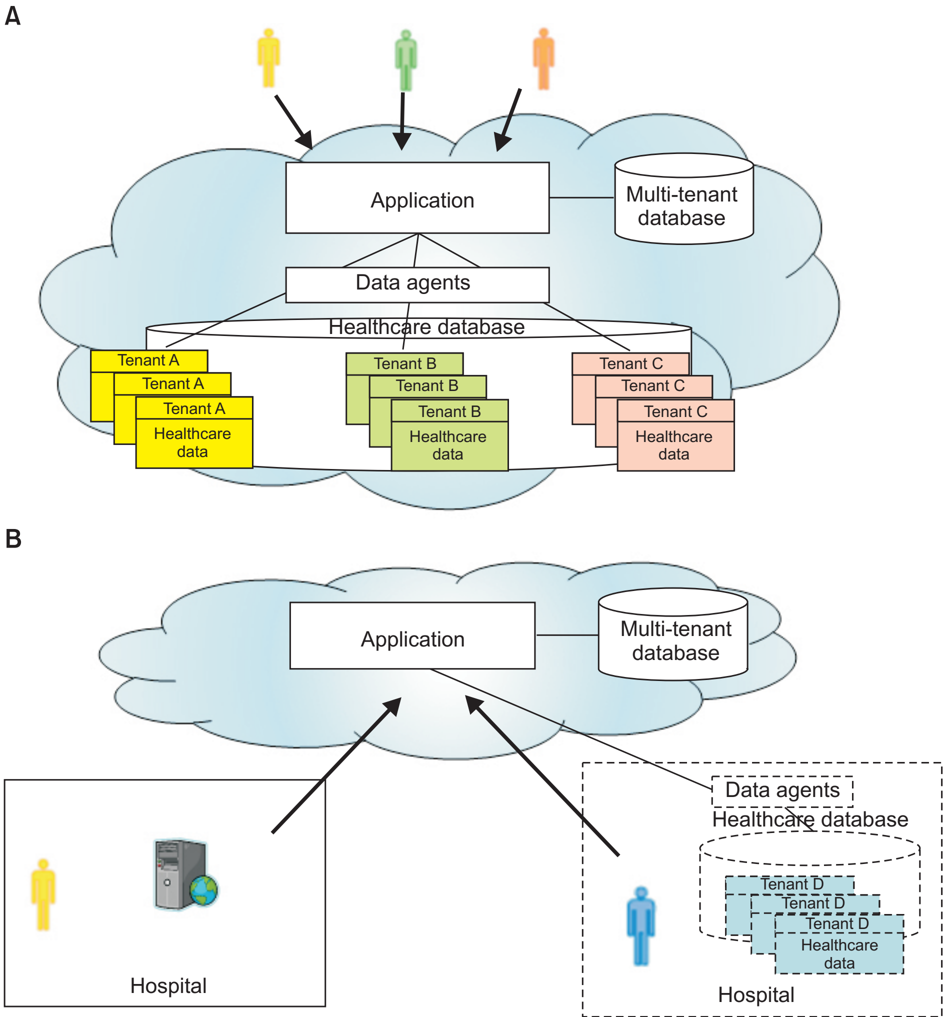

Figure 5. Healthcare SaaS Platform (HSP) multi-tenancy model, depending on the storage location of the healthcare data: (A) cloud storage or (B) hospital storage.

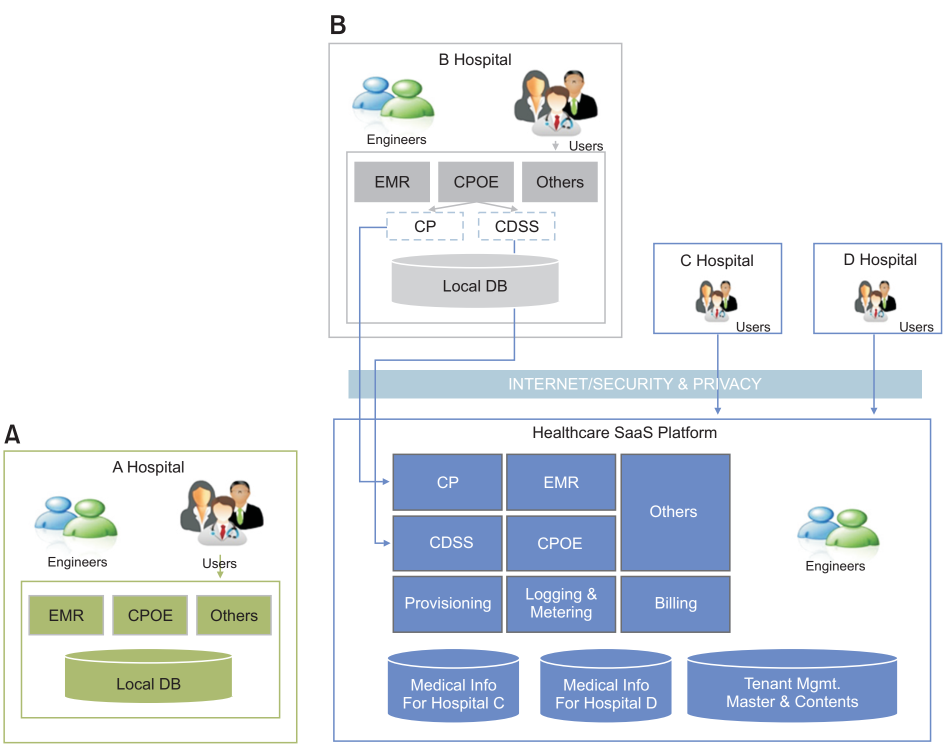

Figure 6. Normal EHR (A) vs. cloud-based EHR (B). EHR: Electronic Health Record, SaaS: Software-as-a-Service, CP: computing platform, EMR: Electronic Medical Record, CDSS: Clinical Decision Support Service, CPOE: computerized provider order entry.

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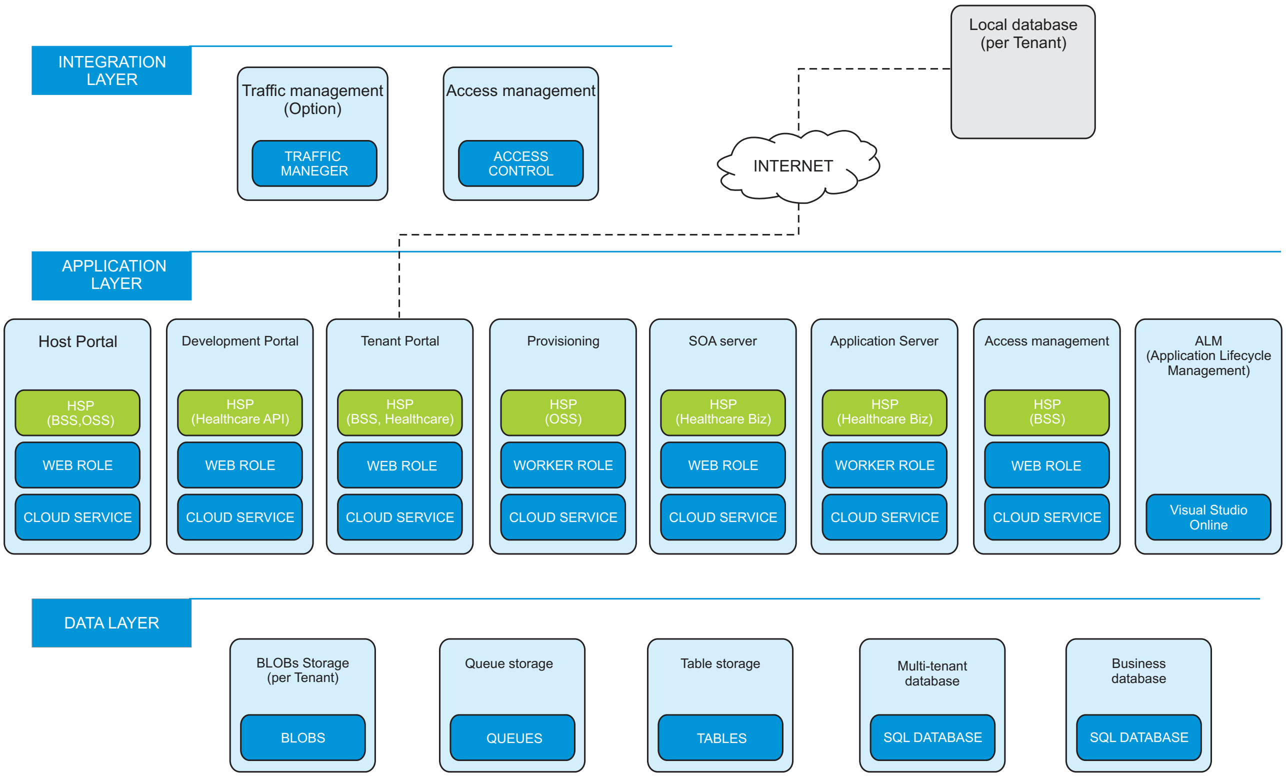

Figure 7. Cloud configuration using Microsoft's Azure cloud computing platform and the Healthcare SaaS Platform (HSP).

infrastructure and health information technology with low system operational and maintenance costs. By integrating the HSP with legacy systems, we expect that hospitals will be able to utilize up-to-date knowledge and various contents for CDS to improve patient safety and quality of care. During implementation of the HSP-based CDS service and other healthcare services, challenges concerning performance, semantics interoperability, usability, and security should be further addressed in future work. In addition, the evaluation of HSP-based clouding healthcare services will be performed in terms of the cost-benefit analysis and usability of the CDS services.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgments

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