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Develop Patient Monitoring and Support System Using Mobile Communication and Intelligent Reasoning

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Abstract—**In hospitals and other medical facilities, nursing staff are responsible for the care of critically ill patients. Many hospitals use information technology to support nursing care. However, most medical information systems use manually recorded vital sign data for patient care and control. Medical staff cannot automatically detect abnormalities and provide consistent and immediate health care services. Thus, in this research, a Mobile Intelligent Medical System (MIMS) is developed that supports mobile nursing applications and clinical decision support. The functions include RFID-based mobile applications for monitoring physiological instruments. A Java-based expert system integrated with an RFID-enabled patient data collection module and a rule base is used to issue warnings and send diagnostic messages. The MIMS network model demonstrates how to bring more efficient services to patients while increasing safety and quality in a dispersed medical environment.**

Keywords—**RFID, Java Expert System Shell (JESS), Mobile Intelligent Medical System (MIMS), u-care**

I. INTRODUCTION

Improvements in medical technology and healthcare have helped people around the world live longer and with a better quality of life. New medical technologies and improvements in health information systems have benefited medical supply ordering and management, patient record administration, medical diagnoses, and the provision of patient services. However, the nursing function of caring for and monitoring patients until health is restored has lagged behind in the development of new information systems and technologies. Patient care records are frequently distributed across a wide variety of health care systems and sites with little consideration of how data are to be shared, transferred or integrated. Nursing care requires that response time for emergency treatment be lowered and that the accuracy of on-site accident or critical care diagnosis be improved. Critical care patients with disabilities or life threatening diseases require continuous monitoring of physiological information to determine if the health indicators are within range. The development of new information systems for nursing and critical care require automatic vital sign monitoring, alarm systems, data integration, and data communications across different sites (ambulances, hospitals, critical care facilities, and outpatient clinics).

Hospitals tend to have numerous and independent medical information systems that support departments, clinical wards, surgeries, and laboratories. For example, radiology may have its own application system that is separated from the database maintained by the hospital's main information system. The critical issue is the ability to integrate the patient's medical records and image files so that different healthcare providers can share and communicate patents' vital signs and health data for immediate and accurate diagnosis and treatment. This paper presents an integrated solution for managing real time remote collection of medical data and the system framework developed for supporting the provision of dispersed nursing care. The paper provides a literature review of related research, a discussion of the proposed Mobile Intelligent Medical System (MIMS), the implementation details, and the conclusion and contribution of the research.

II. LITERATURE REVIEW

The emerging technologies for assisting physicians to order medicines, provide care, and manage nursing efforts are covered in this literature review. Information technologies are often applied to different medical units (e.g., surgery, inventory) to enhance processes and increase the reliability of diagnosis, to eliminate human error, and to search for and provide relevant medical data [1] [2]. Mobile technology has also been developed and applied in hospitals to enhance real-time monitoring and nursing care using mobile and wireless communication networks [3][4]. The speed and security of data transfers for mobile information technology are key factors considered by the users of these systems [5]. In order for mobile information technology to integrate tracking, monitoring, and detection technologies, the nursing processes and records must be well defined and streamlined. Hospitals are beginning to adopt information technologies in an attempt to lower equipment costs, improve processing times, and also allow for focused patient care. Hence, healthcare systems re-engineering consists of identifying the information technologies that will improve processes while reducing operation complexity, eliminating redundancy, and lowering costs [6].

Radio frequency identification (RFID) technology has been shown to provide direct benefits when applied to a hospital environment. RFID allows for the communication of information via an RF identification badge. The data stored in multiple RFID badges (tags) can be read actively and passively from long distances. Information can also be transmitted and stored within the tags. Thus, the RFID tags can be integrated with sensors (e.g., measurement of temperature and blood pressure) to allow for monitoring and record keeping of patient information in different locations at any given time [7]. RFID technology helps to automate both active and passive data collection while eliminating human error. The potential applications of RFID technology in the healthcare industry are reviewed in [8] and [9].

Medical staff report difficulties and inconveniences with processes that require transcribing data onto paper from instruments. Emerging technologies, such as the sphygmogram analyzer (SGA) for cardiovascular monitoring uses embedded systems and microprocessors chips to build a medical advisory system [10] that resolves many of the problems with user interfaces, data capture, and automated and assisted decision making. Related research focuses on advances in sensor technologies for detecting physiological changes [11], the application of Internet technology for remote patient monitoring and data collection [12], and the standardization of medical data for sharing and exchange using IT/XML based protocols [13].

Numerous intelligent decision support systems have been developed for physicians to support medical diagnosis and prescription management [14] [15]. These intelligent support technologies also support the development of more detailed rules for medical diagnosis since the real time data collected commonly combines case history data for current analysis and diagnostics. These approaches use case based reasoning combined with data mining. However, an inference based approach requires a significant amount of historical data to develop rules for automated medical diagnosis. The support systems must also be designed to send warning messages and recommend timely corrective actions. An early example of an intelligent decision support system using rules and data extracted from the patient's history and monitoring instrumentation is discussed in [16]. For this study, a RFID monitoring system is developed which combines an inference engine, a knowledge base, and a user interface to improve patient care. Using rules for cardiovascular diagnostic analysis, nursing action is recommended based on history and current instrument signals.

The Java Expert System Shell (JESS), developed by Ernest Friedman-Hill at Sandia National Laboratories, is a powerful tool for building intelligent applications. The major advantage of the software is the ease of integration with other Java programs using well defined application interfaces [17]. The JESS shell provides the basic elements of an expert system with an inference engine and a knowledge base that includes facts and rules. Facts are the construct that define information generally acknowledged to be true. JESS uses a special algorithm called Rete to match the rules to the facts. The rules are statements that have a left part (IF portion) and a right part (THEN portion) with an "implies" operator in between. Rules are used for taking actions based on facts in the knowledge base. Whenever the patterns of rules match with existing facts, the right hand side actions are executed [18].

III. MIMS DESIGN AND ANALYSIS

The Mobile Intelligent Medical System (MIMS) demonstrates how to receive patient's identification and bio-information using RFID technology and mobile devices. The Java Expert System Software (JESS) provides a rule-based inference engine to analyze real-time data (facts) collected from patient monitoring systems in different locations. Also considered in the system design is the time required for the system computer to access data from the mobile or remote monitoring equipment. The system monitors and periodically collects the patient's vital sign data and feeds this physiological information to the inference engine. The potential system needs and data solutions are described in Table 1.

Based on the needs and corresponding solutions, the system consists of a patient identification and location broadcasting RFID application, an interface to patient vital sign instruments, a mobile nursing application, and a clinical decision support system. The system also includes functions for issuing and detecting alarms, integrating patient information, sending messages, operating RFID tags and readers, synchronizing mobile nursing data, operating the mobile software and user interface, monitoring the database and user authority, encrypting communications, and communicating with a system center server.

The objective of the system is to support nursing and medical staff, reduce data entry error and redundancy, and integrate medical information from various monitoring devices for intelligent decision making. Since the system automatically receives information from medical monitoring devices, the intelligent software can support emergency care decision making and take preliminary action when staff are not available. Thus, the system provides a rapid response to a continuous stream of real-time patient data, a streamlined process for linking mobile monitoring devices to a central data depository, and a secure means of protecting patient data via encrypted EPC code. In the next section, the MIMS operational scope is depicted. Further, the means by which the system is integrated with the existing nursing functions are described.

TABLE 1. THE POTENTIAL NEEDS AND CORRESPONDING SOLUTIONS

Potential Needs	**System Solutions**
Identify and locate patients while reducing information input errors.	● Use an unique identification number (UID) code written onto the patient identification tag which links to the patient's electronic record and medical diagnoses. ● The RFID tag automatically monitors the location of the patient.
Enhance patient monitoring and safety while providing information security in the medical environment	● The RFID system rapidly transfers messages to RFID readers from active tags. ● The RFID tags use an encrypted UID code.
Increase the efficiency and convenience of the nursing process while improving medical care quality.	● Mobile devices can access patient care data and transmit the data to the centralized system. ● The mobile nursing care system can automatically record data to eliminate multiple entries and paper-based record keeping. ● The mobile data collection device provides a friendly human-computer interface (HCI).
The system requires intelligent reasoning and a faster response for emergency care management.	● The JESS inference engine supports diagnosis and treatment decisions based on medical facts and rules. ● RFID tags integrated with sensors allow for continuous and remote monitoring of vital signs. Changes in signs beyond the normal range instantly triggers alarms according to rules and medical processes.

IV. MIMS OPERATIONAL SCOPE

The system supports doctors and nurses monitoring both short term intensive care unit patients and long term critically ill patients. These patients have limited mobility and require the constant attention of the medical staff. Additionally, nurses monitor patient vital information and coordinate medical procedures across different medical units. The data generated at remote treatment and examination sites are recorded and saved in the medical information system. The MIMS replaces traditional paper-based data recording, provides an electronic record, and also provides a basis for message and alarm dispatching. The medical monitoring instruments collect patient information as well as medical process flow data. For example, the following process steps are recorded:

1. Patients check into the intensive care unit using the RFID EPC code which is used for all related treatment and data transfer.
2. All nursing care activities are recorded and centrally stored.
3. The physician's diagnosis, prescription orders, and medical procedures and outcomes are archived.
4. When the patient is discharged from the hospital, a summary of treatment is generated and the patient records are archived.

In order to extend medical services from a single hospital to a network of collaborating hospitals across a healthcare system, the RFID badge (tag) is used for patient identification, data collection and data exchange. MIMS transfers patient data via a secure network using standard XML data technology and the Web Service Definition Language (WSDL). The XML based HL7 data model standard is used as the data transfer schema. The exchange architecture is also based on the XML-EDI schema commonly used for medical information systems.

V. MIMS PLATFORM OPERATIONAL MODEL

The business processes (Fig. 1) for the MIMS platform requires that a Unique Identification Number (UID) be generated for each patient's RFID enabled bracelet. The bracelet, in turn, is linked to the patient's computerized medical record and links to a server running a three layer web based architecture. Included in the patient's records are nursing care instructions, prescribed medicines, diet requirements, and vital sign information. Doctors, nurses, and authorized medical staff carry wireless mobile devices that can also link to RFID readers using USB connectors. The RFID readers wirelessly access data from bracelets and monitoring devices and transmit information, including input from staff, to the MIMS.

The server computer hosts the JESS module which continuously analyses vital signs from both remote and directly connected instruments. The JESS system is used to control the alarm system and provide nursing care decision support. A standard hospital Ethernet link connects all monitoring servers and a data exchange module on the MIMS manages data transfers. The system enables the transfer of patient data within the hospital as well as between the hospital and remote service providers (e.g., physical rehabilitation facilities, ambulances).

VI. MIMS OPERATIONAL FLOW

When the medical staff transfers a patient to the intensive care unit, the patient's data and vital sign information flow is stored in the database. The doctors and nurses then evaluate the patient's status, establish procedures for care and recovery, and set limits for signaling alarms when receiving data from medical sensors. The medical instruments track the patient vital signs, the mobile devices collect the vital data for MIMS server, and the JESS rule-based module monitors and analyzes the data stream. The expert system signals an alarm to multiple mobile devices or the nursing station if abnormalities are identified. The system combines data from personal digital assistants (PDAs) and ultra mobile personal computers (UMPC). The health care and nursing process for MIMS (equipped with mobile device, remote physiological instrument, and JESS module) is shown in Fig. 2.

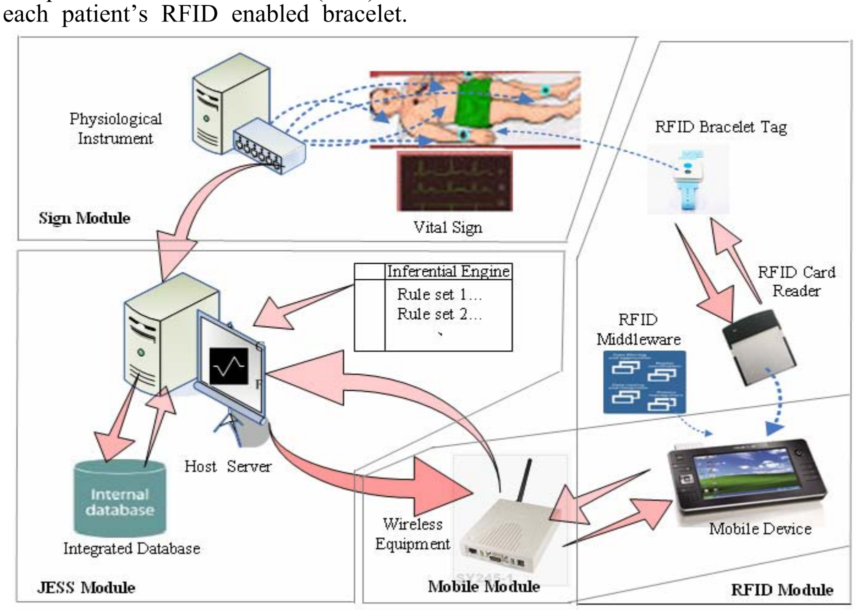

Figure 1. The distributed health care system with vital sign monitoring and alarm

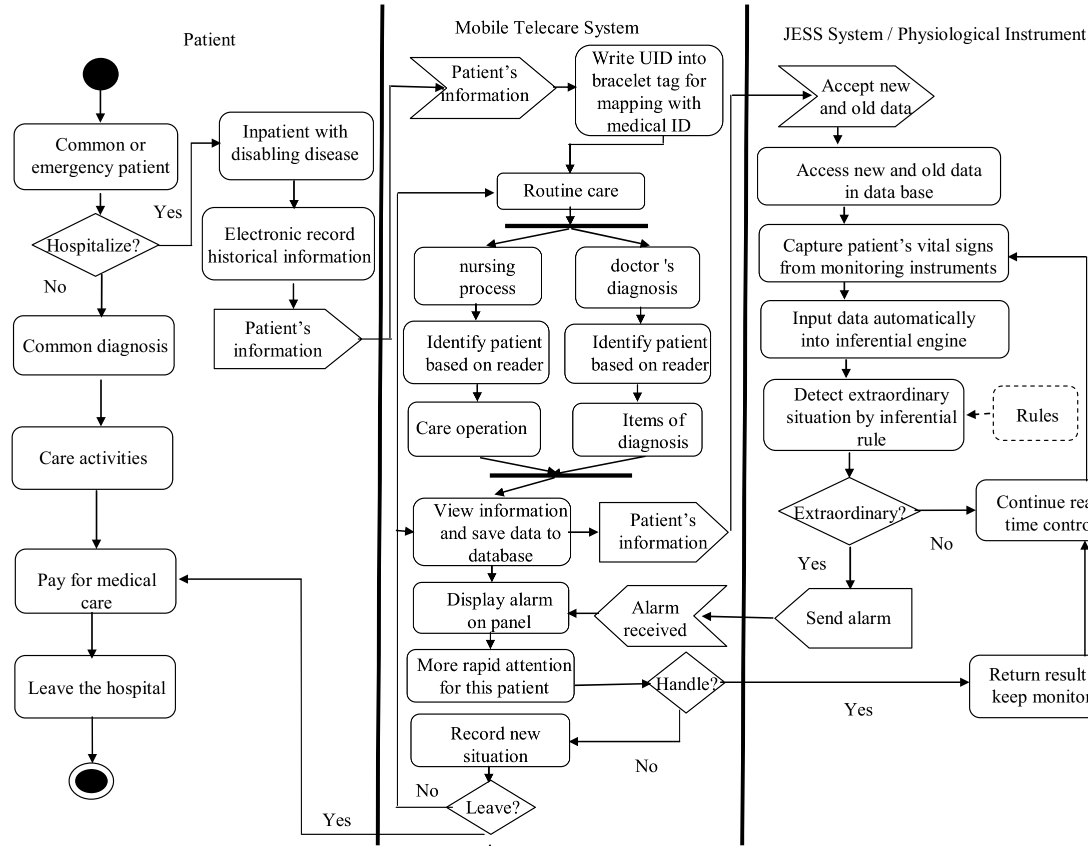

Figure 2. The process diagram for MIMS healthcare and nursing services

The multi-hospital MIMS is designed in a five layer framework as described below:

1. Data Layer: Includes all medical care data such as patient information, insurance data, diagnosis data, and medical treatment data. The data layer integrates with the Health Information System (HIS).
2. Access Layer: This layer includes several logical processing units and integrates nursing data, parameter and knowledge data, and data transmission. The access layer is a bridge between the data layer and the conversion layer.
3. Conversion Layer: Includes message delivery, the graphics unit, the digital data unit, and the data format unit.
4. Operator Layer: This layer includes the message unit, the image unit, the voice unit and the XML unit for data exchanges and sharing in various formats.
5. Presentation Layer: Includes presentation types, handheld devices, voice devices, and the client interfaces to the Health Information System (HIS). The mobile devices (PDA, mobile phone, etc.) are important for the mobility of nurses, physicians, and other healthcare service providers.

VII. IMPLEMENTATION OF MIMS

The MIMS is implemented as a Web-based platform that manages patient information, nursing processes, and care information. The system recodes data into standard data formats for exchanges in a wireless network environment. MIMS supports real-time communication between patients and medical staff using a mobile medical system, an RFID system, the JESS system, and the physiological data capture and transfer system.

A. *Construction of Mobile Telecare System*

The mobile devices connect to the RFID readers and use integrated software to manage vital nursing operations. The Windows operating system mobile devices use a USB connector to connect with the RFID reader. Nurses use the interface to transfer physiological records captured by the RFID reader into the mobile medical system which is then transmitted and archived in the database. The architecture consists of an RFID module, an administration module, a medical process logical module, and a data access module as shown in Fig. 3. The interface uses the Windows XP operating system with wireless access.

The real-time monitoring method was initially designed for mobile devices used to monitor patients with cardiovascular diseases. The medical staff read the physiological signs captured from instruments, stored in the database, and displayed on the panel. Computer terminals in the hospital are also used to read or write data to the database. The mobile telecare system provides doctors and nurses with the latest information from the database.

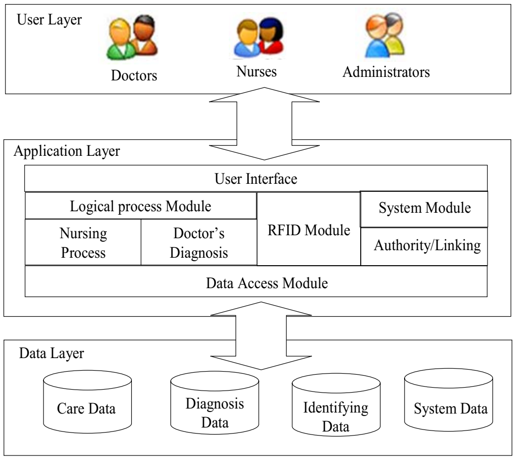

Figure 3. Three-layer architecture for the mobile telecare system

B. *Deployment of Clinical Decision Support*

Monitoring the patient's physiological data and analyzing the historical information is needed to build the internal database. The knowledge base that is constructed contains inference rules based on medical principles and experience. The MIMS, combined with JESS, uses the data and inferred rules to support medical decisions. When the system sounds an alarm, JESS can transmit the alarm to mobile devices and Web-base windows systems and recommend specific action. With the help of MIMS, the risk of serious harm to the patient due to lack of care is reduced. The patient's physiological signs consist of temperature, pulse, respiration, pulse oximetry (oxymeter), and total pulmonary vascular resistance (TPR).

The system is designed for patients requiring that their health condition be monitored for longer periods of time. The system measures the patient's physiological signs at remote locations and transfers the data to the server. Doctors can monitor patients' health conditions by analyzing the data in the server and can test decisions against expert rules. By linking automatic data capture (ADC) technology with computer instruments, the medical staff improves the performance of the intensive care unit. Since the system automatically converts large amounts of data into information, significant gains over paper based decision making is achieved. The rule-based inference engine is shown in Fig. 4.

The heuristic knowledge acquired from doctors and medical experts are built into an initial signal data rule-based expert system (ES). In this case study, the body temperature, pulse, respiration and pulse oximetry are collected from patients in real time. When certain combinations of signs and data are detected and the rules trigger an alarm, the system sends the warning across the hospital network with a recommended action. The operational process for the MIMS runs on the Web-based Java Expert System Shell (JESS) platform. With the flexibility of JESS, new rules can be added and existing rules modified without overhauling the system.

The wireless network communication architecture is capable of querying the patient's information and previous medical history. Therefore, based on the real time signs and historical data, the hospital can serve the patients' medical needs in a timely matter. Further, Fig. 5 demonstrates the cross-hospital MIMS network using the mobile health care system to provide medical services in a virtual health care community.

VIII. CONCLUSION

The mobile nursing care system using RFID technology strengthens the capabilities of staff to track patient's vital signs across various locations and in different medical facilities. The MIMS includes vital sign monitoring and alarming services, mobile nursing applications, and rule-based clinical decision support in a mobile nursing environment. The system continuously monitors critically ill patients with the objective of reducing the risk of serious harm resulting from the slow provision of health care. Further, we also believe the system can be extended to most medical domains and integrated with other hospital information systems. With more medical centers linked into the system, the MIMS will bring better and safer medical services to the healthcare industry. Further implementation efforts will include extending the signal based rules to a more comprehensive set of rules for emergency medical diagnostics and nursing care decision support.

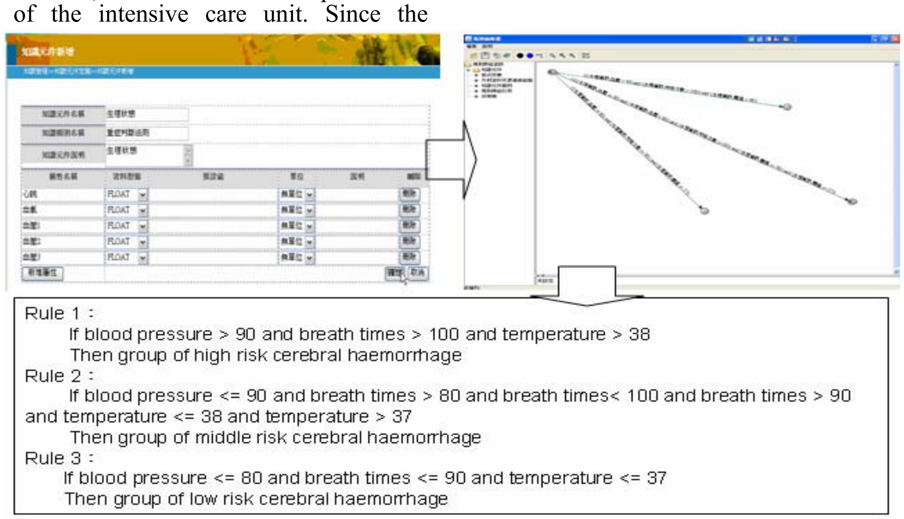

Figure 4. Example rules for vital sign alarm and clinical support

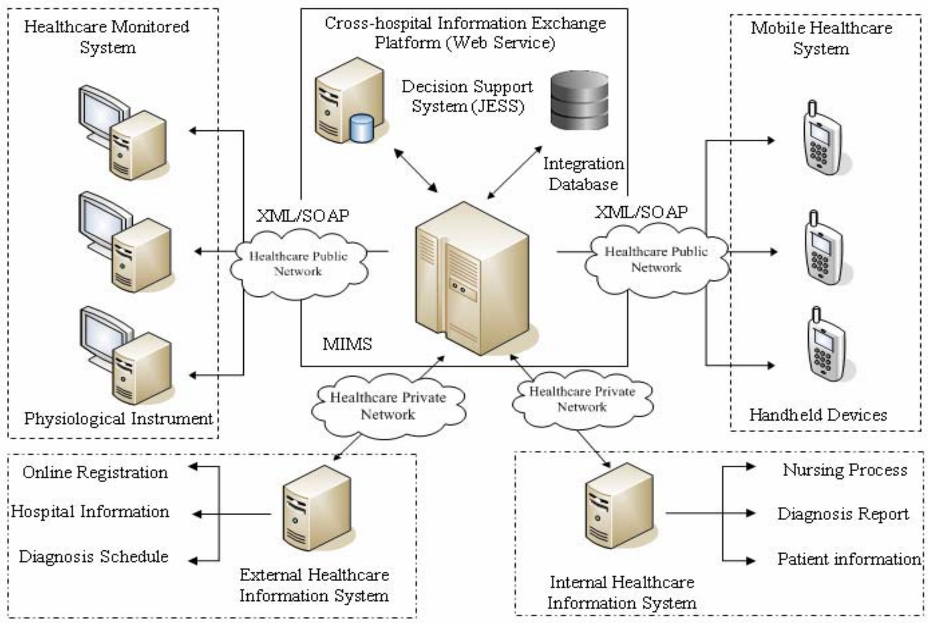

Figure 5. Cross-hospital MIMS network in a virtual healthcare environment

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