Electronic Prescriptions: A Ubiquitous Solution using Jini

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Abstract

Ubiquitous computing has thus far not touched the realm of electronic prescriptions. This paper describes a Jini-based solution for electronic prescriptions, which allows for their wireless transmission to in-range pharmacies and the augmentation of the service levels rendered to the user, with, for instance, information about queue lengths and estimated waiting times being provided to patients. Clinical evaluation of the prototype has highlighted general consensus in respect of its effectiveness, ease of use and usefulness.

1. Introduction

Telemedicine can be defined as the use of telecommunications technologies to provide medical information and services [7]. Recent advancements in information technology and telecommunication, and more specifically technologies such as the General Packet Radio Service (GPRS) and Wireless Fidelity (WiFi) have enabled ubiquitous interconnectivity, access to the Internet and World Wide Web, and opened up a realm of new possibilities for telemedicine solutions. Thus, integrating mobile information systems into the practice of healthcare will add value by helping to reduce costs, increase effectiveness, and improve patient satisfaction. It is only recently, however, that wireless technologies have been harnessed to act as tools coming to the aid of patients and clinicians alike.

The focus of our work has been to implement an ubiquitous solution for an Electronic Prescription System (EPS). Indeed, pilots of EPSs took place as early as 1997 in the UK [11]. These were respectively, the Transcript, Pharmacy2U and Flexiscript model. The Transcript model consists of using a 2-D barcode on a paper prescription that the patient delivers to a pharmacy of their choice. The pharmacist scans in the barcode, validates the digital signature and dispenses the drugs. The Pharmacy2U model relies on the patients using designated pharmacies. The General Practitioner (GP) encrypts and digitally signs the prescription, and sends it directly to the designated pharmacy. Lastly, the Flexiscript model relies on using a central storage where the prescriptions are stored until retrieved by a pharmacist. Although they were all beset by various shortcomings, acceptability of the developed EPSs was high [4]. Needless to say, none of these early developed solutions incorporated wireless technology.

2. Jini-based Telemedicine Applications

In a medical context, Jini has been applied in the department of nuclear medicine at Wilhelminenspital, the largest community hospital in Vienna, Austria. In this study, Knoll et al [6] integrated the combination-computed tomography (CT) scanner and SPECT (single-photon emission computed tomography) camera. The evaluation confirmed that Jini technology had increased Wilhelminenspitals' capacity to spot previously unseen tumors in their patients.

From a different perspective, Petrovski et al [9] integrated The Common Object Request Broker Architecture (CORBA), eXtended Markup Language (XML), Jini, Enterprise Java Beans (EJB), Java server Pages (JSP), HTML, and Wireless Markup Language (WML) to implement a health information system, which allows the health professionals to share their information in a timely fashion, integrated via a central brokering health system. As a part of their proposed solution, Jini technology was utilized to support the interfacing of observational appliances, such as electrocardiogram (ECG) monitoring devices, and applet-enabled PDAs. The resource limited PDAs were linked to the system via a Jini Surrogate host providing a TCP/IP server socket for the PDAs.

In related work, a remote healthcare monitoring system that utilizes 2.5/3G public wireless networks is described in [3]. In particular, the system enables remote monitoring, real-time and store-and-forward mode, of patient data collected by a Body Area Network (BAN). The internal communication via Bluetooth between the entities inside the BAN is referred to as intra-BAN, whilst the external

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communication for remote monitoring via 2,5/3G networks is called extra-BAN. A PDA is used as a gateway for communication between the extra-BAN and the remote back-end system. The platform is designed using Java, Jini and Jini Surrogate technologies. On the other hand, Parkka et al developed a wireless monitoring platform for personal weight management [8]. Their prototype provides the users with information on weight control, nutrition and exercise, which can be accessed anywhere whenever needed. The wireless wellness monitor system is an ad hoc network consisting of a home server, a mobile terminal and measurement devices, connected together via Bluetooth. Data from the measurement devices is captured using Jini and the Jini Surrogate architecture. This and other health related data are processed in the home server and presented on a PDA or a mobile terminal. Finally, Parkka et al argue that their system provides a platform and test-bed for assessing new techniques in the field of personal health management.

3. Wireless Prescription Systems

Bobbie et al [2] designed a wireless electronic prescription system for home-care patients. Their solution, which is based on smart cards, allows a home cared patient to order refill of prescriptions by sending requests to his/her doctors via a home gateway.The bedridden patient interacts with the gateway via a PDA, which is used to display the prescription information loaded from the smart card and to send refill orders. Furthermore, the pharmacy and the doctor can remotely update and manage the prescription through this gateway as well.

From a different perspective, Andre and Pol [1] constructed a middleware for transactional hospital applications running on wireless networks. Their solution allows clinicians to issue prescriptions (using a mobile computer connected to a wireless local network) when being at the patients' bed. However, their focus is on adapting the system to the quality of transmission of the wireless infrastructure rather than the electronic prescription system itself.

In related work, Kiél et al [5] evaluated a wireless prescription system named ePad, which is an application for generating and transmitting electronic prescriptions from PDAs and Web-enabled Personal Computers (PC). In this system, the prescriptions are written on the PDA at the point of care and transmitted during cradle synchronization with the PC, in which a complete prescription is generated and sent, by fax, to a predefined pharmacy. Moreover, ePad also offers a wireless mode. In this mode, the prescriptions are transmitted directly to the PC, without the need for cradle synchronization. The evaluation results were positive. The application was considered easy to install, intuitive, and reliable. Additionally, Kiél et al argue that writing a prescription on a PDA is accurate, simple, fast, and that patients, physicians, and pharmacists benefit from the added safety features of a legible prescription. A wireless prescription system, which provides wireless services to the physicians and web-based services to the system administrators and pharmacies, is described in [12]. The goal of this system is to reduce the time and cost used to create prescriptions as well as to demonstrate the applicability of Java enterprise edition (J2EE) architecture in supporting wireless services as well as Web-based services. Using this system, physicians can, by use of a PDA, issue new prescriptions or retrieve prescriptions by customer name or prescription ID. Pour et al [10] designed a prototype to support access of authorized physicians, pharmacists, and patients to prescription management system via mobile devices (PDAs) and Web browsers. The prototype was implemented using Java micro edition (J2ME) Web services and J2EE. To the best of our knowledge, however, no work has been done employing Jini technology in the implementation of an EPS.

4. Design of A Jini-based EPS

The main components in the prototype are: GP system, pharmacy system and Jini clients (Fig 1). The GP system consists of a desktop computer with a local database, which is connected to a wireless access point. The pharmacy system has a similar structure, but in this case, there can be more than one server in order to handle multiple connections. The system is comprised of several servers which are linked to a shared database. Finally, Jini clients that consist of Jini-enabled wireless devices such as PDAs and Smart Phones.

According to Fig. 1, the GP prescribes a drug and chooses whether to transmit it to a pharmacy of the patients' choice or to start a service containing the encrypted prescription. In the former case, the encrypted data is sent to the pharmacy server, and in the latter a Jini- enabled device connects to the wireless network and downloads the encrypted prescription for a particular patient.

The GP and pharmacy can also query the central storage for patient data regarding the patients' drug history, submission of prescriptions and drug interactions. Whenever the patient is within the range of a Jini-enabled pharmacy system, the wireless device will detect it and the patient can commence the communication process with the pharmacy.

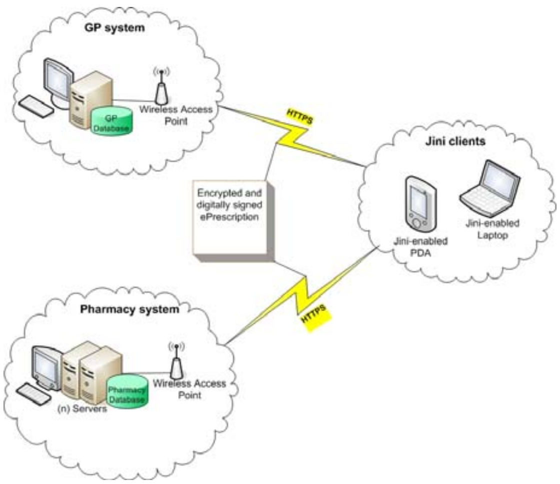


Figure 1 System model

The protection of security and privacy of the health care information is of paramount importance and entails that the unprotected transfer of plain textual prescriptions across insecure networks is clearly not an option. It is thus necessary to ensure that only medical professionals involved in an EPS can access the system and the prescriptions within it. Given this, we have decided to encrypt and digitally sign the prescriptions using session-key encryption. Lastly, the encrypted prescription is digitally signed with an X. 509 public key certificate. This certificate contains information about the public key (e.g. what cryptographic functions the key can be used for and its validity period), the owner of the key pair, and details about the certification authority (CA) which is confirming the ownership. The encrypted data is transmitted using the Hypertext Transfer Protocol over Secure Socket Layer. Moreover, the connection between the entities and the wireless access point is itself secured using 128-bit Wired Equivalent Privacy encryption.

4.2. Implementation

The prototype was developed using Java, Jini and the eXtensible Markup Language (XML) to provide full platform independence, scalability and flexibility. The Jini clients were implemented on an HP iPAQ 5450 PDA running on Microsoft Pocket PC 2002 (Windows CE) and IBM J9 Java Runtime Environment Personal Profile. To support Jini services, client applications need a web server for code transfer. However, in this case, the web server must be small enough to run on a resource constrained device such as a PDA. Sun Microsystems does not include such web servers in their Jini bundle. Thus, for this purpose we chose the PicoWebServer 1.0 from Newmad Technologies.

The central storage behaves as a repository for prescriptions. It receives prescriptions in its central server from the GPs and Pharmacies, and stores them in a local database by the central application through ODBC. The stored data is used to read medical histories and perform security checks, such as prescription integrity and patient drug interactions.

The GP application retrieves patient and drug information from a local database using the Open Database Connectivity (ODBC) to create the encrypted prescription. The prescription is always sent to a central storage, and by the patient's request to a designated pharmacy, or a Jini service. In the first two cases, the application uses a predefined port number and Internet Protocol (IP) address, to send the encrypted prescription. The pharmacy server receives the data, decrypts it in the pharmacy application, and stores it in a local database using ODBC. In the latter case, the GP application uses Jini protocols (join, discovery and lookup) to create and start a prescription service that will use the Jini lookup service to register itself and announce its presence. The GP system also contains a Jini web/code server where the code to execute the service remotely can be downloaded. The same applies for all the web servers in all the entities that need to upload code to remote units. A wireless device consisting of GP and pharmacy client applications uses the Jini protocols to detect a particular service and download the corresponding prescription. Subsequently, the device locates a pharmacy through the pharmacy's Jini lookup service and commences the interaction with the pharmacy service. The pharmacy service will conduct some requests on the pharmacy server and the local database through the ODBC by itself, whilst other requests that require runtime values of objects are conducted through the bridging service. Furthermore, both the bridging and the pharmacy services register their abilities in the lookup service in order to broadcast their existence.

5. Evaluation Results

The prototype was evaluated by 8 clinical staff using a questionnaire (Table 1), based on ratings on a 5-point Likert scale (*strongly agree, agree, neutral, disagree, strongly disagree*). This comprised comprised 18 questions, grouped into 3 categories regarding the usefulness, effectiveness and usability of the application. Participants were given an overview of electronic prescriptions, and were then asked to write and process such a prescription. At the end, participants were asked to complete the evaluation questionnaire. A t-test was applied to the data, and revealed that, with the exception of four questions (Q3, Q9, Q16, Q17), there was general statistically significant consensus at the $p<.01$ level on the expressed opinions.

Table 1 Evaluation Questionnaire

Effectiveness
The application is easy to learn
The process of inputting data on the application is fast enough
I would have preferred instructions that were easier to understand
I would not use this application in my everyday life
The application allows the patient to continue his/her every day life while waiting for the drug to be dispensed
It is not convenient to carry a wireless device around with me
Using the Program
Screen directions are consistent and easy to follow
I had difficulties navigating through the program
It is easy to make mistakes using this program
Program responds appropriately to any mistakes I made
Text on each screen is not clear
It is easy to submit the prescription
Usefulness of the application
I would rather use EPS instead of the current paper based system.
I don't believe this system reduces the time for patients to retrieve their drugs.
I believe EPS facilitates the process of prescribing a drug.
EPS does not eliminate the issues in regards to fraud
EPS will not eliminate dosage mistakes
EPS eliminates the current paper based issues on incomprehensible handwriting.

5.1. Application Effectiveness

As far as application effectiveness is concerned, our results (Fig 2a) showed that the application was perceived by clinical staff as being easy to learn (Q1), with 75% strongly agreeing with this point of view. There was also general agreement (strongly agree: 37.5%; agree: 50%) among participants that the application would be beneficial to patients, by freeing up time while the drug was being dispensed (Q5). Moreover participants generally disagreed with them not using the developed application in their everyday lives (Q4), as well as with respect to the inconvenience represented by carrying a wireless device such as the one used in our experiments with them (Q6). The only question in this category for which the expressed opinions were not statistically significant was the one regarding the ease of understanding of the operating. instructions (Q3). Whilst this might reflect that most clinicians participating in our study did not have a technical background, the opinion is somewhat at odds with the fact that most applicants did find the application easy to learn (Q1).

5.2. Using the Program

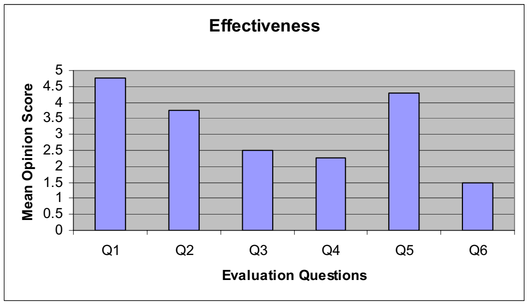
Our evaluation (Fig 2b) highlighted that there was an even split between those who strongly agreed and those who merely agreed that it was easy to submit prescriptions (Q12); moreover there was general agreement (25% strongly agreed and 50% agreed) that screen directions were consistent and easy to follow (Q7). On the other hand, they generally disagreed that the displayed text was unclear (Q11), as they did with respect to any potential navigational difficulties that our developed application might have had (Q8). Whilst opinions with respect to how easy it was to err when using the program (Q9) were mixed (and not statistically significant), we were nonetheless pleased to note that clinicians did in main agree that the program does respond in an appropriate manner to any erroneous course of action (Q10).

5.3. Application Usefulness

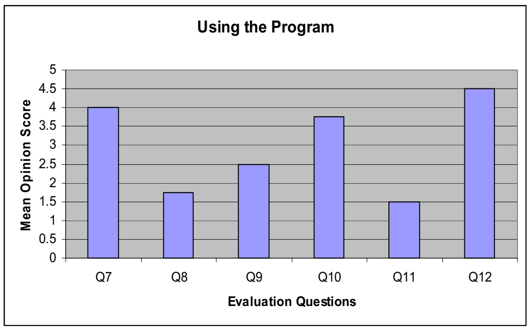
Evaluation with clinicians (Fig 2c) also revealed that 75% of participants would rather use EPS instead of the current paper based system (Q13), with there being unanimous agreement that EPSs would solve problems linked to deciphering hand-written prescriptions (Q18). Furthermore, the GPs believed that using this system would facilitate the process of prescribing drugs (Q15 – there was an even split between those who strongly agreed, respectively, agreed), whilst disagreeing that the developed EPS would not reduce the time that patients would have to wait in order to retrieve their prescribed medication (Q14). Opinions were mixed (and not significant at the .01 level) with respect to the potential occurrences of fraud that the EPS might or might not give rise to (Q16 - some opinions were that it might eliminate fraud as it is currently known, but give rise to new forms), as well as regarding the complete elimination of dosage mistakes (Q17) – the latter seen as a direct consequence of fraudulent activities, on the one hand, but being somewhat overridden by participants agreement on Q18, which is a current major source of dosage mistakes.

6. Conclusions

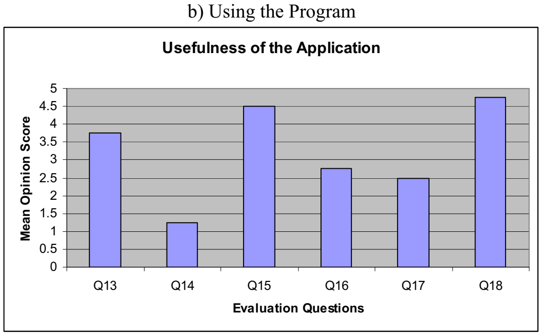
In this paper, a number of benefits with a Jini-based prototypical implementation of an EPS have been introduced. Although existing EPS solutions solve many of the problems associated with hand-written prescriptions, they do not take fully advantage of what an EPS can offer. These solutions are either flexible



a) Effectiveness



b) Using the Program



c) Application Usefulness

Figure 2. Histograms of Clinician Responses

and ineffective, or effective and not flexible. In our work, we have countered this drawback, implementing a flexible, wireless-enabled solution which effectively exploits Jini technology to offer enhanced levels of prescription service.

The developed prototype can be enhanced with further functionality, though. It would, for instance, benefit from supporting the prescriptions being forwarded to a third party. Patients would also benefit from knowing a priori if a prescribed drug was in stock for a particular pharmacy. Last but certainly not least, in our prototype Jini applications are implemented on single machines, but the ideal solution would include replications of services, lookup services and web/code servers on different entities on the network to ensure a more fault tolerant system and increase scalability. All of these directions form part of our future efforts and endeavors.

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