The Digital Patient Push – Using Location to Streamline the Surgical Journey

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Abstract: This paper introduces a patient information management system that uses location tracking of WiFi tagged patients to provide reliable and up-to-date patient information for surgical processes and other clinical sessions. Such a system could eliminate human error in patient identification (saving lives) and enhance hospital resource utilisation. The paper also describes how the information is secured during the dissemination and manipulation processes in the distributed and wireless environments. The system design has addressed several technical challenges such as service assurance, location awareness and security, which leads to a multi-mode (pull, push and combination) and highly available information system for hospital resource and patient management.

Keywords: WiFi, Tracking, Location, Positioning, Safety, Healthcare, Security, Efficiency, Wireless, Patient.

INTRODUCTION

Wireless technology (WiFi) is now becoming pervasive in hospitals [1,2] which enables healthcare professionals to update patient records at the bed-side in real time using a handheld device. Using WiFi infrastructure as its foundation, the system presented here was designed to avoid medical errors and improve hospital efficiency by automating surgical patient management. This unique application provides all information relevant to the patient on clinicians’ PDAs, tablet PCs and computer screens at each point of the surgical journey, driven by the context of the patient location and clinician user id. For example, in the operating theatre, the scheduled patient and operation are displayed; this information cannot be changed or overridden until the patient is out of the theatre. In this way, the system prevents mistakes such as administering the wrong drugs, accessing incorrect records or operating on the wrong patient – serious mishaps that can easily occur with traditional paper-based processes. For the patients the surgical journey is safeguarded with the knowledge that their visit will be mistake free. The system also helps doctors keep close track of patients with infectious diseases in order to limit their spread and be aware of the availability of the theatre and other accommodation. This system was piloted at Birmingham Heartlands NHS Trust [2].

This paper gives an overview of the system to set the context for detailed description of location accuracy analysis and information security architecture. Finally the paper concludes with a review of the key benefits of the system and further research challenges.

SYSTEM OVERVIEW

Seven access points were deployed in the pilot to create a wireless network covering the Ear, Nose, Throat (ENT) operating theatres and the Day Care ward at the Birmingham Heartlands Hospital. In this application, each patient is digitally photographed and fitted with an individual WiFi Tag for location tracking. When the patient arrives in an area, the location of the patient automatically triggers the display of the patient’s photograph, current location and medical records on monitor screens and PDAs in theatres, anaesthetic rooms, nurse stations and waiting areas. This ensures that all doctors, nurses and anaesthetists view the same information simultaneously and know where the patient is at all times – minimising errors that often occur due to logistics.

Location Awareness

Transparent to the patients and doctors, the tags communicate over the WiFi network, continuously sending signal strength and quality measurements to the Positioning Engine (PE) [3]. The PE contains a database of the signal characteristics of each logical area (for example an operating theatre), allowing it to correlate the received data with the calibrated positions it recognises. The PE can then return the current logical area where the tag is located. Initial calibration involves recording signal data from the tag at a known point in each logical area, which is done only once upon the deployment of the system. Figure 1 shows the logical areas defined in the trial scheme, including the ENT twin theatre area of the Heartlands Hospital.

Figure 1: Logical areas at the Heartlands Hospital
Wireless Security

There are a number of concerns when using a wireless system in a confidential healthcare environment. Wireless LANs are inherently insecure [4, 10] mainly because anyone in the vicinity of the access point has access to the ether (medium), allowing them to “snoop” or listen to the traffic. For wired LANs the lack of security may be overlooked as the access to networks is difficult, but for wireless LANs which are being used increasingly in healthcare and business environments, concerns over data security and integrity are becoming priorities. This also adds complexity to the configuration and maintenance of a network [7].

There are a number of options to secure a wireless network and protect data transferred across radio waves. As part of the deployment security features were investigated on all 5 layers of the TCP/IP 5-layer model, which are shown in Figure 2.

![Figure 2: Various security levels in the TCP/IP 5 layer model.](image)

Within all security measures there is a compromise between the level of security and usability. It was decided that the system should utilise WEP/WPA along with a session layer protocol such as SSL to encapsulate sensitive data. This combination is transparent to the end user and requires no intervention. The SSL service was installed and run from the central Linux server and WEP/WPA were supported natively by client devices. Table 1 shows the maximum throughput achieved through the implemented security architecture.

<table>
<thead>
<tr>
<th>Wireless Security</th>
<th>Throughput SSL (Mbps)</th>
<th>Throughput w/o SSL (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>19.3</td>
<td>23.1</td>
</tr>
<tr>
<td>WEP 128bit</td>
<td>16.0</td>
<td>20.1</td>
</tr>
<tr>
<td>WPA-PSK</td>
<td>18.8</td>
<td>22.0</td>
</tr>
</tbody>
</table>

Table 1: System throughput with different levels of security

From the results we can see that changing the level of wireless security (WEP/WPA) did not affect overall throughput significantly. However with the introduction of session layer security in the form of SSL encapsulation, throughput is reduced by a significant amount. This drop is most likely due to the processing overhead of the encryption process. The encryption on the wireless layer is processed in hardware, while the SSL encryption is done in software by the central Linux server and client device. The limited processing power of the client devices causes the drop in overall system throughput. In the scale of the pilot scheme throughput was not an issue as we were only tracking no more than 20 devices at any one time, resulting in a relatively low load on the wireless network. Throughput will be a major concern when the system is deployed widely in the hospital where tracking will involve hundreds of devices. This could be addressed by segmenting the wireless network in various parts of the hospital. A basic example would be In Patients and Out Patients, with further partitioning as the size of the deployment increased.

Current development on the system uses the location awareness function of the PE to authenticate users to the system. This has been explored in recent publications [6].

Application Overview

The conventional operating list was generated in a paper-based process. The list normally needs to be updated, reprinted and distributed – often up to three or four times a day due to changes made in the operation schedule. This process caused delays and opened opportunities for human error. The digital operating list developed can be easily updated and shared among practitioners using PDAs and tablet PCs. This application improves the logistics of moving patients throughout the surgical process. By simply pressing a button on a screen in the operating theatre, for instance, a surgeon can alert the nurse station that the operating theatre is ready for a particular patient. When the patient arrives, the medical record details are automatically made available by the system for final pre-op checks. When the patient has recovered from surgery, a similar action can be done for the patient to be taken to his/her room.

A central Linux based server hosts the PE software, WiSec middleware and application software. The PE communicates patient location information to the application software, which then correlates patient record and current status information along with the surgical process. The WiSec middleware then secures and delivers this information to the authenticated users via the WiFi network. This information appears on screens across the operating theatres and ward areas – informing all staff, in real-time, where infection risks are located. Figure 3 shows the different stages of interaction, marked by the numbers in circles, between hardware and software components in the system. These stages are described as follows:
- Stage 1. WiFi tags send unique tag ID and signal data to the PE over the WiFi Access Points (AP).
- Stage 2. PE calculates the position of the tag and passes the unique ID and logical area to the application software.
- Stage 3. Application then matches patient records with ID and sends information to the WiSec middleware.
- Stage 4. The security middleware sends appropriate information to authenticated devices (PDAs, PCs, and tablets) through the WiFi network.

Figure 3: System interaction [8]

At each stage of the surgical journey, patient’s location is recorded along with a timestamp in an SQL database, which can be accessed using a web browser. Key decisions by clinicians are also time stamped and logged to the database. This allows the hospital management team to monitor the theatre efficiency and identify any logistical problems that may be present. Through efficient operating list handling and process improvement, the system is expected to bring about huge staff time savings for hospitals.

Positioning Engine

The positioning engine technology is based on each logical area having a unique “radio signature” (RS). This comprises of signal strength and signal-to-noise ratio at any given point. In order to track the devices, the PE must first be calibrated. This is done by sampling the RS in each logical area over short period, which is then averaged to eliminate any time varying anomalies. After repeating the procedure for each logical area, the database of RSs allows the PE to track devices within the defined area.

It was found in this project that location accuracy was generally within 2 – 3 meters. Some positioning errors were generated when a device was in a small logical area (e.g. between patient beds on a ward). Often the reported logical area by the PE would change continuously, even when the device was stationary. This was due to the RSs being too similar. Accuracy to within a few metres is required as many of the logical areas (e.g. Theatre to Recovery) were relatively close together, a lower accuracy would result in a longer latency between changes in the logical areas, reducing efficiency. Large open areas, such as patient wards, tended to be less accurate than enclosed spaces, such as corridors and cupboards. Problems with wireless location technologies have been explored in recent publications [9]. A useful way to increase accuracy was to augment the system with “Dummy APs” (D-AP). These were access points not connected into the network. The PE software is able to use the beacons broadcast by these D-APs, in order to build a more accurate description of the RS. This was especially useful in the areas where positioning, rather than data delivery, was required.

As part of the deployment, the area was surveyed for any possible sources of interference in the ISM (Industrial Scientific Medical) band as hospital equipment may share frequencies with the 802.11b/g standard [5]. Interference survey was done using a portable spectrum analyser. A major source of interference was found near one of the theatre areas.

Figure 4: Interference in the theatre area

Figure 4 above shows a screen capture from the spectrum analyser of the 2.4 GHz ISM band. As we can see the channels from 5 to 13 are affected by the interference, leaving only 1 to 4 usable. The only solution to this problem was to modify the channel assignments among the Access Points (AP) so that only interference free channels (1 to 4) were used. The source of the interference was found to be a faulty PIR motion sensor. Figure 5 below shows another screen capture of a normal area without any interference. Only low level background noise is present, under which the system operates properly.
CONCLUSIONS

This paper has illustrated the benefits of combining secure wireless information with location technology to increase accuracy and efficiency of the surgical process. The intelligence of such a patient management system is derived from the awareness of the patient location, combined with the clinician (user) context (id). The result is a simple-to-use application which provides passive decision support. The application ‘pushes’ only relevant information to clinicians, thus removing the need to click through (pull) a myriad of menus to try and find the right information. This approach can be applied to many other clinical processes for improving the quality of patient care whilst saving costs by increasing efficiency.

Future research will focus on investigation into reducing positioning errors within the system. This will involve the techniques such as multi-AP tracking, system monitoring, and dynamic channel allocation in order to avoid interference. Building on this approach, the application could benefit from the awareness of positioning accuracy and the ability of minimising error.

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References


