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# Location-Based Patient-Device Association and Disassociation

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**Abstract**

Electronic associations between a medical device, a patient, and a care provider (e.g., a nurse) are new problems in hospitals. As today's devices transmit data to electronic health records, correct associations are necessary. Moreover, the unknown location of required mobile devices (e.g., cardiac monitors) represents additional issues such as unnecessary search effort, delays, and equipment underuse. To mitigate such issues, a patient-device connectivity management system that monitors and tracks patients and their assigned devices becomes an interesting option. Popular approaches for managing associations often involve bar-coding systems, which still require scanning time and which do not solve equipment location issues. This paper proposes a new system that exploits existing Real-Time Location System (RTLS) technology to track patients and devices and support simpler association by a nurse, until disassociation (intended or not) happens, at which point the nurse is notified. The system interacts with nurses through their mobile device (e.g., a tablet). A prototype version of this system was developed as a proof of concept, with correct behaviour. We expect this system to help avoid the above issues while increasing patient care quality and efficiency.


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*Keywords:* Real-time location systems; patient tracking; patient-device associations; mobile asset management

## 1. Introduction

As today's mobile devices in hospitals can transmit information directly to patient health electronic records, it becomes essential to ensure that each device is properly associated with its patient. Device-patient associations are

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also useful for ensuring that the right medication is given (patient safety), for infection control (by knowing which device is with which patient), for investigating equipment malfunction, and even for billing purpose. The current methods for associating a device to a patient and a provider (typically a nurse) exploit bar-coding systems. Such approach is time-consuming, error-prone, and not very practical as the number of medical devices increases: bar codes can be damaged or switched, and they require a special reader and line of sight by the nurse [12].

The unknown location of required mobile devices (intravenous pumps, cardiac monitors, etc.) is another issue. Tracking equipment is crucial in asset management and especially in a centralized distribution model. Yet, a recent study illustrates that next to 60% of mobile devices remain idle at any given time while nurses spend over 20 minutes per shift looking for mobile equipment [7]. With better real-time tracking, hospitals can often reduce the amount of equipment inventory, which consequently reduces maintenance and service costs. In this paper, we present a new approach that aims to overcome the issues mentioned above using an automated real-time patient-device association and disassociation system (RPDAD), which exploits RTLS technology to control and monitor associations between a patient, a mobile medical device, and a provider (nurse). This system also records and notifies any disconnection (disassociation) between the patient and the device, which could happen for example due to a mistake made by the patient or with patients with mental health issues. Our system makes use of off-the-shelf RTLS already in place for asset tracking in hospitals, hence minimizing infrastructure investments [3].

## 2. Related Work

Concerns about patient tracking automation go back to the end of the 1980's [6]. Today's technologies, which target mobile asset /device tracking, often involve ultrasounds and radio frequency identification (RFID), either working over Wi-Fi or Wireless Sensor Networks (WSN) [11].

In the past few years, several hospitals started looking into automating patient-device association management. In 2010 at the Tokyo Medical and Dental University, a smart room with four beds was set up with a wireless network. Passive and active RFID tags were attached to patients, nurses, major medical equipment such as carts and an intravenous (IV) poles, as well as medications and small medical supplies. This configuration was studied to ensure patient safety by reducing misidentifications of patients, medical errors, and nurse workload [9]. In 2011, the Memorial Sloan-Kettering Cancer Center (MSKCC) in New York used a different configuration involving barcodes and RTLS as a smart environment that provided a robust infrastructure (with a combination of wired and wireless networks) for associating the right patient with the right medication and the right dosage [5]. In 2013, a patent was issued that describes the use of an association mechanism based on image processing (images of patients and devices), but which is still costly [10]. In 2012, a new secure RFID smartcard model based on the ISO/EIC-14443 standard [8], which offers more storage capacity and higher processing power than previous RFID tags, has been proposed to contain human information [1]. The integration of active RFID and WSN is hence another possibility to monitor body sensors connected to patients [11]. However, again, these solutions incur costs additional to those already invested in RTLS-based mobile asset management. Also, none handles automatic disassociations.

The system proposed in this paper makes use of existing asset management infrastructure based on an RTLS and RFID tags (from Ekahau in our prototype [4]) not only to track mobile assets, or track healthcare providers and patients (as in care flow management scenarios [2]), but also to provide the hospital with an automated, interactive system for patient-device association/disassociation that aims to eliminate the steps that cause errors and delays.

## 3. RTLS-based Patient-Device Association and Disassociation (RPDAD) Architecture

Figure 1 highlights the architecture of our RPDAD system. First, as for any RTLS, it is necessary to map (using Ekahau Map [4] in our case) floors and rooms of the environment for tags to provide accurate location information through communication with Wi-Fi access points and infrared beacons. Then, the RTLS server can receive location information (X-Y and floor coordinates) from asset tags, patient tags, and nurse badges. A custom-made server application (RPDAD server, written in Java), collects the location of tags from the Ekahau RTLS server (through API commands) and then computes distances between mobile equipment and patients: i) in the room where the nurse is located (for potential new associations), and ii) for existing associations (to ensure that the patient is not too far from his associated devices, independently of the location of the associated nurse). Interactions with nurses are managed through a custom-made mobile application running on a tablet or a phone (using Android in our prototype, with TCP/IP as a communication protocol). There are essentially five types of interactions done via the application:

1. The system suggests the closest patient and device to the nurse for a new association.
2. The system suggests available patients and devices in a room to the nurse.
3. The nurse confirms an association between the selected patient and device.
4. The nurse confirms the manual disassociation between the selected patient and device.
5. The system notifies/alerts the relevant nurse of an automatic disassociation.

In this system, an *association* links a patient, a mobile medical device, and the responsible nurse. Associations (current ones, old ones under notification, and historical disassociations), together with basic identification and location information about patients, providers, and devices, are stored in a database according to the schema shown in Figure 2. Communication between the RPDAD and the database is done via JDBC and SQL queries. Reporting to managers (for trends) is done using a Business Intelligence (BI) tool, namely IBM Cognos BI in our prototype. The *OLDAssociation* table stores the initial and final locations of the three entities involved. The *Disassociation* table stores separately the old associations whose notifications have been acknowledged by the relevant nurse, for performance reasons (in order to keep the other two tables as small as possible, and to facilitate BI reporting).

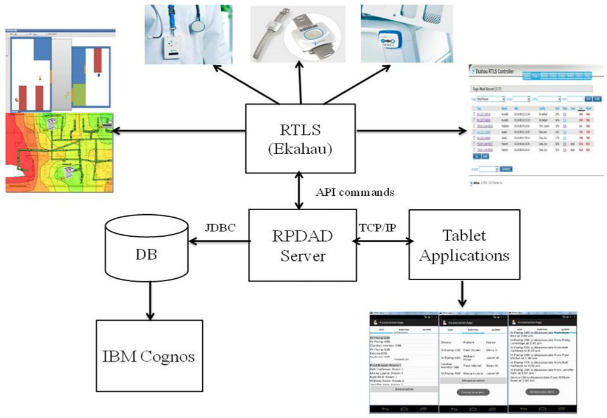


Figure 1.System Architecture

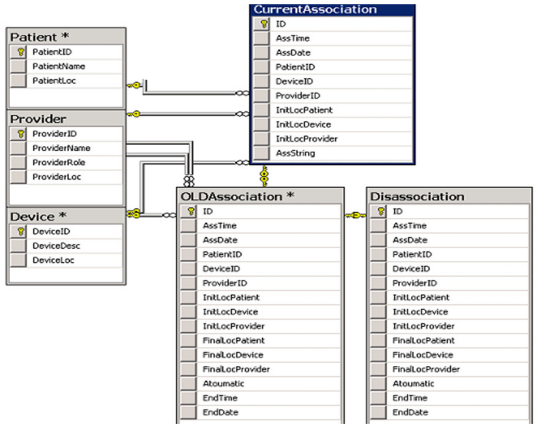


Figure 2. Database Schema

## 4. Prototype Implementation

In our prototype, the only person interacting with the RPDAC system is the nurse, via the tablet application. Figure 4 describes, with a simple Use Case Map model, the three main scenarios supported by the application, whereas Figure 3 provides partial snapshots of the graphical user interface on the tablet.

When opening the application (OpenApp in Figure 4), the nurse is identified (through the RTLS) and the patient and device closest to him/her is suggested right away as a potential association, to avoid wasting time (Figure 3 left). If he/she agrees to the suggestion, the association is created and added immediately, otherwise he/she can select a patient and a device from all options in the room (sorted by proximity), which are available in the first tab of the Android application, and then confirm. The nurse can create many such associations for one patient, but only unassociated devices will be shown by the application (as one device can only serve one patient).

At any time, the nurse can monitor existing associations with the second tab of the Android application (top-right of Figure 3). One association can be selected and ended manually (EndAsso in Figure 4), leading to a disassociation.

If the RPDAC server detects that the distance between the patient and his associated device becomes too large (DistanceTooLarge in Figure 4) according to a predefined maximum distance for this type of device, then an automatic disassociation occurs and the nurse receives an alert, also listed in the third tab of the application (bottom-right of Figure 3). Once this alert/notification is acknowledged, the record is moved to the *Disassociation* table. Given that a nurse is responsible for maybe a dozen associations, nurses should not be overwhelmed by alerts.

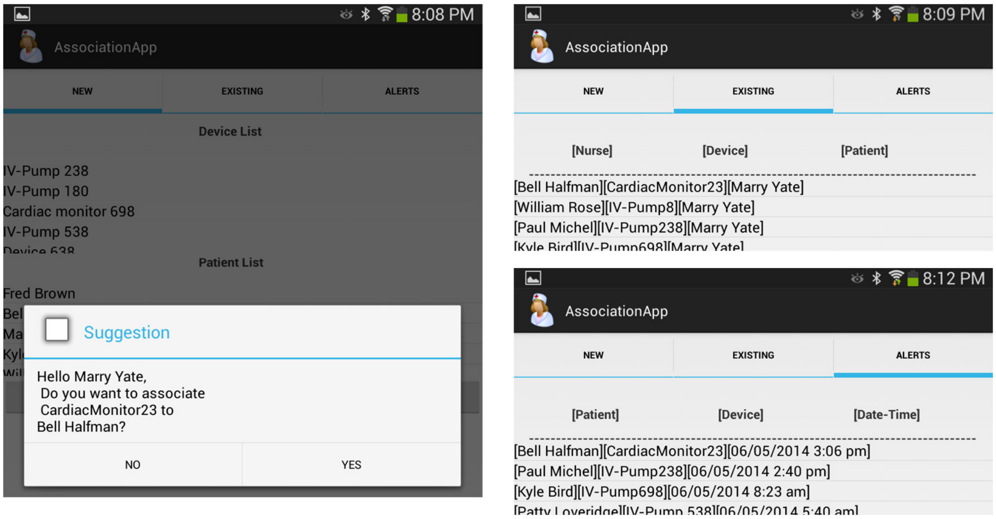


Figure 3.Android tablet application: new association, existing associations, and alerts tabs

## 5. Testing and Validation

We have deployed our system in a two-bed patient room at The Ottawa Hospital (TOH), as shown in Figure 5. Our RTLS server communicated with a private Wi-Fi network composed of a router and two access points (for triangulation). We also installed infrared beacons in the corridor and at the head of each bed, for a higher accuracy (as otherwise, the resolution of the Wi-Fi location would not distinguish between the two beds). We equipped IV pumps and monitors with asset tags, (mockup) healthcare providers with badges, and two (mockup) patients with patient tags. As we were on a busy floor, the system was in a realistic environment in terms of interferences.

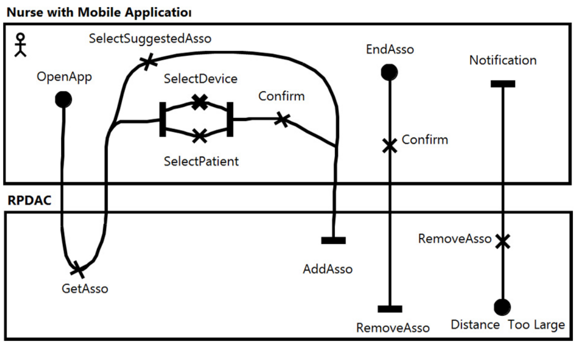


Figure 4. RPDAD general scenarios

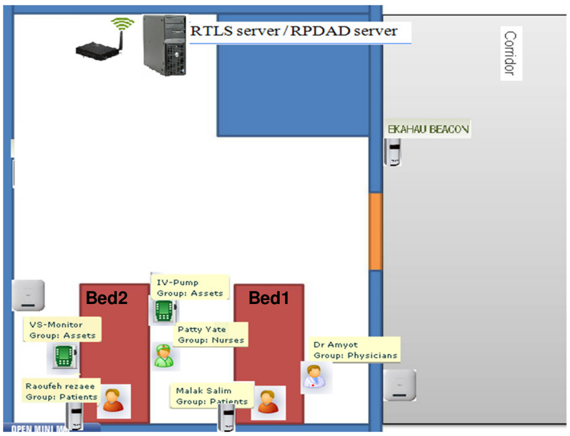


Figure 5. Deployment of RPDAD (Ekahau map)

In order to test RPDAC's logic and accuracy, a two-part scenario was used and demonstrated at TOH:

- **Part 1**: The provider enters the room and goes to the right of bed1, starts the application, accepts the suggestion from the system (which shows the patient in bed1 and the closest device) enabling an association between the provider, the patient and the device, checks the list of associations, and does a manual disassociation of this recently-added association with the tablet application.

- **Part 2**: The provider, still next to bed1, opens the application but now rejects the suggestion. He/She selects another patient (in bed2) and another device in the room and associates them. The patient in bed2 goes to the corridor with the device (no alert) and comes back without it (the patient-device distance is now too large). The associated provider gets a disassociation alert, and removes it from the alert tab in the tablet application.

These two parts achieve an excellent coverage of the intended functionalities of the RPDAC system, and the latter behaved as expected. This increases our confidence in the system's logic. However, during the deployment, we faced several challenges related to the positioning of beacons (whose infrared signals initially reflected on the walls) and to Wi-Fi accuracy. In addition, asset tags have a location refresh rate that is low (~1 minute), in order to save energy, so device location was not always reported in a timely manner for our application. Higher rates can be set, but at the cost of reduced battery life. In the near future, we plan to test further scenarios and room/asset configurations with a number of repetitions high enough to get statistically significant results (in terms of precision and recall) regarding the accuracy (for reasonable times and distances) and robustness of the system.

## 6. Conclusion and Future Work

In our prototype, we examined the potential use of an *existing* RTLS system to improve patient safety in terms of having correct creation and deletion of patient-device associations, in real-time and with minimal effort. By integrating RTLS technology, a *new* RPDAD server, and a *new* phone/tablet application, we showed the feasibility of monitoring and controlling associations between a patient, medical equipment, and a provider. Our approach goes beyond existing solutions (such as those sampled in section 2) by handling automated disassociations, and likely at a lower cost by reusing existing infrastructure (e.g., an RTLS acquired for asset management and/or care flows).

For future work, in addition to more extensive validation (discussed in the previous section), we plan to improve and assess the usability of the tablet application's user interface, better handle situations where nurses are about to associate the same mobile device to different patients, start using IBM Cognos BIs for creating reports, and evaluate how best to integrate such system with existing hospital information systems. In the long term, a pilot study will be needed to assess the real impact of such system on the reduction of effort and errors in hospitals.

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