Procedures for Testing and Troubleshooting Radianse RTLS

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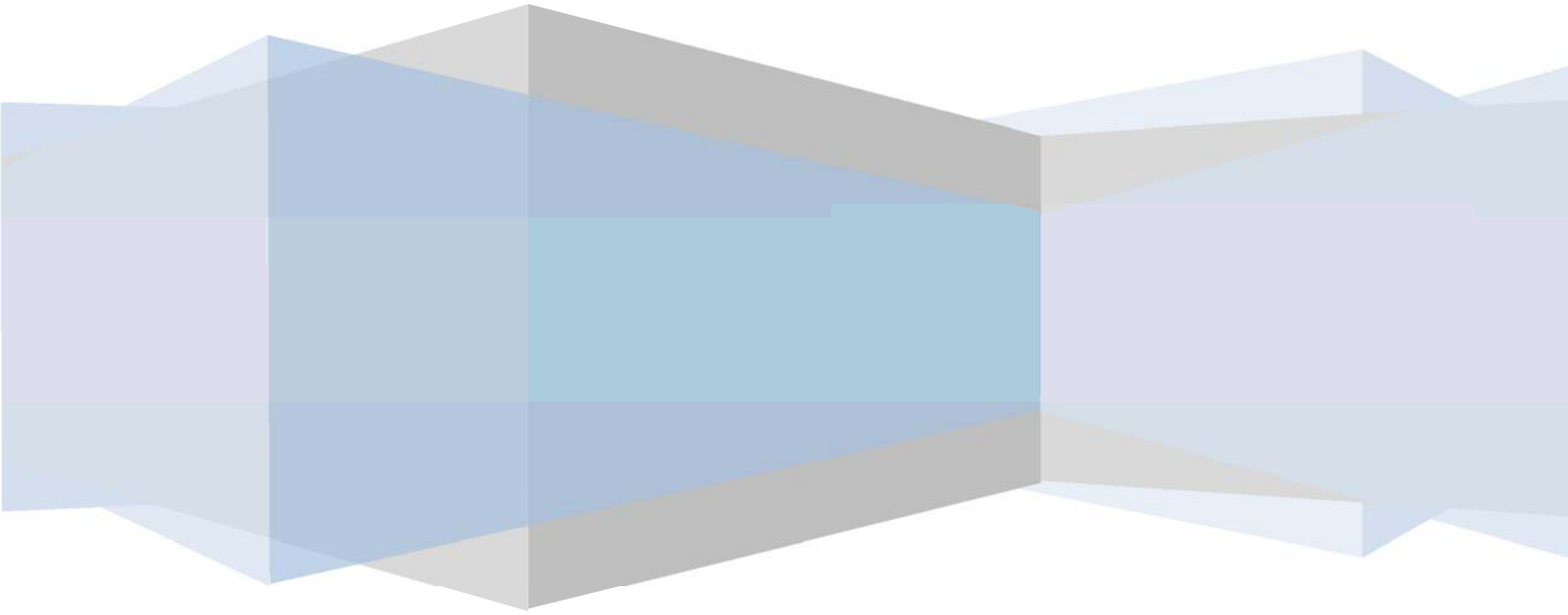
Spring 2013



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Executive Summary

Brigham and Women's hospital (BWH) uses a Real Time Locating System (RTLS) developed by the company Radianse for tracking devices throughout the hospital. Tags are placed on certain devices in the hospital, and receivers pick up the signals transmitted by tags. The tracking system is important for the efficiency of hospital operation. Hospital personnel use Radianse's web-based software to find medical devices. They may search for the location of a device by using the device's Biomedical Engineering control number, which is the number created for the device by the hospital's computerized maintenance management system (CMMS), or they may search with various filters such as device type. Biomedical Engineering Technicians (BMETs) use the tracking system to locate devices due for preventive maintenance (PM) testing.

The Radianse employees have come several times to BWH to try restoring the system to its original state by using a tuner. A clinical engineer (CE) and I tested how well the system was performing after the tuning was performed. At BWH there are forty-eight ORs; the Biomedical Engineering (BME) department tested the RTLS in forty-four of these rooms to determine the percent of devices located accurately and other statistics such as missed devices and extra devices displayed in each room. We determined that tuning has not improved the system significantly. Consequently, the Radianse team and a few Biomed members went to all the receivers in the hospital to check if the serial numbers of the ones not connecting to the server matched those on the Radianse database and floor map. After this effort, BME members developed a plan to troubleshoot the receivers not connecting to the server and thus alleviate some of the Radianse system issues at BWH.

Problems with the Radianse RTLS system at BWH

BWH has used the Radianse tracking system for seven years. The system has not been well maintained, and consequently, the tracking system is not always reliable. The Radianse system may display the device in one location when it is in fact at a different location. The system inaccuracy may be due to human factors, or the Radianse technology. A technological shortcoming occurs when a device in a room is tracked as being in the hall instead of in the room. This may occur when the device is placed near a wall and is closer to a receiver in the hallway than the receiver in the room. Furthermore, devices on one floor are sometimes tracked as being on a floor above or below the floor they are located on. These errors happen since the signals transmitted by tags are capable of traveling though floors, and consequently being picked up by receivers on multiple floor levels.

Not all devices have working tags, which makes trying to find them difficult. Some tags become damaged, or their batteries are not replaced every two years which means the tag stops transmitting signals. As a part of our PM procedures for medical devices, we change the Radianse tag batteries to ensure the each tag's functionality. Devices that do not have PMs scheduled every year or couple years are more likely to have dead batteries compared to devices

with PMs scheduled more frequently. Additionally, not all tags are assigned to the device on which they are located. Thus, when someone tries to search for the device using the Radianse website, no result is generated for the device's location.

Another issue with the Radianse system is bouncing. Bouncing occurs when the tracking system locates a tag in one room and after a few minutes the system locates the tag in a different room. In other words, tag location switches or bounces back and forth between two different rooms. This issue happens when a receiver is removed from its original location to another place. The IP address for the receiver that was moved is then inconsistent with the server's identification of that receiver.

RTLS Technology Description

Receivers, also known as tag readers, pick up signals sent from the tags. Each receiver has its own unique, static IP address with an attached label such as 'Biomed shop,' or the name of the place where the receiver resides. The receiver sends information to the server through this labeled path. The server may be located at BWH, or a server farm outside of the hospital. The server connects to panels of switches which are wired to jacks in the OR rooms. The jacks are located on the walls in front of receivers, and a short cable is attached from the jack to the receiver.

The receiver has either three or five LED lights, positioned in a vertical line. The newest receiver model, the 410 series, has five LED lights while the older 400 series model has three lights. The top and bottom lights on the 400 receiver series have the same meaning as the top and bottom lights on the 410 series. The bottom light must be constantly lit in order for the receiver to communicate with the server. When this bottom light is on, the IP address for the receiver is correct and working. The top light indicates that the receiver is powered on. The second light from the top on the 410 series is called the heart beat, and it indicates that the receiver is working. The third and fourth lights flash to indicate that the receiver is sending and receiving packets. Similarly, the middle light on the 400 series receiver flashes to represent network traffic.

The Radianse tags are active tags because they have internal battery power and ping receivers intermittently. On the other hand, passive tags do not have batteries and exciters must be used to activate them. Radianse tags have two three-volt batteries. This battery type has a two-year battery life. As previously mentioned, BMETs replace these batteries when they perform repairs or preventive maintenance on the tagged devices. The tags have two programmable buttons which are used to activate tags once a set of new batteries have been installed. One button has a single dot and the other button has a pair of small dots. Also by pressing the button with two dots, and noticing the green LED light flash on the tag, the user knows the tag is sending a signal and working properly.

The receivers use both infrared (IR) and 433 MHz radio frequency (RF) to locate Radianse tags. This multi-media wireless solution saves the Wi-Fi (wireless fidelity) network for other hospital uses. The use of RF allows coarse-grain positioning (e.g., floor) while the IR

signals provide additional resolution (e.g., room). IR signals do not go through walls and there are two IR sensors on each receiver.

A series of algorithms calculate the real time location of the Radianse tags. The algorithms mainly use strength information and multilateralization to calculate the tag positions. Multilateralization collects data from multiple receivers near a tag; these receivers could be on floors above or below the floor where the tag is located, or on the same floor as the tag.

Comparison of the Radianse tracking system to other RTLS companies' systems

Radio Frequency Identification (RFID) architectures are called presence, location or choke-point based on their range and technology employed. Presence simply identifies that a specific tag is visible within the field of an access point (AP). Presence identifies devices within a thirty foot range. Location is a more accurate tracking technology compared to presence in that it tracks tags in a fifteen foot range. Location RFID uses triangulation algorithms to track tags. Triangulation algorithms use three receivers that encompass the tag and are on the same floor as the tag to calculate tag positions. Time of arrival data from multiple access points and power measurements from the tag transmissions are used for the algorithm calculations. The most accurate tracking architectures are choke-point architectures that provide room-level locating ability. Choke-point structures generally use secondary hardware, such as low frequency transmitters or infrared (IR) receivers. When a tag is located within an envelope defined by the secondary hardware, a location ID corresponding to that particular envelope will be assigned to the data string of the RFID transmission. The RFID system then uses this transmission data to locate the tag in relation to the choke-point hardware. In all three RFID architectures, range resolution depends on the distribution of access points and the construction of the facility.

The company Ekahau makes an RTLS technology that is a competitor for Radianse RTLS. Ekahau RTLS is a Wi-Fi based technology. The Wi-Fi network sends signals to the Ekahau RTLS controller (ERC), which calculates the accurate locations of the tags. This information is then submitted to the Ekahau vision application. Signal measurements are taken from the radio communication, and delivered to ERC, along with other information such as button presses, battery information, and temperature measurements. Additionally, location accuracy can be obtained in areas where Wi-Fi coverage is not sufficient to support RTLS by using small, battery powered Location Beacon infrared transmitters. The Ekahau LB2 Location Beacon transmitters provide RTLS accuracy to approximately one meter (3.5 ft.). The transmitters can be programmed to one of five different modes to specify the desired accuracy level.

Aeroscout is another RTLS technology. The Aeroscout tags transmit messages at 2.4 GHz, and support choke point exciters at 125 kHz. Each tag has a single 3.6 V lithium battery that is replaceable and has a battery life of up to four years. The tag gives a report on its battery level so that the battery can be replaced in time. The tags can be programmed to have up to fifteen messages of fifteen bytes each. The tags also use a beaconing communication method to extend battery life and minimize network impact. Aeroscout tags can be activated wirelessly via

Aeroscout's Tag Management Suite; in contrast, the user must press the buttons on the Radianse tags to activate them.

My Involvement

I helped one of our CEs with testing the Radianse tracking system performance in the operating room (OR) area. We conducted the testing when the OR was not busy because it was a holiday or before surgical cases started for the day. First, a report of all the devices in a certain operating room (OR) was generated using the Radianse web-based application. We determined whether each device listed on the report was actually in the room by searching for the device and matching the control number on the device with that on the report. The devices that were on the tracking system list and located in a room were checked off on the list. The results of the tests and the calculations based on the test data are shown in Table 1.

If a device was on the tracking system list, but not found in the room, its location was noted on the comments document if it could be located. For instance, I found that one of the 'Extra Devices Detected' was a defibrillator listed as in OR 24, but instead it was in the hall outside of OR 22. Devices that were not on the list, but in the room, were also documented in the comments column on the Excel spreadsheet, along with a description of their location in the room. I found that one infusion pump module was tracked accurately while the infusion pump module that was attached to it was not being tracked; however both infusion pump modules had working Radianse tags.

One of the BMETs and I located receivers that were on, but not connected to the server on a few patient floors. We searched for receivers with a bottom light that was either off or blinking. We were able to locate six receivers on the list of problematic ones, and obtain port and device IDs for four of these six. We obtained this ID information from the jacks by connecting an Ethernet cable from the jack to a laptop and using a network protocol analyzer program called Wireshark. The receivers that have no power over Ethernet (POE) will be traced back to the closet to make sure they are connected to the correct switch panel and port.

Conclusion

Radianse RTLS technology was installed at BWH seven years ago to improve asset management and detection. Radianse tags send signals to receivers, which are wired to switches in network closets and servers outside the facility, to locate devices. Although the Radianse team has tuned RTLS multiple times, the system does not accurately track all devices that have Radianse tags. We tested the Radianse system performance in the OR area and found that the system did not detect some working tags, and some tag locations were incorrect. From our testing, we found that the room accuracy was one-hundred percent, and the missed devices percentage was zero for eight of the rooms (ORs 2, 6, 21, 25, 28, 44, 46 and 47). The missed devices percentage is the fraction of devices in the room, but not detected by Radianse divided by the total number of devices in the room, multiplied by one-hundred percent. However, a couple areas had less than eighty percent accuracy. These areas were rooms twenty-nine through

thirty-one, and rooms 12, 14 and 15.The receivers in these areas may need to be relocated to improve the tracking system's performance.

As an initial attempt to remedy the Radianse system's problems, a team of Radianse employees and a few Biomed members went around the hospital to locate all the receivers. The serial number on the receiver was confirmed with that for the receiver in the same location on the Radianse team's floor map. Cables were plugged back into receivers that were not powered on and had loose connections to the jacks. The port ID and data ID of a jack were obtained if the receiver appeared to be functioning normally, but a Radianse report told otherwise, or if the receiver was powered on but not connecting to the server. Currently, there is a list of the receivers that are not connected to the server, but powered on, and the receivers that have no power over Ethernet (POE). We have been acquiring the device ID and port ID information for receivers that are not connected to the server but powered on. The receivers with no POE will need to be traced back to the patch panel and switch ports in the network closets using toner and probe network testing devices. Any mismatch from the switch port to the receiver location identifying by this testing will need to be resolved. Additionally, any cables that do not transmit the signal, possibly from being torn, will need to be replaced. If the hospital and the BME department decide that the system accuracy is still unsatisfactory after this work is completed, the Radianse team plans on installing new equipment tracking software to improve the accuracy of the system's location tracking capabilities.

Acknowledgements:

I would like to acknowledge Prakhar Kapoor**,** clinical engineer at BWH, for being an integral part of the data collection and analysis process. Prakhar led the study and developed the charts shown in tables 1 and 2 in the appendix to track the data analyzed. Prakhar was also a great mentor and has taught me a lot about the Radianse RTLS system and maintenance of the system. In addition, I would like to thank Steven Hicks, BMET at BWH, for his help with troubleshooting the receivers that were not connecting to the Radianse server.
Also Nathalia Londoño helped with reviewing and commenting on the paper.

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Appendix:

Location	Day And Time Radianse Report Generated	Day And Time of Test	Total Devices Detected (Radianse List)	Extra Devices Detected (Radianse List)	Total Devices Actually In Room	Devices Not Detected	Devices Identified Accurately
OR1	9:14 AM	9:20 AM	6	0	11	5	6
OR2	9:25 AM	9:40 AM	16	3	14	0	14
OR3	9:55 AM	9:57 AM	25	8	18	1	17
OR4	10:19 AM	10:22 AM	19	2	19	2	17
OR5	10:44 AM	10:50 AM	13	1	13	1	12
OR6	11:02 AM	11:05 AM	19	1	18	0	18
OR7	10:55 AM	10:58 AM	14	0	16	2	14
OR8	11:12 AM	11:15 AM	10	3	8	1	7
OR9	11:29 AM	11:30 AM	19	2	19	2	17
OR10	3:35 PM	3:40 PM	18	6	14	2	12
OR11	11:48 AM	11:48 AM	15	0	16	1	15
OR12	11:56 AM	11:58 AM	10	3	10	3	7
OR14	11:00 AM	11:05 AM	13	2	17	6	11
OR15	11:41 AM	11:45 AM	14	6	13	5	8
OR16	12:11 PM	12:15 PM	16	1	16	1	15
OR17							
OR18	8:55 AM	9:01 AM	11	1	12	2	10
OR19	9:40 AM	9:42 AM	11	0	15	4	11
OR20							
OR21	12:50 PM	12:55 PM	18	8	10	0	10
OR22	10:00 AM	10:00 AM	23	13	10	3	7
OR23							
OR24	10:21 AM	10:24 AM	14	4	12	2	10
OR25	3:53 PM	3:57 PM	22	5	15	0	15
OR26	4:12 PM	4:14 PM	15	5	11	1	10
OR27							
OR28	10:32 AM	10:35 AM	21	6	15	0	15
OR29	10:20 AM	10:21 AM	6	1	10	5	5

OR30	10:10 AM	10:11 AM	8	0	13	5	8
OR31	9:58 AM	10:00 AM	6	0	11	5	6
OR32	9:30 AM	9:32 AM	15	8	9	1	7
OR33	9:22 AM	9:24 AM	3	0	9	6	3
OR34	9:10 AM	9:12 AM	8	0	10	2	8
OR35	8:50 AM	9:00 AM	13	1	15	3	12
OR36	8:15 AM	8:27 AM	6	1	8	3	5
OR41	12:34 PM	12:36 PM	24	8	17	1	16
OR42	12:34 PM	12:50 PM	48	33	16	1	15
OR43	1:04 PM	1:05 PM	14	0	15	1	14
OR44	1:41 PM	1:42 PM	15	1	14	0	14
OR45	10:40 AM	10:50 AM	10	0	12	2	10
OR46	10:25 AM	10:28 AM	13	0	13	0	13
OR47	10:08 AM	10:10 AM	13	4	9	0	9
OR48	9:56 AM	9:58 AM	7	0	8	1	7

Table 1. Data collected based on counting working Radianse tags in most of the fourty-eight ORs.

Explanation of column headings:

'Total Devices Detected (Radianse List)' was the number of devices listed on the Radianse list. 'Extra Devices Detected (Radianse List)' was the number of devices that were on the Radianse list, but not actually in the room. The 'Total Devices Actually in Room' was calculated as the number of devices with working Radianse tags in the room, whether or not they were on the Radianse list. 'Devices Not Detected' was the number of devices with working tags in the room, but not on the Radianse list. The 'Devices Identified Accurately' was the number of devices in the room that were also on the Radianse list. From this information, the following percentages were calculated: Room Accuracy, Missed Devices, and Extra Devices Displayed (see Table 2).

Location	Room Accuracy (%)	Missed Devices (%)	Extra Devices Displayed (%)
OR1	54.55	45.45	0.00
OR2	100.00	0.00	21.43
OR3	94.44	5.56	44.44
OR4	89.47	10.53	10.53
OR5	92.31	7.69	7.69
OR6	100.00	0.00	5.56
OR7	87.50	12.50	0.00

OR8	87.50	12.50	37.50
OR9	89.47	10.53	10.53
OR10	85.71	14.29	42.86
OR11	93.75	6.25	0.00
OR12	70.00	30.00	30.00
OR14	64.71	35.29	11.76
OR15	61.54	38.46	46.15
OR16	93.75	6.25	6.25
OR17			
OR18	83.33	16.67	8.33
OR19	73.33	26.67	0.00
OR20			
OR21	100.00	0.00	80.00
OR22	70.00	30.00	130.00
OR23			
OR24	83.33	16.67	33.33
OR25	100.00	0.00	33.33
OR26	90.91	9.09	45.45
OR27			
OR28	100.00	0.00	40.00
OR29	50.00	50.00	10.00
OR30	61.54	38.46	0.00
OR31	54.55	45.45	0.00
OR32	77.78	11.11	88.89
OR33	33.33	66.67	0.00
OR34	80.00	20.00	0.00
OR35	80.00	20.00	6.67
OR36	62.50	37.50	12.50
OR41	94.12	5.88	47.06
OR42	93.75	6.25	206.25
OR43	93.33	6.67	0.00
OR44	100.00	0.00	7.14
OR45	83.33	16.67	0.00
OR46	100.00	0.00	0.00
OR47	100.00	0.00	44.44
OR48	87.50	12.50	0.00

Table 2. Room accuracy, missed devices and extra devices displayed percentages calculated from the data in Table 1 for each OR tested.

Equations used to calculate the percentages in Table 2:

$$Room\ Accuracy = \frac{Devices\ Identified\ Accurately}{Total\ Devices\ Actually\ In\ Room} * 100\% \quad (1)$$

$$Missed\ Devices = \frac{Devices\ Not\ Detected}{Total\ Devices\ Actually\ In\ Room} * 100\% \quad (2)$$

$$Extra\ Devices\ Displayed = \frac{Extra\ Devices\ Detected\ (Radianse\ List)}{Total\ Devices\ Actually\ In\ Room} * 100\% \quad (3)$$