Evaluation of RFID and Wi-Fi Technologies for RTLS Applications in Healthcare Centers

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Abstract--**The purpose of this paper is to provide a comparative analysis about Radio Frequency Identification (RFID) and Wireless Fidelity (Wi-Fi) technologies for the Real-time Location System (RTLS) applications in healthcare centers/hospitals. Focus is on the 5 criteria and 9 sub criteria for choosing a RTLS and the research about the features of RFID and Wi-Fi technologies is done. Firstly, these criteria are used for the evaluation purpose based on literature review; secondly, the RFID and Wi-Fi technologies are compared by listing out the facts, pros and cons, according to the problems found out during the investigation about the technologies and the result of interviews with the IT experts in healthcare centers/hospitals, nurses, vendors and engineers of RTLS. Finally, an information retrieval guideline for the RTLS solution selection is given out and demonstrated with RFID and Wi-Fi technologies.**

I. INTRODUCTION

The need to locate people and objects in real time is important to healthcare centers/hospitals. With the increasing incremental innovation of wireless technology, it is now practical to locate people or objects in real time. The systems that accomplish this are Real-Time Location Systems (RTLS). Initially introduced to the market in early 2000, RTLS continues to grow as the need to track resources within an enterprise becomes more and more critical to operations. The growth of RTLS is partly due to the healthcare industry, which is leading the adoption of RTLS. Healthcare centers/hospitals have unique needs to track people and assets. The healthcare industry has utilized RTLS technology for over a decade and continues to be popular. RTLS in healthcare applications provides vast improvements to its operations because of the problems the systems can solve. To take several examples, RTLS assists in tracking asset, staff and patient flow for throughput management, optimize processes to eliminate operational bottlenecks, and facilitate better task coordination and communication among the staff. All these improvements lead to better patient care, reduced cost and increased safety. The RTLS application is growing fast. The Veterans Affairs (VA) Department of the US Federal Government views a planned $550 million Real-Time Location System as a way to ensure its hospitals properly sterilize medical instruments, improve efficiency and track equipment [1]. VA released a draft request for proposals for RTLS in December 2011, which will use signals from Wi-Fi networks already installed in its hospitals to track equipment -- and potentially employees -- within a meter or better. According to Dr. Peter Harrop [2], Wireless Sensor Network (WSN) will grow rapidly to well over two billion US dollars for the systems in 2022. See Appendix 1.

RTLS are local systems for identifying and tracking of the location of assets and/or persons in real-time. RTLS technology consists of fixed receivers or readers receiving wireless signals from small ID badges or tags attached to objects or people. Real Time Location Systems use several technologies such as RFID, Ultrasound, Bluetooth, Zigbee, Ultra Wide-band (UWB), Infrared and Wi-Fi. The RFID technology is the big brother in the technology family of RTLS, which is mostly used among the several optional technologies since 2000[3] till present. RFID's are small low-power transmitters; and are either attached to an asset or worn. There are three types; active, semi-passive and passive. Wi-Fi technology has been getting into the market of RTLS applications since 2008 and has a very high growth rate. Wi-Fi is similar to RFID but use 802.11 wireless networks for communication. RFID and Wi-Fi technologies are competing with each other. These two technologies are to primary discussion topics discussed in further detail in this paper. Both technologies are very different in many aspects, RFID uses radio-frequency identification (RFID) tags and readers while the other uses 802.11 Wi-Fi networks and tags.

II. PROBLEM DEFINITION

Determining which RTLS technology is more optimal to use per healthcare may be unclear due to requirements that need evaluated. This paper focuses in building some criteria for the technology and vendor evaluation of RTLS applications for healthcare centers/hospitals. Firstly introduce and discuss some criteria for the evaluation purpose based on literature review, then conduct interviews with the IT experts in healthcare centers/hospitals and vendors of RTLS to discuss and improve our comparison. A comparison of the RFID and Wi-Fi technologies is done by listing out the facts, pros and cons, and literature review findings.

III. LITERATURE REVIEW

Kamel Boulos and Berry [7] point out that in healthcare facilities, RTLS can be used to locate portable assets and equipment, locate staff quickly and efficiently, and improve workflow. Hospital processes can be improved by ensuring that the correct medical staff and equipment are in the correct place at the right time. RTLS is very useful in the following three aspects:

A. Asset Tracking and Inventory Control

The potential return on investment (ROI) of using RTLS to

track expensive medical equipment is high, therefore many hospitals are using RTLS to track and manage the physical assets within a hospital or healthcare facility. For instance, hospitals use RTLS to monitor the location and availability of infusion pumps, each costing no less than $2.5K. By pinpointing locations of the equipment, the healthcare centers can make better use of supplies, reduce rental costs and improve delivery times. Hospitals also rely on wireless RTLS solutions to track the availability of beds and speed bed turns, and monitor wheelchair availability; thereby it can reduce the annual costs by hundreds of thousands of dollars.

Tracking systems can also be used for inventory control and prediction, for example, to generate reports on usage trends or resource forecasting and future equipment purchases and rentals. RTLS is used to track medicine inventory and generate reports for the use and disbursement of highly-controlled medications.

B. People Tracking

This system can be used to track and locate staff and patients for example to coordinate activities and simplify the shift transition process. For example, Wi-Fi-based location tracking can be used to provide real-time tracking of patient records, and coordinate the flow of time-sensitive information and services between doctors, patients and laboratories. In operating and emergency rooms, RTLS can be applied to the work area and medical bay to pinpoint the precise location of doctors, nurses and other healthcare personnel, and coordinate activities between pre-operation and recovery operations. Wireless location-based networks can also function as the backbone for time management and prioritization systems to maximize the time spent with patients, provide real-time data for activities, and streamline patient workflow without sacrificing quality of care.

RTLS can also be applied to track at-risk patients (Alzheimer, psychiatric, elderly, etc.) within a hospital environment or assisted living facility to monitor and restrict their locations and to trigger alerts in an emergency to contact specific medical teams or security personnel.

Other healthcare organizations are taking wireless RTLS a step further by tagging doctors, nurses, patients and equipment and then tracking the interaction of all the players and resources to build a highly-accurate profile of a patient's course of treatment. This information can be used to generate a highly-detailed billing profile, or produce reports that can be used for provider accountability and responsibility.

IV. ANALYSIS OF THE PROBLEM

The IT department must be very careful about the choice of RTLS technology. Despite of all its merits, a given technology or hardware may not work well if not properly matched to the intended application or the physical environment. The department should also consider the budget and future expansion plans; the latter will require an adequately scalable RTLS solution. For example, not every environment is suited for RF (radio frequency) systems. Radio signals are susceptible to interference via signal propagation, metals, water, people, and radio signal collisions. [10]

Jill A. Fishera and Torin Monahanb [11] evaluated RTLS in hospital context. They conducted a qualitative study of 23 U.S. hospitals that had implemented RTLS for the purpose of tracking assets, personnel, and/or patients from 2007 to 2009. They observed the systems in use and conducted 80 semi-structured interviews with hospital personnel and vendors. In the 23 hospitals, 16 of them use RFID technology, 3 of them use Ultrasound technology, 2 of them use Zigbee technology, 1 of them uses Infrared technology, and 1 of them uses Ultra-wideband. There is no Wi-Fi RTLS technology among the interviewed hospital; Wi-Fi was still entering the market in healthcare RTLS application. Their findings are (1) substandard functionality of most real-time location systems in use and (2) serious obstacles to effective deployment of the systems due to the material and organizational constraints of the hospitals themselves. They gave real life examples RTLS benefits rather than evaluate the technologies according to a decision model. Their research focuses on the serious technological, material, and organizational barriers to the implementation of RTLS rather than the selection of technologies of RTLS application.

With the success that early adopters have had with RTLS, the question is not whether to implement, but which technology is best suited for the many applications that can benefit from location awareness. In order to evaluate the different RTLS technologies, we need to list out the criteria and subcritical for the selection. To obtain maximum benefit, 5 critical factors have been identified to help ensure long term success of RTLS investment.[12] The 5 critical factors are enterprise-wide coverage, location accuracy, installation and maintenance, interoperability, and financial risk.

A. Enterprise-Wide Coverage

Because assets and people rapidly move throughout the hospital, knowing about the location, status and movement of equipment and people provides valuable information that used to reduce expenses and increase productivity. Therefore, your RTLS deployment must cover every square inch of your enterprise to achieve maximum benefit. A system which covers only specific areas or departments will quickly lose its effectiveness and truly impacting the success with RTLS.

B. Location Accuracy

In RTLS today, room level accuracy is the minimum actual standard. To meet the requirements of different applications, various RTLS solutions are available that can report tag location at different resolutions, as shown in Tab. 1. The Accuracy Levels of RTLS for Healthcare Centers/Hospitals [10]

TABLE 1. LOCATION ACCURACY LEVELS

No.	Level	Describe
1	Area Level	Presence in a given (relatively wide) area
2	Room Level	Present in a specific room
3	Sub-room level	Locating tag to a specific part of the room, e.g., in hospital rooms accommodating multiple patients, such as dual-bed rooms and larger wards.

The locating method varies according to the purpose, the environments and requirements of the specific application, there are three methods of locating a tag. [10]

(1) Locating at choke points: tag location is returned by a specific choke point (an entry or exit point, such as a ward entrance; it is assumed that individuals or assets move from one area to another through these points). By monitoring the time a tag was detected at specific points, one can also determine the direction the tag is moving.

(2)Locating by associating: tag location is returned as proximity with respect to another tag, e.g., if each patient in a hospital wears a tag and each IVF (intravenous fluid) pump has a tag, the location of a given IVF pump can be returned as present next to a specific patient (and for how long).

(3) Locating precisely: the exact tag location is pinpointed precisely on a map of the world and/or a detailed indoor map/in a given building and reported as absolute or relative position as described above.

RTLS must provide accuracy within the 4 walls of an enclosed room. The entire hospital is not comprised of rooms only. When an asset or a person leaves a room and travels through the hallways and corridors of your enterprise, RTLS should be responding to the movement as well. The working flow of a hospital is conducted in rooms, hallways, open areas, corridors, etc. Dozens of business applications will demand this level of accuracy to truly drive value innovations.

Zone level accuracy reports the asset location on the correct floor, or within a cluster of rooms. Room-level accuracy locates a person or asset in an exact room. To affect the highest impact for your strategic initiatives, room level accuracy is a clear critical success factor. See Appendix 2.

C. Installation and Maintenance

Cost and ongoing success of your RTLS deployment is largely dependent on the installation. It is vital to find a minimally invasive solution which does neither compromise your existing information technology network nor interrupt daily business operations, and can be installed in days or weeks, not months or years.

a) Whether Need Hardwire Installation

A RTLS network needs to be established, which is comprised of access points, also referred to as sensors, receivers or detectors. They need to be strategically placed throughout a building in order to accurately locate the tags. The way the network access points are installed will determine the period of time for business disruption during installation. Many RTLS networks require that access points are hardwired.

In many instances, people have to drill in walls, remove ceiling tiles to run cable and pull power for each access point, because that, in many cases, hardwired infrastructure is needed in each room for achieving room level accuracy. This process is extremely disruptive, expensive and time consuming. Hard-wired network also eliminate the flexibility needed for it to adapt to the new environment, which need change in the infrastructure.

b) Network Interference and Security

In the process of planning a RTLS, potential information system networks interference should be considered. People want to leverage existing Wi-Fi infrastructure as a suitable solution[14]. The problems brought by the idea include not only location accuracy, which is typically limited to zone level, but also the network traffic and security concerns, which can be a challenge when attempting to leverage Wi-Fi. The Wi-Fi information system network is used to support and maintain many vital systems. It is a significant consideration to select technology that doesn't affect other critical applications.

c) Time to Deployment

Installation time is critical since the opportunity cost of RTLS installation per day is equal to the income of the hospital per day. When evaluating a technology we have to think about the installation period is in weeks, months, or even years. This also demands that complex planning, coordination for installation.

d) Ongoing Maintenance

It will be too expensive if a hospital has to support a team of IT professionals to keep the RTLS running. RTLS not only includes hardware and software, but also service and maintenance. Some vendors provide 24/7 monitoring service, system maintenance, data back up and system recovering services. The ongoing maintenance costs may affect the budget or impact internal staff.

D. Interoperability

The location engine software communicates with tags and location sensors to determine the location of tagged entities in a RTLS. The location engine relays this information to specialized middleware and applications. The middleware in an RTLS acts as the convertor between the core RTLS components, i.e., tags, location sensors, and location engine software, which comprises a range of software applications capable of exploiting the RTLS status information for the tracked entities. Via standards-based, open APIs (application programming interfaces), the middleware enriches many systems with location information necessary, which include simple RTLS end-user interfaces and more comprehensive integration into existing systems such as ADT (hospital admission, discharge and transfer systems) and HIS(hospital information systems).[10],[15].

Fully interoperable RTLS can seamlessly integrate with other software systems which can be enriched with real-time location information. To achieve the potential extension functions of RTLS, the RTLS should be supported by standard-based technology; RTLS platform should offer an open API (Application Programming Interface) so that data deprived from it can be input to the third party software. Proprietary systems will limit the ability to fully leverage the RTLS without being supported by standards-based technology or an open API.

E. Financial Risk

Hospitals/healthcare centers are dynamic environments with unique needs. Hospitals look for a flexible business model that removes barriers to entry. One that doesn't require a large capital purchase or long-term contractual commitment, and allows you to easily expand assets as needed. The investment includes installation cost and maintenance cost which are definitely major concerns.

V. CONCEPTUAL MODEL

Based upon the above analysis, we give out the following evaluation model for the candidate technologies as Figure 1. [16]

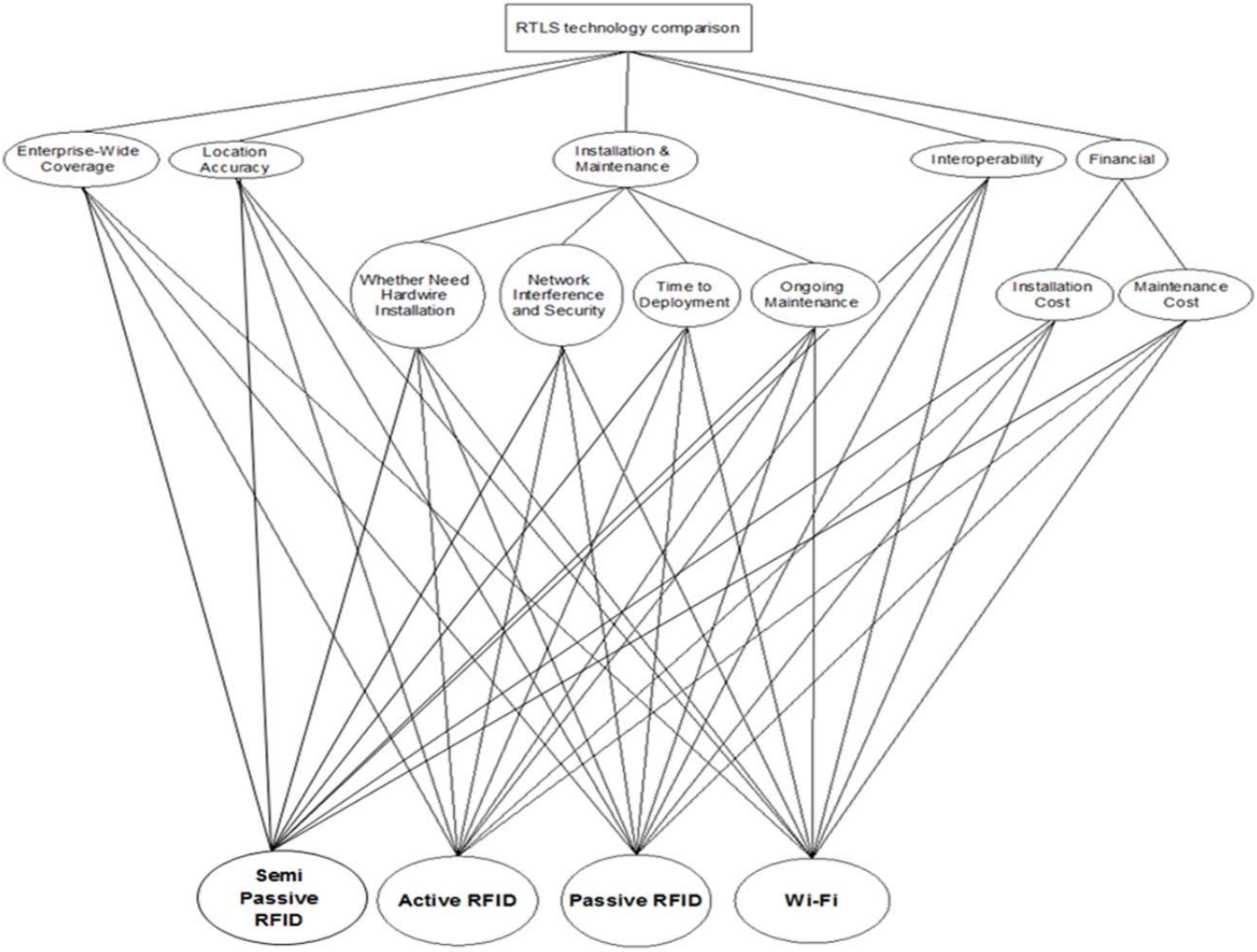

Figure 1. Prototype Hierarchical Decision Model for Three RTLS Technological Solutions

VI. DATA GATHERING

A. Introduction to RFID Technology for RTLS

RFID has become mainstream technology that helps speed the handling of manufactured goods and materials. RFID enables identification from a distance. RFID tags support a larger set of unique IDs and can incorporate additional data such as manufacturer, product, type, and even measure environmental factors such as temperature. Furthermore, RFID systems can discern many different tags located in the same general area without human assistance [17].

There are several kinds of RFID tags according to the Electronic Product Code (EPC) Standards as shown in Table 2. RFID mainly includes two categories, i.e., passive RFID and active RFID.

TABLE 2. THE ELECTRONIC PRODUCT CODE (EPC) STANDARDS FOR RFID TAGS

EPC Class Type	Features	Tag Type
Class 0	Read Only	Passive (64 bit only)
Class 1	Write Once, Read Many (WORM)	Passive (96 bit min.)
Class 2 (Gen2)	Read/ Write	Passive (96 bit min.)
Class 3	Read/Write with battery power to enhance range	Semi-Active
Class 4	Read/Write active transmitter	Active

Active, semi-passive and passive RFID tags are making RFID technology more accessible and prominent in our world. These tags are less expensive to produce, and they can be made small enough to fit on almost any product.

Active and semi-passive RFID tags use internal batteries to power their circuits. An active tag uses its battery to broadcast radio waves to a reader, whereas a semi-passive tag relies on the reader to supply its power for broadcasting. Because active and semi-passive tags contain more hardware than passive RFID tags, they are more expensive. Active and semi-passive tags are typically for high valued assets that followed over greater distances -- they broadcast high frequencies from 850 to 950 MHz and read at distances of 100 feet (30.5 meters). If it is necessary to read the tags from even farther away, additional batteries can boost a tag's range to over 300 feet (100 meters).

Like other wireless devices, RFID tags broadcast over a portion of the electromagnetic spectrum. The exact frequency is variable and can be chosen to avoid interference with other electronics or among RFID tags and readers in the form of tag interference or reader interference. RFID systems can use a cellular system called Time Division Multiple Access (TDMA) to make sure the wireless communication is handled properly.

Passive RFID systems are composed of three components – an interrogator (reader), a passive tag, and a host computer. The tag is composed of an antenna coil and a silicon chip that includes basic modulation circuitry and non-volatile memory. The tag is energized by a time-varying electromagnetic radio frequency (RF) wave that is transmitted by the reader. This RF signal is called a carrier signal. When the RF field passes through an antenna coil, there is an AC voltage generated across the coil. This voltage is rectified to supply power to the tag. The information stored in the tag is also transmitted back to the reader. This is often called backscattering. By detecting the backscattering signal, the information stored in the tag can be fully identified.

Passive RFID tags rely entirely on the reader as their power source. These tags have a limited range of up to 20 feet (six meters) away, and have lower production a cost, meaning their application is for less expensive assets. These tags are manufactured to be disposable, along with the disposable consumer goods on which they are placed. Whereas a railway car would have an active RFID tag, a bottle of shampoo would have a passive tag.

Active RFID tags use radio frequency energy to communicate between a tag and a reader. Active tags use an internal power source such as a battery within the tag to continuously power the tag and its RF communication circuitry. Whereas passive tags rely on RF energy transferred from the reader to power the tag. Active tags can generate high level signals to the reader. Active tags can also contain external sensors for example monitor temperature, humidity, and motion.

There are two types of active RFID tags, transponders and beacons. Active transponders are responsive when they receive a signal from a reader. For example toll payment collection, when a car with an active transponder approaches a tollbooth, a reader at the booths sends out a signal that wakes up the transponder. The transponder then broadcasts its unique identifier to the reader. This active RFID conserves battery life by having the tag only broadcast when it is within range of a reader. Beacons are RFID tags that can initiate communication with a reader. A beacon emits a unique identifier at pre-set intervals for example every 3 seconds or once a day depending on how important it is to know the location. The beacon's signal is picked up by at least three reader antennas positioned around the perimeter of the area. Using the known location of the reader antennas, it will determine the location of the tag.

A semi-passive tag uses an on-tag battery to improve performance. The battery powers the tag so that the tag does not need to use energy harvested from the reader to operate the tag's memory or applications. This significantly improves backscatter performance and read/write ranges.

Another factor that influences the cost of RFID tags is data storage. There are three storage types: read-write, read-only and WORM (write once, read many). A read-write tag's data can be added to or overwritten. Read-only tags cannot be added to or overwritten -- they contain only the data that is stored in them when they were made. WORM tags can have additional data (like another serial number) added once, but they cannot be overwritten.

Most passive RFID tags cost between seven and 20 U.S. cents each. Active and semi-passive tags are more expensive, and RFID manufacturers typically do not quote prices for these tags without first determining their range, -storage type and quantity. The RFID industry's goal is to get the cost of a

passive RFID tag down to five cents each once more merchandisers adopt it.[18]

The main difference between passive and active RFID tags is that active tags are powered by a battery and automatically broadcast their signal, whereas passive tags do not have a power source and only transmit a signal upon receiving RF energy emitted from a reader in proximity of the tag. The features of the three categories are listed below as Table 3.

B. 6.2 Introduction to Wi-Fi Technology for RTLS

Wi-Fi RTLS is mostly compatible with the existing IP-based network and computing architectures, which support IEEE 802.11 a/b/n/g Wi-Fi standard. The concept behind Wi-Fi RTLS is that this technology can utilize the existing Wi-Fi infrastructure to communicate with Wi-Fi tags. Typically Wi-Fi networks are not designed initially to meet the requirements of RTLS. Additional access points will need to be added to the existing system in order to achieve real time object or people tracking. This will increase the cost of deployment, maintenance and support. Relatively compared to RFID, Wi-Fi based RTLS has better security, more scalable and flexible.

However, the concept is misguiding in some sense. First, the RTLS has to work in different frequency band from the wireless communication applications in case the RTLS interfere with other wireless communication applications. Secondly, to get the desirable performance, hospitals and companies that would like to deploy this technology might have to consider the huge cost of deployment, for example, RTLS equipment costs, software license, labor cost for installing an extensive Wi-Fi network and Wi-Fi RTLS system, and also maintenance cost. For better performance and accuracy, using the existing Wi-Fi network components is not truly enough because the quality depends on the density of APs that are entirely installed to cover the required areas. Also, the increasing cost involves network component costs; switches, server, and server-license and Wi-Fi RTLS equipment; Wi-Fi tags. When added together, the overall cost of Wi-Fi RTLS deployment is high in order to get higher reliability and accuracy.

There are three technological concepts to explain how Wi-Fi RTLS platform work. First, Nearest Access Point (NAP) is considered for detecting the presence of an asset, person, and equipment within a set area. A single Access Point or Location Receiver will detect tags and Wi-Fi devices. Second, the technology is called Time Difference of Arrival (TDoA). This method depends on the time of a packet that needs to be sent from a transmitting device towards a receiving device. Using Wi-Fi means the client sends out a time stamped signal, which is received by access points. Knowing the time difference, the distance between the AP and the client can be calculated. In a system with at least three visible access points, it becomes possible to estimate the location of the client. The third technology is Received Signal Strength Indicator (RSSI). The client device measures the signal strength of the access points and sends the values to a server. On the server, the location of the client can be calculated, handle tags management, and provide Application Programming Interface (API). Once, API receives the location data, alerts, and maps form server. Then, it will show real-time maps, handle alerts, and ultimately provide reports. The RTLS with Wi-Fi technology system flow can be seen in Figure 2.

TABLE 3. THE FEATURES OF THREE CATEGORIES OF RFID TAGS

Categories	Passive RFID	Semi-Passive RFID	Active RFID
Pros	-Reader talks first -Low power passive backscatter -Low overhead, simple communications protocol -Low cost	-Readers talks first -Low power passive backscatter -Low overhead, simple communication protocol -Long read/write range (>100m) -Medium Reliable in RF challenging environments -Sensors and data storage[19]	-Long read range (>100m) -Reliable in RF challenging environments -Sensors and data storage
Cons	-Short read range -Even shorter write range -Unreliable in RF challenging environments -No sensor support	-Less reliable than active RFID tags -More costly than passive RFID tags	-Tag talks first (for beacons) -Higher power requirements -Slow inventory, poor counting at portals -Relatively high cost
Read Range	Up to 40 feet (fixed readers) Up to 20 feet (hand-held readers)	Up to 300 feet or more	Up to 300 feet or more
Power	No power source	Battery powered	Battery powered
Tag Life	Up to 10 years depending upon the environment the tag is in	Up to 5 years	3-8 years depending upon the tag broadcast rate
Tag Costs	$.10-4.00 or more depending upon quantity, durability, and form-factor	Volume price: ~$3-5/tag [20]	$10-50 depending upon quantity, options (motion sensor, tamper detection, temperature sensor), and form-factor
Ideal Use	-For inventorying assets using handheld RFID readers (daily, weekly, monthly quarterly, annually). Can also be used with fixed RFID readers to track the movement of assets as long as security is not a requirement.	-Track, locate, and manage high value assets - Yard management, parking, hospitals, industrial parts [20]	-For use with fixed RFID readers to perform real-time asset monitoring at choke-points or within zones. Can provide a better layer of security than passive RFID.
Readers	Typically higher cost	Medium cost (For example , intelleflex reader priced $2500-3500/reader) [20]	Typically lower cost

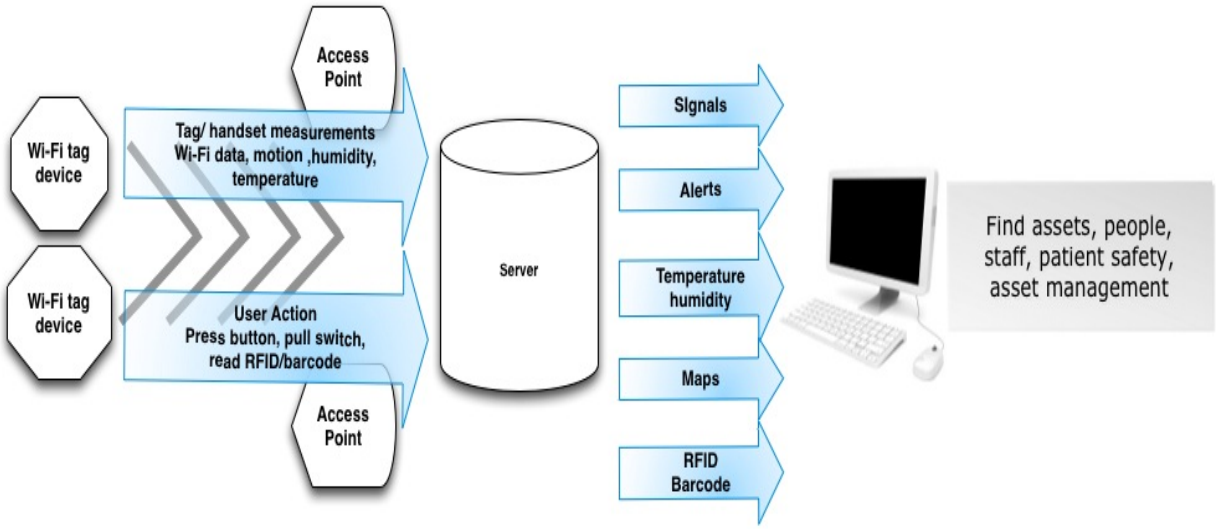

Figure 2. The RTLS with Wi-Fi technology

C. RFID Technology Evaluation Based on the Conceptual Model

1) Enterprise-Wide Coverage

Passive RFID range of coverage is up to 40 feet when fixed readers with multiple antenna options like portal, ceiling and wall mountable are used. Passive RFID with portable hand held readers and barcode readers have a maximum of 20 feet read range. These types of readers normally come with a touch-screen interface and Windows Mobile based operating system. Active RFID tags can have a range up to 300 feet. They operate at 455 MHz, 2.45 GHz, or 5.8 GHz. The active RFID tag can be read reliably because they broadcast a signal to the reader. Some active tag manufactures provides tags that have a battery life up to five years.

2) Location Accuracy

Active tags used in most real-time location systems can usually be read 100 percent of the time, since they broadcast their signal like a cell phone. However, if there is a metal barrier blocking the tag from the reader it might not be able to read. Passive RFIDs are highly reliable, but passive tags produce a weaker signal that is more easily blocked. A passive tag's signal might be deflected by metal, or it might not penetrate a pallet of bottled water or thick planks of wood. Most passive and active RTLSs can locate a tagged object to within 10 square feet. The exception is ultra-wideband (UWB) systems. Because they don't have the same challenges facing multipath solutions, they can locate objects to within a few centimeters.

It is also possible to use RF based RFID readers at choke points (in halls or doors) to provide room level accuracy. There already available of a new RFID technology capable of dividing a room or segmenting a bay by creating radio frequency identification (RFID) “virtual walls.” The technology was developed to meet the needs of healthcare providers to track tagged mobile medical equipment down to portion of a single room. This sub-room-level distinction in certain areas of the hospital provides an important enhancement to RFID room-level accuracy.[21]

3)Whether Need Hardwire Installation

RFID is a technology that relies on bi-directional, wireless, transmission between readers and tags. In passive RFID systems the readers produce a signal that induces a current in the tag to power the tags transmitter. However in healthcare applications and in particular, pharmaceuticals, sensors are used for monitoring of a variety of parameters like temperature and humidity. Those sensors are either hardwired or add to the background EMI with wireless interfaces.

4)Network Interference and Security

Active RFID tags are consistently broadcasting a signal; they might cause interference with other technologies. There is always a risk of interference between RFID and other technologies in the workplace or the data center. Two types of interference may happen: (1) Interference that prevents correct data being transmitted and/or received. (2)The risks that signals from one system will be interpreted incorrectly as valid data by another system.

5)Time to Deployment

The time to deployment is dependent on the installation and system implementation.

6) Ongoing Maintenance

After an RFID system has been successfully installed, there is a possibility that it will face various performance-related issues. These issues can involve reader failure, tag failure, problems with the middleware, RF environment changes, network, power, or computing systems. Active RFID tags have the risk of power source or battery outages that may cause poor signal and possible misreads. Maintenance will increase as the hardware of the tag becomes more complex.

7) Interoperability

RFID Interoperability refers to tags from any vendor to be able to communicate with RFID readers from any other vendor, and also to when a given tagged object is able to be identified by RFIED readers of any user in a wide variety of application conditions.

In order for RFID to successfully penetrate into large open systems, RFID interoperability is a necessity. Currently there is a vast amount of literature that focuses on dealing with RFID interoperability by proposing various protocol standards. The second-generation standard ensures that RFID tags and readers work globally. This new standard has been submitted for certification to the International Organization for Standardization (ISO).

8)Installation Cost

RFID installations consist of a large number of interdependent components that work together as a unit for proper functionality of the system. These components include tags, readers, antennas, networks, computing systems, power supplies, and peripherals, accessories and other mechanical systems that are controlled by the RFID implementation.

Passive Tags:

Passive tags generally range from 10 cents for the simplest to several dollars for a transponder embedded in a key fob or plastic housing when purchased in high volume. In addition to the tag price, companies have to consider the cost of testing passive tags. Failure rates among passive tags can be up to 20 percent.

Active Tags:

Active tags generally cost from $10 to $50, depending on the amount of memory, battery life requirements, additional functionality such as temperature sensor, and ruggedness. More durable material used for the housing will be more reliable under stressed conditions and will increase the cost. [22]

Readers:

Readers vary in price from $500 to $3,000, depending on their functionality

Middleware:

Middleware is a generic term used to describe software that resides between the RFID reader and enterprise applications. Cost of middleware is about $183,000 for a $12 billion manufacturer looking to meet the RFID tagging requirements.

Other Cost:

Other costs include consulting and integration, project team and tag and reader testing.

9)Maintenance Cost

Passive tags normally operate at far lower cost and with less ongoing maintenance. Active tags require a power source to operate. Some active tags contain replaceable batteries for years of use, others may be sealed. It is also possible to connect the tag to an external power source.

D. Wi-Fi Technology Evaluation Based on the Conceptual Model

1)Enterprise-Wide Coverage

Wi-Fi technology provides enterprise-wide coverage. The coverage range of a universal Wi-Fi tag is up to 200 feet (70 meters)[23]. Once Wi-Fi RTLS system and devices are installed in every suitable spot throughout the hospital to achieve maximum profits, each spot with deployed Wi-Fi RTLS will provide the location information, real-time patience and staff moving status throughout the hospital. To obtain the Enterprise, the hospitals have to reinstall many Access Points (APs) to ensure that the tags can be detected at a reasonable level, because that the density of APs of a RTLS must be much higher than a communication system. This destructs the expectation from the hospitals to utilize the existing Wi-Fi network because the APs required are in a large number; they pull the cost of Wi-Fi network to a high level.

2) Location Accuracy

The Wi-Fi RTLS usually can provide zone level accuracy, it is hard to provide room level and sub room level accuracy. The 2.4 GHz Wi-Fi RF signal cannot easily be interrupted by moving assets (carts, beds, equipment) or human bodies that obstruct the path between tags and APs. In the dynamic environment of a hospital, the result is meaningful and accurate determination of location impractical.

3) Whether Need Hardwire Installation

In the initial phrase of deployment, it requires outlets in each spot in order to power APs for tracking processes. It also needs WLAN cabling to connect with each AP within the existing wireless network.

4) Network Interference and Security

Cell phones, microwave ovens, tablets and laptops works basically operate at the same frequency level as Wi-Fi devices. The interference from mentioned devices directly affects the Wi-Fi performance and reliability; result in dropping connection, and lower performance. Usually, the vendor comes up with the tools to help users to optimize and troubleshoot the existing Wi-Fi network called “Spectrum Analyzer”. This interface will analyze frequency band, identify what is causing the interference, discover and locate interference sources, investigate affected channels, analyze interference variation over time, and save captured data for later analysis.

In terms of safety and security, when people can be tracked and recorded, and authorization levels allocated, Wi-Fi RTLS provides an additional level of security by making sure that tagged people is in an appropriate location and do not move to undesired or unauthorized areas, for example, outside the hospital.

5)Time to Deployment

Some vendors claim that each installation is 30-day project. The short-period installation is important to minimize the disruption of healthcare activities. Wi-Fi RTLS is effortlessly compatible with the existing WLAN infrastructure, but the Wi-Fi RTLS requires more infrastructures with added cost to be useful. The time consumption depends on how big of area that the hospital wishes the system to cover, the larger the area the more time for the installation is required, ignoring the deployment of existing network infrastructure.

6)Ongoing Maintenance

Once the hospital has optimized its Wi-Fi infrastructure for RTLS, it would require an extensive location planning of highly trained IT personnel to keep the system calibrated. If the hospital doesn't have this expertise on staff, or, like most hospitals, have an IT department that is strained in resources, a primary WLAN provider conveniently offers professional services that include the tuning of location performance. This service offering enlists the skills of trained WLAN engineers to deliver an integrated solution that includes services identified as essential for successful deployment of a secure location-based services solution.

The need to optimize and troubleshoot the existing Wi-Fi network augments the job of maintenance because once the Wi-Fi RTLS is installed it would need calibration to ensure that equipment is working in the proper frequency.

7)Interoperability

In the Wi-Fi RTLS, it will support standards-based technology that makes it compatible with all Wi-Fi networks, supporting IEEE 802.11a/b/g/n standards, and provide the user-friendly API (Application Program Interface) for users to retrieve, track, and record the related data, the historical reports, and business reporting in and from the RTLS server. From the server, client can conveniently know or find patient/people/staff's location. The user can promptly be notified in case of emergency and instantly know where the patience is. Other than that, API can clearly generate the map for people and safety management.

However, the Wi-Fi RTLS technology is still developing, the problem caused by the reality is that the new standards always bring new equipment, the old and new equipment have to be compatible to work together. The Institute of Electrical and Electronics Engineers (IEEE) standards govern the operation of Wi-Fi devices and systems, referred to as 802.11. IEEE standards are constantly updated to accommodate changes in technology. The Wi-Fi standard was recently enhanced by the new 802.11n specifications. The presence of thousands of 802.11b asset tags and other legacy devices will force a notable capacity slowdown of the 802.11n wireless communications network.

8)Installation Cost

Hours of installation can vary depending on company's rate.

Software and hardware costs:

- ✓ Vendor's software license for API
- ✓ The amount of devices (tags) needed; approximately $35-$50/tag
- ✓ Server and software server; Window server software
- ✓ Access points and switches; $441/Cisco router with 802.11g and $403/ Cisco switch.

9) Maintenance Cost

For Wi-Fi RTLS system, the maintenance cost for hiring trained IT staff for maintaining the network performance and the ongoing calibration needed, otherwise, the maintenance cost for payment to vendor if the vendor is taking responsibility.

E. The Comparison Summary

TABLE 4. THE SUMMERY OF COMPARISON OF RFID AND WI-FI TECHNOLOGIES FOR HEALTHCARE RTLS

Technology / Criteria	RFID		Wi-Fi
	Active RFID	Passive RFID	
Enterprise-Wide Coverage	300 feet	Fixed readers:40 feet Handheld readers: 20 feet	200 feet
Location Accuracy	Room level 1-3 meter	Zone level	Zone level
Whether Need Hardwire Installation	Yes	Yes	Yes
Network Interference and Security	None	None	Heavy Interfere
Time to Deployment	Depending on environment and vendor	Depending on environment and vendor	Depending on environment and vendor
Ongoing Maintenance	Medium	Low	High
Interoperability	Good	Good	Medium
Installation Cost	Depending on environment and vendor	Depending on environment and vendor	Depending on environment and vendor
Maintenance Cost	Depending on environment and vendor	Depending on environment and vendor	Depending on environment and vendor

F. Interview about RTLS

1) Interview Questions

After we conduct the technology investigation of RFID and Wi-Fi, we still have several questions about the implementation of RTLS. We list the questions below:

Questions to healthcare centers/hospitals staff:

- ✓ How is the inventory control application working in healthcare centers/hospitals?
- ✓ How is the high value asset tracking application working in healthcare centers/hospitals?
- ✓ How is the people-tracking application working in healthcare centers/hospitals?
- ✓ Questions to RTLS vendors:
- ✓ How are the performances of RFID (including active, semi passive and passive RFID tags) and Wi-Fi tags technology get recognized in the market?
- ✓ Which technology is the best performer in the market according to your experience?
- ✓ How is the feedback from the users about the accuracy, coverage and reliability of RFID and Wi-Fi RTLS?
- ✓ Questions to the RTLS vendors and engineers:
- ✓ Do RTLS readers need both power cable and communication cable with hardwired installation?
- ✓ Does choke point technology coexists with locating by coordinates to help obtain the room level or sub-room level accuracy in Wi-Fi and RFID technologies?

In a RTLS network of a healthcare center/hospital, there usually are several requirements such as inventory control, high value asset tracking and people tracking, and is it possible for these functions to be achieved by using one set of RTLS rather than deploy a number of real time location systems with different technologies?

Once the hardwire installation is finished, if the present RTLS technology is not performing well, is it practical to use the original installation infrastructure but only change readers and tags?

2*) Interview Feedback from Hospital Staff*

In order to understand the usage of RTLS in hospitals, we conducted interviews with staffs from 4 healthcare centers/hospitals. They are Deborah Shockley, titled as Labor and Delivery nurse in Legacy Emmanuel; Ann Marie Collinson, titled as the Director of Operations in Oregon Clinic; a technical consultant in Keiser Permanente; a nurse practitioner and care provider at Adventist Clinic and SW hospital. They all use RFID technology as the technology for RTLS. They think RTLS is an outstanding use of technology when applied to the correct use such as it functions well when urgently needing to find either people or equipment.

Their responses received are as follows:

> "Tracking equipment was great, able to track and locate all staff quickly. Also used in labor and Delivery to track infants, used to track 'high risk' patients used in ICU and other critical care units. Found system to save time and lives! The downfall was that you could not get away to relax."
>
> "RFID, is used in supply ordering, patient tracking, and disciplinary patients. The positive is the cost savings, patient savings, better care, fewer wrong medications, marketing, inventory, and ability to identify patient's locations. The downfall was the learning curve and batting with physicians. In addition, the time lost in initial data entry."
>
> "Used in operating rooms to ensure equipment trays are correct and if returning inventories are correct. They are used to track lab specimens to ensure that there is continuous accountability and temperature control of critical specimens. Positive attributes are that it monitors constantly. Downfalls are the battery consumption and the size makes tags very difficult to place on small items."

They gave some responses for the usage of RTLS in inventory control, high value asset tracking and people tracking in healthcare centers/hospitals.

For Inventory control, the Material Science Office of hospitals loves RTLS. It works well for this purpose. For high value asset tracking, RTLS helps track high value items for return. It is able to locate critical equipment instantaneously. RTLS is used to find highly mobile, high cost items like fusion pumps and loaner equipment; it is also used on items of low cost but high importance such as keys. For the large equipment, most users do not need it because it is easy to locate and the cost is not worth it. For people tracking, they find that RTLS is extremely accurate; people can be found quickly in emergencies. It gives the ability to locate people quickly, which equates to lives saved. However, currently in some hospitals, RTLS is only used to prevent infant abduction; there are some plans to implement in other areas in the future.

In people tracking, the staff (nurses and doctors) tracking is the relative newer application, so we interviewed with the nurses at Adventist Clinic and SW hospital located in SW Mill Plain Blvd in Vancouver. They think people tracking application is very important for hospitals where there is a need to locate doctors and nurses for emergency situations. It is very useful for tracking nurses and doctors, especially where they are needed for an emergency situation. In that case they can be located and contacted through room's intercom pagers. They think that tracking patients are not as necessary as it is for the doctors and nurses unless if they are being tracked for safety and security purposes. Hospitals have time regulations for responding to emergency patients as they walk in SW hospitals they were able to use their RFID system to collect data and perform some analysis to reduce this time from 60 minutes to 34 minutes for cases when patients need surgery. Specifically, the interviewees think that for RTLS selection, one important factor is the size, weight and design of the tags for as how people are supposed to carry them. Everyone has

their own tags that need to be carried on people's upper body part. The nurses think that the tags were heavy and uncomfortable and they couldn't put them in their pocket due to weak reception. The only way to carry the tags was attaching them to the back of their collar which causes their shirt to be pulled back as the tags are heavy. They hope that the tags are redesigned and the reception ability is improved so that the tags can be carried in their pockets. Also, it is important to educate hospitals on data intelligence and analysis so that they are able to get the maximum advantage of the system to improve their efficiency. Besides the interview, we also refer to the email from RTLS expert, Tim Gee, please see Appendix 3.

3)Interview Feedback from RTLS Vendors and Engineers

In order to get the opinions from more professional persons, we interviewed the national sales and 2 engineers of SATO, a RTLS vendor.

The responses received are as follows:

They think that the software is an important aspect for technology selection, for the bottom level of control, some software uses triangulation as locating method, some don't. The locating method and the software impact the speed, accuracy of locating and interface with other applications. So the model should include software as an important aspect for evaluation.

The RFID still have a very big market share. The passive RFID is mainly for inventory control and asset tracking, the active RFID is used in people tracking more because the signal of passive RFID is not as reliable, for example, when the human body blocks the signal, the object can't be identified. The active RFID tag is much better with the signal strength, but the cost is too high. The Wi-Fi tag has several problems, one is that the signal is not accurate, there are some occasions that the identified object is not in the specific room, and it might be in another room or just another floor. The best performer in the market is ultrasound technology, which gives good locating accuracy and reliability.

Most RTLS readers only need a power cable, they don't need communication cable, and most of them use wireless communication with the servers. The RTLS can use choke point technology wherever needed, it can be at doors or just install on the walls, when people walk by the signal is get identified, this technology is very helpful in getting room level and sub-room level accuracy for RFID and Wi-Fi technologies. Usually, if you have different level of usages in one system, you need different APs, or readers. It is not practical to use one set of RTLS. For example, you have passive RFID tags, then you must have passive RFID readers, if you still need active RFID tags to be identified, you need other type of active readers. At present, the inventory control use bar-codes for inventory control and ultrasound technology to track high value asset and people. Once the hardwire installation is finished, if the present RTLS technology is not performing well, it is practical to use the original installation infrastructure but only change readers and tags. However, different technologies require different level of density of readers, there are also other technical requirements in the locating for the readers to get installed, so when changing technology, there are usually need to do site survey again and change the location of some readers or install some new points.

VII. SOLUTION

A. The Evaluation Matrix for RTLS Technology Selection

After the detailed research and interview with experts, we reconsider the original concept model for the technology evaluation of RTLS and found out that the model needs some improvement in order to guide the comparison for the healthcare centers/hospitals to select technology systematically. We revised the original evaluation model as shown in Fig 3 and Table 5.

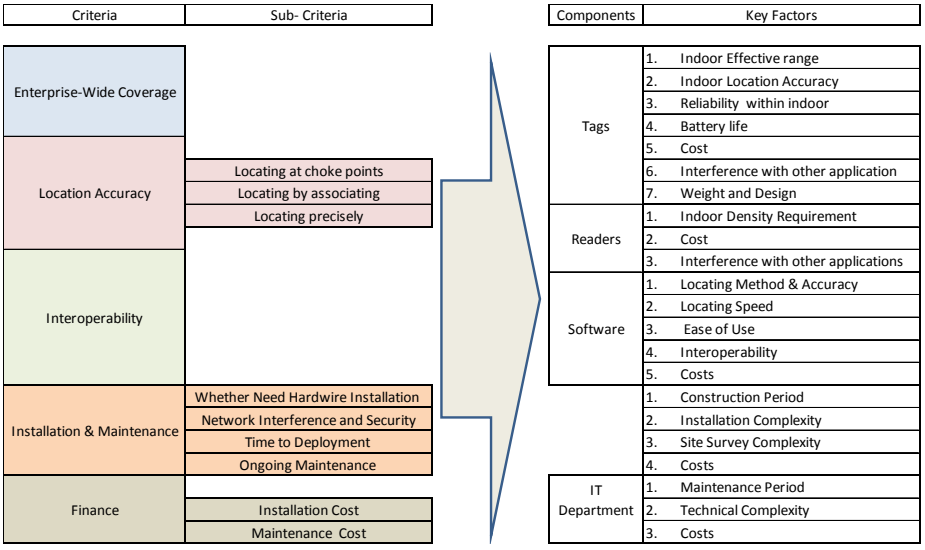

Figure 3. The Improved Evaluation Model for RTLS Technology Solutions

TABLE 5. COMPARISON DESCRIPTION OF THE RFID AND WI-FI TECHNOLOGIES FOR RTLS APPLICATIONS

Criteria	Sub-criteria	RFID			Wi-Fi
		Passive RFID	Semi passive RFID	Active RFID	
Tags	1. Indoor Effective range	20-40 feet	300 feet	300 feet	200feet
	2. Indoor Location Accuracy	Zone level	Zone level	Room Level	Zone level
	3. Reliability within indoor	poor	medium	good	poor
	4. Battery life	Up to 10 years	Up to 5 years	3-8years	Up to 6 years
	5. Cost	low	medium	high	high
	6. Interference with other application	low	low	low	high
	7. Weight and Design	mall	medium	big	big
Readers	1. Indoor Density Requirement	Use choke point usually Or handheld readers	medium	medium	high
	2. Cost	according to vendor	according to vendor	according to vendor	according to vendor
	3. Interference with other applications	low	low	low	high
Software	1. Locating Method & Accuracy	with triangulation	with triangulation	with triangulation	no triangulation
	2. Locating Speed	fast	fast	fast	fast
	3. Ease of Use	according to software	according to software	according to software	according to software
	4. Interoperability	good	good	good	medium
	5. Costs	according to vendor	according to vendor	according to vendor	according to vendor
Installation	1. Construction Period	according to vendor and negotiation	according to vendor and negotiation	according to vendor and negotiation	according to vendor and negotiation
	2. Installation Complexity	easy	medium	medium	high
	3. Site Survey Complexity	easy	medium	medium	high
	4. Costs	according to vendor and negotiation	according to vendor and negotiation	according to vendor and negotiation	according to vendor and negotiation
Maintenance	1. Maintenance Period	according to vendor and negotiation	according to vendor and negotiation	according to vendor and negotiation	according to vendor and negotiation
	2. Technical Complexity	Low	medium	medium	high
	3. Costs	according to vendor and negotiation	according to vendor and negotiation	according to vendor and negotiation	according to vendor and negotiation

VIII. CONCLUSION AND RECOMMENDATIONS

This paper researched key requirements of RTLS for healthcare centers/hospitals, accordingly by the setup of a concept model and conducted technology comparison of RFID and Wi-Fi technologies. Interviews were then conducted with healthcare staff, RTLS vendors and engineers using the concept model as a discussion point. The feedback provided from the interviews were positive, RTLS is very beneficial in healthcare. RTLS allows for tracking of assets and people thus improving patient flow, better coordination and communication among staff and safety. These are just several benefits of integrating RTLS into healthcare, there are many more. The feedback from the interviews also led to the original concept model developed to be altered into a more practical one. One that is easier to use and fit the needs of healthcare centers/hospitals. The next paragraph provides a summary of the technologies and which application it is better suited for in healthcare.

According to evaluation, passive RFID is more suitable for the inventory control of low-cost items due its low cost in tags and its read range limitation of 40 feet (fixed readers) and 20 feet (handheld readers). Active RFID differs from passive RFID in that it uses an internal power source. RFID tags use their power source to boost their transmission signal to have a much greater range and clearer signal. These tags are more expensive and generate signals back to the reader thus are better suited for tracking high-value assets and people throughout the enterprise. Semi passive tags are the middle group in RFID technology and are similar to active RFID because it possess internal power but cannot broadcast nor has the range that active has. Semi passive is suitable for tracking of assets and people. RTLS using Wi-Fi is suitable for tracking both assets and people throughout an enterprise by using an existing WLAN.

As the need to locate people and objects in real time becomes more important to healthcare, RTLS technology is going to continue to grow in the future because of its capabilities. Technology assessment of different technologies is more important than before. There are many RTLS technologies in the field, such as RFID (active, passive, semi-passive), Wi-Fi, Ultrasound, Infra-red, Ultra wide-band,

Bluetooth, Zigbee. Deciding which technology is best suited for a particular healthcare is difficult to assess due to factors that need to be evaluated. This makes the technology evaluation much more critical.

The limitation of this document is that more RTLS technologies could have been compared as well as more interviews could have been conducted to verify the concept model's relevancy. More detailed research would give better guidance to the application use of RTLS for healthcare as well as provide a clearer direction for researchers and vendors. The model illustrated in this document provides a great starting point for evaluating RTLS technology.

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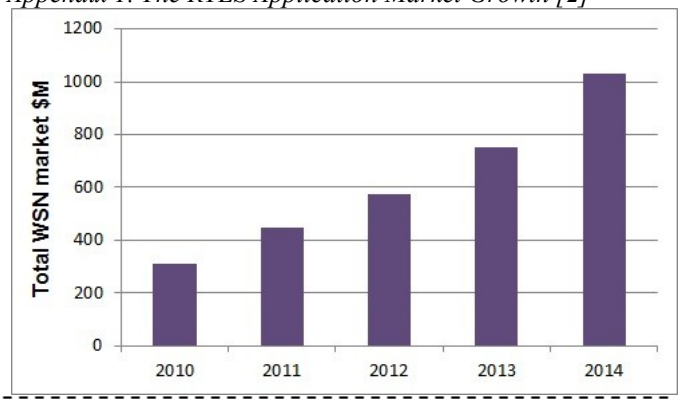
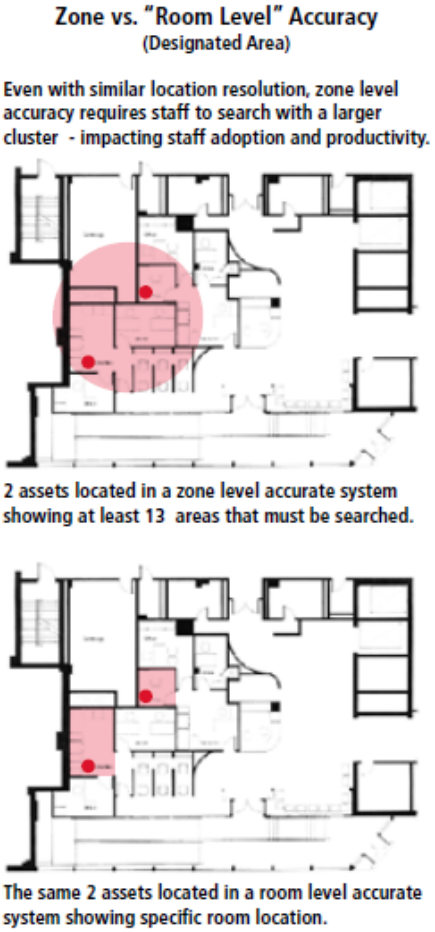
APPENDIX

Appendix 1. The RTLS Application Market Growth [2]



Appendix 2: The Comparison of "Zone Level" and "Room Level" Accuracy[12]



Appendix 3: Email from a RTLS expert, Tim Gee [24]

Tim Gee is the Principal of Medical Connectivity Consulting and a Principal Consultant with Santa Rosa Consulting. He revealed the technology adoption reality in his Blog.

I would be glad to share some info with you. From your email it appears you have a number of different indoor positioning applications which you want to undertake. The key to RFID is that there is no one best system or technology for all applications. You have to match the requirements of your positioning applications to the various capabilities of different systems, and many hospitals end up with more than one RFID system as a result.

You also mentioned Wi-Fi in conjunction with RFID. Many people mistakenly think that Wi-Fi is the only common sense solution for RFID. Sadly, this is not true. To get reasonable RFID performance from Wi-Fi you need a lot of access points. If your WLAN is already designed to support wireless VoIP, then you probably have enough APs to get decent RFID performance. If haven't deployed wireless VoIP plan on at least doubling the APs you have installed for typical data applications like computers on wheels. The actual location of APs also has a big influence on indoor positioning performance, and differs from where they would be sited for optimal data or wireless VoIP performance. As a result, you will likely have to move some of the APs you have. And even with a gob of APs, all in the most optimal positions, you still won't get reliable room level accuracy – which is critical for some RFID applications.

There are two key variables in RFID performance, spacial accuracy and reliability. Spacial accuracy is the resolution or specificity with which an RFID system can place a tag in space, e.g., plus/minus 10 meters, 3 meters or 1 meter. Reliability is the RFID system's ability to consistently indicate the correct location for a tag.

While RFID system performance can be thought of as a continuum, there are two common performance groupings – RFID that can resolve the general location of tags (e.g., the west wing) and those that provide room level accuracy. Most RFID technologies that are good at determining the general location of tags use some sort of RF triangulation between tags and multiple readers. Examples are Wi-Fi based systems from AeroScout and Ekahau and plug in readers from AwarePoint and Radianse. With RF triangulation systems, the greater the density of readers deployed the higher the spacial resolution. Even with a high density of readers, I'm not aware of any RF triangulation system that provides reliable room level accuracy. RFID systems that utilize ultrasound (Sonitor) or infrared (Versus or Centrak) are often the best at room level accuracy. It is also possible to use RF based RFID readers at choke points (in halls or doors) to provide room level accuracy.

Asset management applications for finding and generally tracking equipment like IV pumps and wheelchairs typically provide general locations. Room level accuracy is required for workflow automation such as ensuring medical devices are cleaned prior to being put back in service, or clearing a nurse call when a caregiver enters the patient's room.

Infant abduction systems can be implemented using readers at the locations where people enter or leave the unit, or systems that track infants from room to room. The latter systems are more expensive than the former due to the greater number of receivers or APs.

You should also be aware that the hidden cost of RFID systems is the cabling and installation costs of readers, The costs of receivers and tags themselves is pretty transparent. Tag replacement and maintenance (battery replacements) costs also tend to be hidden.

Application software – especially for specialized applications like infant abduction – are often tied to a specialized type of RFID system. An alternative is RFID application software that is RFID hardware agnostic; examples include Intelligent InSites and ConnexAll.