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Leveraging existing wireless networks for location tracking. The issues and concerns surrounding this design model

Tracking Critical Assets and Patients Can Dramatically Impact the Continuum of Patient Care Provided the Proper Systems are in Place©

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Synopsis

The concept of tracking infusion pumps and other medical equipment and the benefits to the hospital has been well documented by many in the Radio Frequency Identification (RFID) & Radio Frequency Location System (RFLS) industry. As well, the capability to deliver such benefits has been, in many cases often overstated by others. Adding to this confusion in the marketplace is the derived and perceived differences between RFLS and RFID, and the basic notion of tracking versus locating. *For many hospital leaders and purchase decision makers RFLS is today's healthcare location awareness paradigm.*

The Market for RFLS

Whenever RFLS or RFID is discussed in hospitals, what really matters is leveraging this technology for improving workspace and productivity and improving the continuum of patient care experience. Many hospital administrators believe they need to implement RFLS into their facilities, but they also remain unsure as to what form of RFLS will work for them. A report released in 2005 by Spyglass Consulting Group indicated that 45 percent of those interviewed expected to have such systems in place by the end of this year for tracking expensive medical equipment. This same report stated that an active RFLS application, i.e., tracking assets on an RTLS network was favored over passive "choke-point" alerting systems. When asked what barriers needed to be overcome to implement such systems, network infrastructure was identified by 92% of those interviewed. Many indicated that they wanted to be able to use existing wireless WiFi networks rather than a dedicated RFLS network for tracking. Yet, recognizing the vulnerability of trying to leverage these existing networks these same healthcare organizations worried that tracking thousands of items may overwhelm their networks preventing clinicians from accessing the clinical information system. Their concerns are not without merit as this paper will attempt to provide an explanation.

The Past and Current Paradigms of RFLS

It may be useful to think of infrastructure today in terms of installing air conditioning in the 1950's and 60's, it was limited to certain areas inside of the building mostly due to the lack of infrastructure, retrofit challenges, and costs. Obviously people without air conditioning could still work, but perhaps not as efficiently as they could otherwise. Also, as technologies advanced and more automation was introduced into the office environment by way of photo copiers, electric typewriters and later, large mainframe computers, the overall burden on the air conditioning system was increased.

Often these additional demands on the system overwhelmed the air conditioning's capability to keep up with cooling demands leading to failures with overheated office equipment and the overworked cooling systems themselves. Today of course building climate control is common place throughout much of the world and very well managed. The data obtained from these systems allows for the automation of building climate control thus being proactive in utility and energy cost savings.

In the world of indoor positioning systems the term "*tracking*" has become somewhat overstated, and overused marketing jargon. The reality is that most companies offering RFLS tracking systems are actually offering "locating" systems. The distinction between the two should not be lost on those charged with implementing such systems into the facility. *Tracking is "knowing" the full history of the item, as well as its current location.* Tracking also provides full insight as to the item's duty cycle as it is being tracked, its status at every step in the duty cycle, and its interaction to other assets or people in the clinical environment. A valid tracking system should be capable of conveying in real-time the assets in-use status, its state of cleanliness, and its operating health as well as maintaining an accurate history of each of these elements. A well designed tracking system goes far beyond the limited capability of "locating" or providing location knowledge, which merely provides answer to the basic questions of "where is my asset?", or "where is my patient?"

Creating the Business Model for RFLS

The business model for asset and patient tracking is one that has been around for several years now. Yet today, beyond many limited pilots of RFLS the industry offerings for these systems have been less than cost-effective or manageable. The desired price points were not there and the overall integration into the way hospital's deliver patient care was lacking in several areas. In effect, the technologies driving RFLS were not mature enough for widespread acceptance into mainstream hospital care, and all too often they over promised and underperformed. *Yet, the U.S. healthcare system is clamoring for a winning RFLS solution that will deliver on all of the promise of what these systems propose.* Many hospital leaders recognize that as each day passes they are potentially wasting thousands of dollars for their facility if process improvement and greater efficiency is not achieved.

Often overlooked, they may unknowingly place their institutions at greater risks of exposure from extended patient stays and potential litigation. Such exposure often is often a result of mismanaged medical care or nosocomial infections that otherwise might be avoidable if an effective tracking & surveillance solution was in place.

An effective network infrastructure for tracking can be measured by the overall number of tags to be tracked, the granularity of reporting and most importantly, the repeatability of the data. In terms of where things are "at this current time", this obviously needs to be "real-time", and flexibility should be given to tracking 1,000.s of items at the same time with additional flexibility to the granularity of location. Finally, there should be use models that tie the "awareness of location" to the healthcare application space. Without this the value of "tags" and associated hardware just may not have business value to the hospital. For this reason many of the RFID and RFLS pilots have not progressed beyond the pilot stage; the value proposition could not be adequately demonstrated.

WiFI or 802.11b/g used for RFLS?

Wireless technologies such as 802.11b/g, WIFI, or Zigbee currently enjoy success in those working environments where they have a demonstrated business value, e.g., COWS, EMRs, Bar Code Medication Administration, etc. When the discussion however shifts to the topic of RFLS there are some severe potential limitations associated with these technologies that may preclude them as an effective solution for this purpose.

802.11b uses a spread spectrum approach that employs three non-overlapping channels whereby Zigbee was designed as a use model for home and building automation. The crux of the equation for using RF (RF mathematical) is worthy of further discussion. Certainly one only has to look at the early days of engineering WIFI networks when data was the only traffic placed upon the network. When the additional demand for voice fell onto the network, they simply did not work well without costly re-engineering of the design (wireless system designers had to take into account the signal levels required for voice as well as latency requirements.). Hospitals CIO's & CTO's were painfully made aware of the challenges of dealing with converged networks and having voice work within this environment at an acceptable level. In 802.11 networks, packet delays of varying lengths will occur due to the random back-off periods required in the standard. As part of the MAC layer implementation of carrier sense multiple access/collision avoidance (CSMA/CA), random back-off is required after every packet transmission. The intent is to provide equal access to the media. With voice devices, the resulting variable delays are undesirable. They also discovered that there are strict limitations to VoIP on 802.11b in terms of the number of channels available thus forcing an industry migration from 802.11b clients to 802.11a clients.

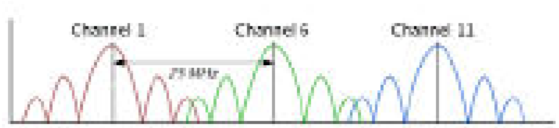


Figure 1 - WiFi 3 Channels

Location Awareness versus Location Accuracy

Or what does all this mean? In terms of location awareness (not tracking, because awareness means "real-time") this simply defines a level of granularity reporting. Perhaps the business model requires knowing by wing where a particular tag is located. Or, maybe the requirement is by floor, by room, or in a particularly area of the surgical area. In some instances this need may be as refined as down to inches. It stands to reason, as a matter of physics, that the measurement tool should be scaled appropriately to the item being measured. Using 802.11b with its long wavelength form will provide results accordingly. Therefore employing 802.11b for this purpose will provide wide-ranging results, with little chance for refined granularity. So the problem becomes one of limited flexibility, scalability, and functionality to make the right business model work, which is increasingly important in mission critical environments that are in today's acute care hospitals.

The Value Proposition of the Data

Beyond reporting tag accuracy, there is the tenability of data that must be considered. Aside from reporting the tag's location, how repeatable is the data, and is it accurate and can it be trusted? It is also meaningful to once again note that any worthwhile tracking system should be measured against the number of applications served. This requires pushing concepts beyond location knowledge while providing the passive collection of data for the benefit of tag-to-tag relationships, or tag-to-environment relationships, in effect, *creating "smart clinical environments"*. When certain conditions are present, i.e., when a tag enters or exits a predefined area, or as tags come into contact with other tags, certain events may be triggered automatically. For example a tag-to-tag example can be made for proper pairing of mother and infant in the newborn nursery. In another situation a triggering alert could be automatically communicated to the Central Sterile Supply staff when a piece of medical equipment separates from the patient indicating it's out-of-use status while at the same time noting its soiled condition thus preventing further use of the equipment until it is once again cleaned. In all of these situations, the collection of data is made passively without any additional demands placed upon the caregiver.

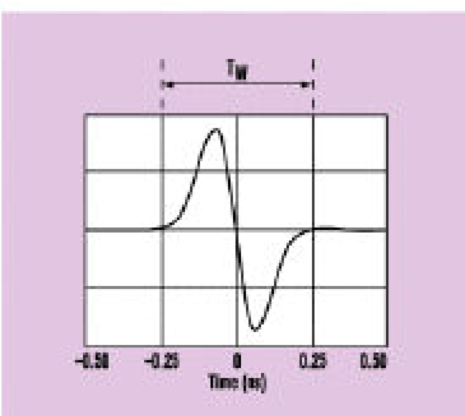
Additionally, in many of these situations the status of the patient's whereabouts or medical equipment status may be also communicated without the need to validate with either manual entry or the use of bar code scanning. Above and beyond the goal of capturing and communicating status passively, there should be additional goals of eliminating the manual entry of data wherever possible using location data. Reinforcing this concept, automating many of the processes of providing patient care should be the goal of any RTLS or RFLS system. That being said however, it stands to reason that achieving such an objective can only be realized with accurate (submeter), and repeatable data. If the RFLS system can only perform at this level say 40% to 60% of the time, then the confidence to automate the collection of data and trigger events is lessened. If WIFI or other proprietary solutions have not taken off over the past five years, then someone simply has to ask why when such a compelling business requirement is present.

It is worth pointing out that there is no "one-size fits all" WiFi technology. From a marketing perspective it sounds wonderful to have data, voice, location tracking, etc, on the WIFI network as simplistic and appealing as this may sound. However achieving this goal in real-world environments often proves more capricious than one would hope. In the final analysis it all comes down to basic physics and the limitations it places upon all of us. *Just like the limitations and the failure model of trying to cram WiFi onto a passive distributed antenna system confirms there are limitations to what can realistically be expected from the existing network.* Certainly companies that are leaders in the 802.11a/b/g space have not fully embraced this marketing direction and are having to contend with balancing out the right message to the marketplace.

Their message sounds very appealing, especially to the uninitiated and uneducated and those looking for a quick solution. But are the adopters of such tracking solutions mortgaging the near future of their existing WiFi network in order to achieve a quick fix today? Enthusiasm for trying to leverage the existing network can fade quickly when managers of these wireless networks work to overcome the issues of "signal to noise" ratio, let alone the cost economics which also leads to the scrutiny of the more expensive WiFi tags.

Ultra Wideband Technology (UWB)

Over the past several years UWB has emerged as the leading technology for healthcare asset and patient tracking signaling the maturing and coming of age for these systems. *However, recent advances and improved designs have also made UWB an attractive choice when performance is critical and price to acquire and own is important.*



2. The basic pulse transmitted by a UWB transmitter is called a monocycle. It's not one cycle of a sinewave, but a unique pulse shaped by a Gaussian filter.

Figure 2 - UWB Pulse

The leading developer of UWB is Time Domain Corp. of Huntsville, Alabama. Parco Wireless has an exclusive license to develop and distribute UWB tracking systems using Time Domain's PulsOn technology in healthcare.

Instead of traditional sine waves, UWB devices emit a series of extremely short pulses (billionths of a second or shorter) simultaneously across a wide band of frequencies.

In its most recent UWB Report and Order, the FCC defined UWB as an RF transmission with a bandwidth that exceeds either 500 MHz or 20 percent of a specific frequency band, between 3.1 GHz and 10.6 GHz. In contrast, conventional UHF RFLS interrogators and tags in the United States operate between 902 and 928 MHz and can transmit a signal with a bandwidth of no more than 500 kHz. (In Europe, UHF RFLS devices operate between 865.6 and 867.6 MHz, and can transmit signals with a maximum of 200 kHz.). Parco's UWB technology is characterized by:

- Ultra-short duration pulses that yield ultra-wide bandwidth signals
- Extremely low power
- Excellent immunity to interference from other radio systems
- High bandwidth, multi-channel performance
- Co-exists with existing spectrum users

An Appeal to Physics

The big unanswered question remains; "Should I attempt to leverage the existing WiFi network for asset or patient tracking?" Pushing aside all of the marketing hype for a moment, a strong case can be made against this practice using basic laws of physics. It remains a simple matter of physics that if one wishes to measure a short distance using a radio-frequency waveform, then the waveform ought to be correspondingly small. It's rather like trying to measure the diameter of a pea: one is much better off using a ruler with a scale of 1/16", than a scale of feet. So it is with any type of RF; if the desire is to measure ranges to within a few inches, one is better off deploying a waveform that is of the order of a few inches, and not a few feet.

Here's another fact of physics: anything that is very short (in duration/length) has a wide bandwidth; the shorter the wider. Stated another way a wide bandwidth is required to measure range accurately.

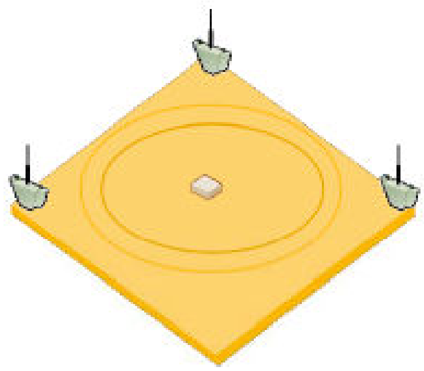


Figure 3 - TOA 2D Ranging

Accuracy, and Why is it Important? Going back to the intended use model and the desired flexibility to the healthcare institution, why would one want to limit the accuracy and confidence in tag reporting? In order to measure an object's precise location one requires at least three ranges (or times of arrival) in order to do achieve this in 2D. This means that the 2D error is the sum of the individual component errors (well, not quite the sum to be pedantic, but certainly greater). This is not our biggest problem however. Multipath, receiver geometry, the motion of the tag, interference, noise etc. all contribute to errors, and when all is said and done, a good rule of thumb is to remember that the position error can end up being 10x the individual range or time of arrival (TOA).

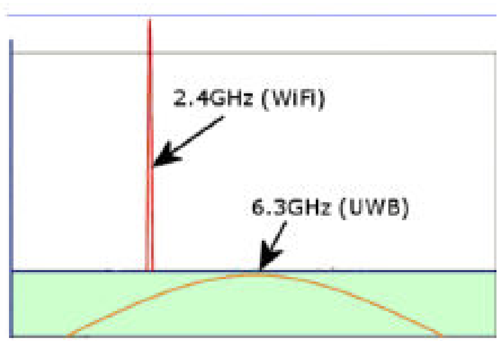


Figure 4 - WiFi v UWB Power / Bandwidth

Considerations of Technology

So, what are some of the issues with WIFI or even Zigbee? One characteristic is that they just do not have much bandwidth; about forty times less than a UWB tag, give or take. So, is WiFi or Zigbee forty times less accurate than UWB? It would be a stretch to conclude as much as WiFi systems tend to transmit much more power. Increased power can help contribute to greater accuracy. Much of the original concept of using WiFi tags for location tracking was in the warehouse or large outdoor space environments. In this instance, WiFi more than likely performed well due to this relatively wide-open environment. However in healthcare which is known as one of the worst RF environments there were and still are challenges related to "multi-path."

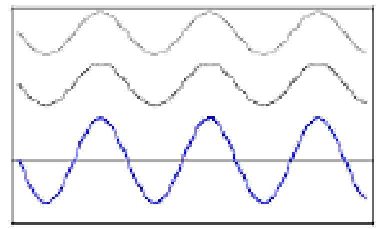


Figure 5 . Multipath

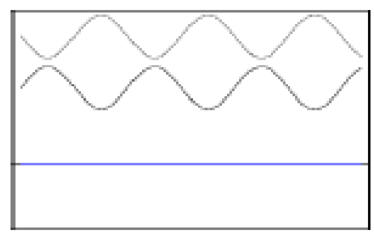


Figure 6 Multipath Fading

While were on the subject of power, it should be noted that battery life tends to be an issue with these type tags. Some WiFi providers have tried to overcome this limitation by putting the tags on a longer dwell time - off for many seconds. This trade-off defeats the real-time nature of monitoring assets. With security applications assets can leave the building during the "sleep time" of the tag. If a laptop computer's built-in WiFi transmitter is being used to locate the laptop, the device must be powered on in order to transmit. These types of systems are also incapable of tracking as was defined earlier. It's probably safe to estimate that the increased power associated with WiFi tags gives standard WiFi technologies between 2x and 4x performance boost, meaning that they're between 10x and 20x less accurate than UWB. This is an accurate assumption whereas UWB can locate to a foot of accuracy whereas WiFi is up there around 10 feet or more. That tracks with what the market has been told about WiFi systems; sometimes as good as 10', often more like 30' feet, and sometimes as inaccurate to 100'. *These systems are adequate for what is sometimes called a "presence" system, but do not provide much value for "real time" Tracking. With this wide-ranging reporting of the tags improving work-flow is severely limited.*

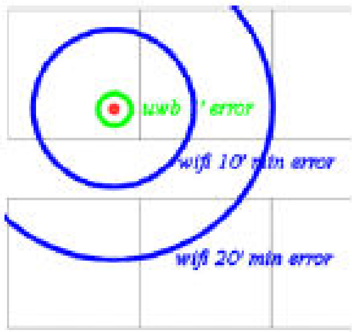


Figure 7 - Accuracy Comparison

Provisioning the Infrastructure

WiFi providers may state that the existing data infrastructure can serve a dual function to include a tracking reference system. Such a utopian claim is not exactly off-base, but it may also be not as clean and simplistic as it sounds. It's pretty safe to say that the overwhelming majority of WiFi systems have been installed to support data communications and only recently have been modified to deal with Voice over IP (VoIP) and its related requirements. In these cases the access points tend to be arranged in a spine-like array down the length of a building. A tracking system, however, needs a 2D grid of access points, and particularly around the perimeter of the building. One rarely finds data communication access points around the perimeter; what would be the point? Half the coverage would fall outside the building!

So if one wishes to use the existing infrastructure, he or she will to need to install many more additional access points. (Here's an interesting article on the topic.http://www.rfidjournal.com/ article/artic leview/2672/1/82/)

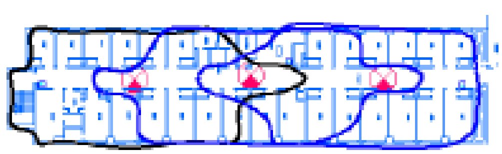


Figure 8 - WiFi Zone Coverage for Communications

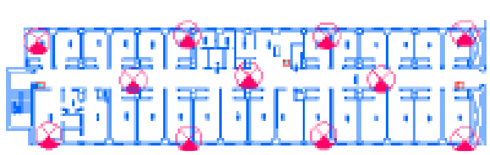


Figure 9 - WiFi Coverage for Location

Figure 10 - WiFi Coverage for Location

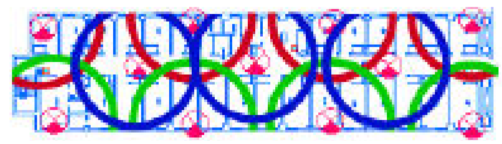


Figure 11 - WiFi Zones for VoIP

Capacity Or how many tags can the network handle?

There are two parts to this question: a) how long does a tag need to be on air?, and b) what happens if two tags transmit at the same time? Although the answer to the first question varies for various WiFi providers, the firm answer for UWB systems is 88 µs. (microseconds or one millionth of a second) Stated another way, this represents 11,000 tags per second if they all lined up neatly. But tags transmit at random times. Network designers love this kind of math and tell us that in a "shout at random intervals" network (called an Aloha network), about 18% of the tags actually get heard. That leaves UWB at about 2,000 tags per second, per receiver.

So, let's get to the second part of the question: what happens if 2 tags transmit at the same time? Well, for WiFi they just may both be in trouble as they tend to talk over each other whereas neither gets through.

UWB however is quite more sophisticated in how this is handled and ensures that one of the tags always gets heard. This puts the Aloha throughput up to something above 18% (this varies by UWB manufacturer), so even if the WiFi providers can get a packet length as small as UWB (88 µs) they still suffer from the Aloha throughput problem with packet collisions.

Anecdotal data tells us that a representative WiFi system can possibly handle between 250 to 300 tags in total, but it's not clear whether that is an RF issue, or whether that's all the tags that the positioning software can handle. Yet, there's another aspect of capacity that might be even more important though, and that brings us back to the WiFi provider of technology.

"You can use your existing infrastructure." Taking into consideration the caveats mentioned above, this statement is basically true. However it is crucial to remember that the hospital is not going to stop using the WiFi infrastructure for moving hospital data. In fact many hospitals are expanding the demands on the network to handle voice, video, and other traffic. So, when the discussion of capacity comes into focus, we have to think about the entire capacity of the network, data plus tags, and perhaps VoIP.

Under these circumstances the WiFi network is feeling the strain from a lack of bandwidth. The manager of the network is also feeling the strain especially when he or she has to appease the CIO by making sure that any mission critical data takes priority over tags. For this to occur the tags can't use up airtime for they will run the risk of colliding with or running over critical hospital data. How does the wireless manager assure this does not happen? To avoid hundreds of tags taking priority over mission critical data already flowing on the network there needs to be a method for communicating with the tags in order to tell them to shut down. This would require that they have a receiver on board, which kicks off another discussion:

Price. or the Total Cost of Ownership?

WiFi tags are just more expensive than UWB tags (about 5x at the moment). But won't volume manufacturing and bulk purchasing make them less costly? Well, let's revisit the discussion of physics and remember a couple of things. First, it's much easier to ping out UWB pulses than it is to make a WiFi waveform (in all it's direct sequence spread spectrum -sequence glory).

It takes much more electronics to make a WiFi signal than a UWB signal, and that directly equates to increased costs. Also, if the WiFi tag is going to fit into the existing network, then it's going to need a receiver on board. Receivers also add significantly to the overall cost. However one looks at it, WiFi tags are going to cost more than UWB tags. Then one has to consider why the move from DSSS to OFDM for 802.11g and 802.11a?

Robustness to issues, like "multi-path"

Healthcare applications place critical demand on robustness and reliability, and it's a key factor in comparing UWB and WiFi. Again, when comparing technologies it is always a good idea to avoid conjecture and appeal to physics.

A major consideration should be given to the issue of multipath, i.e., signals bouncing around inside a building. (remember the challenging RF environment of healthcare?)

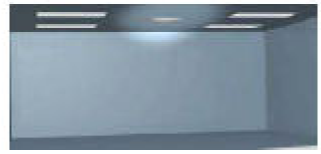


Figure 12 - UWB Reader Ceiling Mounted

When a signal travels from a transmitter to a receiver, the receiver receives many copies of the original, all spaced apart in time. The copies are "echoes" from around the room, with latent echoes being the ones that traveled the farthest. Typically the echoes will be spaced apart by mere nano-seconds (one trillionth of a second). That's hard to imagine. It is easier to think of the signals as arriving spaced apart by a couple of feet or so.

Now, recall the earlier discussion about bandwidth and signal length? UWB has wide bandwidth and therefore very short pulses (a couple of feet in the case of Parco Wireless. UWB tags), while WiFi signals are much longer in length (along the order of 50 to 100 feet). When the echoes come back spaced apart by a few feet, the UWB pulses rarely overlap. It may be helpful to think of UWB pulses like clapping in a church full of people. WiFi signals on the other hand overlap by a much greater degree. A way to conceptualize this is to think of two trumpeters blowing a series of long notes on a trumpet in a church. Under these circumstances the sound's wave will overlap along the majority of their length. If it just so happens that they overlap in a manner that the peaks and troughs line up from different echoes they cancel each other out. It is helpful to think of someone posting on a trotting horse; horse up, bottom down. Horse down and bottom up. The equal and opposite motions cancel each other out leaving the rider's head moving smoothly and steadily along.

This is similar in describing what multipath fading is; there are simply places in a room where there is no WiFi signal, despite the fact that an access point might be close by due to the fact that the echoes cancel each other out.

The Subject of Interference

This discussion will focus around the issue of interference. It is often stated, when referring to the frequency of operation of WiFi systems, they operate in the Industrial, Scientific and Medical (ISM) band. This is mostly accurate. The FCC requires that WiFi signals operate at the same frequencies as ISM equipment, so they do indeed coexist. It is not uncommon therefore for medical devices to emit RF (sometimes at high power) at the same frequency as WiFi. For this reason wireless network administrators should pay particular concern as to the deployment of the wireless networks in sensitive patient care areas. This trepidation is exaggerated with the introduction of dozens of WiFi emitting tags in patient care areas without the proper EMI testing.

UWB is designed from the ground up to operate outside of the ISM band, and at such low power levels that it is virtually non-interfering in even the most sensitive patient care environments. Hundreds or thousands of UWB tags can easily co-exist along side monitors and other susceptible medical devices.

In terms of Quality of Service (QoS) and security there are several ways to harness and manage the WIFI space via 802.11i and 802.11e. But the challenges remain of how to manage the hundreds of tags contending with the same bandwidth requirements for data and voice using WiFi. The promise of 802.11i and 802.11e does adequately take this into account and it is questionable whether the tags will adhere to the ongoing IEEE security and QoS specifications. Most recently pending standards such as 802.11k and 802.11v are going to help address the management of WIFI RTLS tags/clients in the enterprise WLAN. 802.11k will define and expose radio and network information to facilitate *the management and maintenance of the WLAN.* This will standardize some basic radio information required to support standards based location tracking. 802.11v will provide extensions to the 802.11 PHY and MAC standards to improve the *management capabilities of WLAN clients.* This is positive for the industry as provide more enterprise compatibility among tag manufactures, software and location tracking enabling appliances.

Zigbee has never really been considered a use model for RTLS or RFID tracking but provides an excellent use model of home and building automation. Use this link to learn how Zigbee has endorsed this business model: www.zigbee.org

Value Proposition and Conclusion

Existing data indicates the existing WiFi network for asset or patient tracking has returned very little value over the past few years. Due to inherent physical limitations WiFi has not been able to demonstrate true tracking capabilities. *The best outcome from these systems has been what is refereed to as "knowledge location", whereas a general wide-ranging reporting of the tag's location as measured against its actual location is given.* These systems provide very little capability in automating process, or in enhancing patient care or in incorporating themselves into overall hospital continuum of care. *The reasons associated for this lack of integration can be directly attributed to the physical attributes and limitations of physics that these technologies utilize.* These limitations lead to a potential lack of accuracy, and the inability for such systems to provide reliable and repeatable results. In order to overcome stated limitations these wireless networks used for locating people or assets necessarily require the addition of additional access points to the existing network, increasing installation and overall network maintenance costs. Other methods to overcome existing limitations of these tracking systems include increasing the power output of the tags. This has the undesired effect of limiting the overall battery life of the tags (days), and the chirp rate to 1x every several minutes thus subjugating real-time capabilities. These networks also operate within the same ISM band as some medical equipment therefore increasing the possibility of interference with medical equipment. The demands placed upon the existing network will require the addition of many more access points, as well as staggering and managing the data traffic across the network.

UWB, on the other hand has the inherent capability of providing a consistent granularity of one to two feet of accuracy with extremely high data repeatability. This capability along with its high refresh rates (four times per second) makes it possible to provide true tracking of assets and patients in real-time. Moreover, the accuracy of the tags reporting is well suited for seamless integration into many existing hospital processes. UWB can provide quick and easy integration to existing LAN infrastructures even using POE (Power over Ethernet).

From an EMI perspective, UWB is considered true Hospital Grade Wireless: 1) low probability of detection, and 2) low probability of intercept, 3) reliable, and 4) EMI compatible within all hospital environments. The UWB tag's low power consumption equates to a life time of a tag that is measured in over 4.4 years. The cost to acquire the UWB tags are less than the traditional WiFi tags.

The consistent, accurate, and repeatable data received from these systems allow many clinical information systems to leverage the capability of tag-to-tag relationships, and tag-to-environment relationships thus creating "smart clinical working environments."