CHOOSING THE OPTIMUM ARCHITECTURE FOR UWB RTLS
Executive Summary

Real Time Locating Systems (RTLS) operating in the Ultra-Wideband domain are becoming more common in many applications; ranging from automated student attendance verification to tool tracking for major aircraft manufacturers. The reason that UWB is gaining in popularity is that it has many attributes that allow it to provide new capabilities that are not possible with traditional RTLS. The choice of UWB RTLS architecture will impact the ability to achieve the greatest ROI from these new capabilities.

Some system architectures are designed to only provide locating in specific areas of coverage. This is a result of architecture choices that make the system too expensive for continuous coverage. Typically these architectures use discrete, multi sensor cells with inward focused antennas for each area of coverage, with each cell being a complete subsystem. For the purposes of this paper, we’ll term this discrete cell architecture. Unfortunately these architectures can add cost, complexity, and the potential for error associated with cell handoff.

Discrete cell architecture can affect not only the cost of coverage, but the cost of installation. Systems built with discrete cell architecture must rely on sophisticated radio channel schemes, which increase the cost of site design and increase the complexity of post installation tuning. Although there can be some benefits, these same results can be achieved by other means without adding the complexity of additional long range radio links.

Cost of Ownership can also be affected by architectural fundamentals. The addition of two way radio communication using non-UWB channels draws significantly higher power from the tag and can thwart one of the prime advantages of UWB: Ultra long battery life at very fast update rates.

By choosing a system architecture that is designed to provide complete coverage over large areas and utilizes simple beacon UWB radio links, assets or people can be constantly tracked throughout an entire enterprise in a cost effective manner, over a long period of time, without interruption.

A system that is designed for continuous coverage can utilize receivers that don’t view a single direction, but look in all directions at once. This allows a single location sensor, (radio receiver) to replace 4 cell type location sensors that only have a 90 degree field of view. The result is a greatly reduced number of sensors, and a corresponding reduction in costly cabling.

Additionally, it is possible to have tags that blink at a rate of once per second, but will still blink continuously for 7 years without the complexity of motion sensors and other sources of field failures. Since the update of rate of these tags is so high, a second radio to manipulate that update rate is not required. This simplifies installation, virtually eliminates post installation tweaking, and minimizes maintenance.

Introduction

Ultra Wideband RTLS can maximize its ROI when it is able to provide its primary function: accurate tracking of resources (assets and people), in real time throughout the factory, store, office building, or even sports arena. One of the key reasons to invest in an RTLS system vs. an RFID system is to replace sporadic portal level information with a continuous and persistent flow of location information. The value of RTLS is realized by knowing the exact location of any resource, at any moment in time, and taking immediate action based on that knowledge. As an example; if a system is tracking tools, knowledge of the exact location of those tools when they are in the wrong place can be as important as the location data provided when matching them to a target process and work cell.

UWB RTLS has unique attributes that make it specifically qualified to provide this continuous stream of information. These unique attributes are:

- Precision Locating
- Fast Update Rates
- Long Battery Life
- High Capacity

Because of its superior capability to discriminate direct signals from reflected ones (the “multipath” problem inherent with narrowband RTLS), UWB RTLS can provide location data with levels of accuracy not possible with other technologies. Systems are available that can consistently provide accuracy of less than 1 m and even as precise as 15cm under certain conditions. Resource tracking tags can provide multiple updates per second and still yield battery life measured in years. Additionally, the high data rate utilized in most standardized designs allow thousands of tags to be utilized in a rather compact area and still be able to be located at high update rates.

The key to receiving maximum benefit from these attributes is to use the unique data they can provide to make better quality decisions. It is an acknowledged fact, that better data yields better decisions. Therefore, as an essential requirement of any system that is going to be used to streamline a business process or to change an application paradigm, this location data must be available everywhere throughout a facility or area of interest. Additionally, in order for it to be financially viable, it must be essentially maintenance free.

In order to provide maximum value, and be cost effective, an RTLS architecture should not target discrete areas of coverage. The architecture must allow for shared radio coverage across multiple cells. Additionally, it should have the ability to provide redundancies so that failure of a component or a cable does not cause the entire system to fail. It must also be as simple as possible to make it robust and long lasting. Therefore, it should minimize the use of multiple radio technologies that add cost to the components, reduce battery life, and add complexity to the system installation.
Architectural Challenges

Ultra-Wideband technology utilizes a transmission signal that is spread across a very large swath of frequencies; typically more than 500 MHz wide. In fact, these signals coexist with other narrower licensed frequencies that are used for many different purposes including radar, radio astronomy, and a variety of other applications. In order to coexist with these other radio systems, the power from the UWB transmissions is constrained by regulations to be extremely low and distributed across this very large portion of bandwidth. Therefore, virtually all the other users of these bands do not even recognize that there is a UWB radio transmitting across their frequencies. However, licensed users have still resisted allowing UWB systems in their band and this has caused regulatory bodies to push these systems into less crowded areas of the radio spectrum. As a result, 6-8 GHz is the most common UWB band across the globe. These are very high frequencies.

Operating at this high frequency and low power shortens the systems range. There are multiple potential techniques utilized to maximize this range. Since the power limitation is measured using peak and average power, one technique is to use small messages that are only peak limited. This applies the most energy per bit. Two other techniques are to use a coherent form of UWB, and/or use directional antennas.

Coherent UWB is a technique in which each bit that makes up a message is sent many times, (commonly 32 to 512) instead of just once within every message. This allows the receiver to use coherent processing to combine these repeated pulses together in order to create a stronger version of each complete bit. The positive attribute of this technique is that it may extend range under certain conditions, the negative is that it makes each message last much longer, and therefore uses up airwaves capacity and energy. This means that a system using this technique would be able to support fewer tags, or require them to blink at a slower rate. It would be possible to mitigate this to some extent by coordinating the blink times of the tags and finding a way to focus the field of view of the receiver to only see the tags in an area of interest. Of course this would be obtained at the cost of adding significant complexity to the system.

Using directional antennas in this manner, an architect could utilize coherent UWB and reduce the negative effect of consuming too much capacity by separating the areas of coverage into discrete cells as shown in Figure 3. This would allow the cells to operate independently and not interfere with each other, thus increasing the total system capacity beyond what it would be for a coherent system utilizing omni-directional antennas. However, if the cells are adjacent, the self interference is not eliminated; it is only reduced, causing airwaves congestion and ambiguity in areas where a tag transitions from one cell to another.

A discrete cell architecture adds additional complexity in that in order to recognize the benefit of this increase in capacity the cells must each be synchronized independently. This requires a different control system for each cell. This control system may consist of a second two-way radio operating on independent channels. In order to properly assign a tag to the correct synchronization channel, the system must know in which cell a tag is located. The complexity caused by coordinating these handoffs from one control channel to another in a discrete cell structure can cause location results during transitions from one cell to another to be delayed for up to 15 seconds due to ambiguity at the transition areas between cells.

A discrete cell architecture also requires 4 antennas to be at the center of any intersection of 4 discrete cells even if they are adjacent to each other as shown in Figure 4. This makes continuous coverage of a large area with discrete cell architectures very costly. As a result most installations using this architecture do not provide complete Enterprise coverage, but focus on discrete areas leaving "no locate" areas between as shown above in Figure 3.

There are multiple techniques that can be used to determine the location of a transmitter (tag). Among the most popular are Received Signal Strength Indicator (RSSI), Angle of Arrival (AoA), and Time difference Of Arrival (TDOA). RSSI is the least accurate of these techniques and does not take advantage of any of the special characteristics of UWB. Therefore it is rarely used as it is unable to reliably provide sub-meter accuracy, although it can sometimes be utilized to determine proximity of tags when their signals are received by only one or two sensors.
If a system is designed with an architecture that uses the inward looking discrete cellular architecture shown above, then it is possible to design a sensor that houses several antennas that can be used in an array to determine the Angle of Arrival (AoA) of the incoming signal. AoA determines the direction that the signal is coming from and uses the input from two or more sensors to determine a point of transmission as shown in Figure 5. Requiring only two sensors could be an advantage. However, some researchers have found that these systems provide a low confidence of accuracy. This low confidence is caused by reflections which may be mistaken for true Line Of Sight signals and therefore introduce error in the angular measure of the received signal. Additionally, any inaccuracy in the determined angular measurement is amplified as the distance between the sensor and the tag increases. This error is in the shape of a cone that starts at the sensor and expands with distance as shown in Figure 7.

GPS provides amazing accuracy given that the satellites used for determining location are in orbits that are more than 20,000 km above the earth’s surface. This accuracy is achievable by using time based locating. Similarly the most accurate RTLS systems are also time based. The most common technique is Time Difference of Arrival (TDOA) which compares the exact arrival time at different reception points as shown in Figure 6. Therefore, measuring the exact time that a signal arrives is critical to developing an accurate system.

UWB does not place data on a sinusoidal waveform as is done with all conventional radio systems. Instead of modifying a sinusoidal wave by changing its amplitude, frequency, or phase, UWB systems carry data in the form of bursts (pulses) of energy. The fact that the signal is carried in an energy bursts across a very wide frequency band makes it easier to find the exact leading edge of the signal with sub-nanosecond accuracy. These very wide-band signals make it possible to determine the first Time of Arrival, (TOA) of a signal, and ignore reflections. This is what makes time based UWB RTLS so accurate.

A system designer that has chosen to use a discrete cell architecture capable of providing AoA location may choose to combine AoA with TDOA in order to achieve high precision RTLS with only two sensors. Unfortunately, while this does improve the likelihood of a better locate, it is not equivalent to TDOA using three sensors. As shown in Figure 7, while the time based TDOA hyperbola is quite accurate, the actual location could still be anywhere on the hyperbola within the intersection of the two cones of uncertainty. Given that the discrete cell architecture requires so many additional sensors at the intersections of the cells, this is a poor trade-off from a cost and therefore ROI perspective.

One of the complications that resulted from UWB systems coexisting with radios in other bands is that initially there were concerns by the current licensed operators that UWB would be a significant source of interference. That is why the power is regulated to be so low. In addition, the initial radio rules that allowed the use of UWB required that a radio system could not make UWB transmissions unless they were coordinated and acknowledged over a standard radio channel. It was a requirement to receive an acknowledgement within 10 seconds or cease transmitting. This caused some architecture designs to include traditional narrowband radios operating in the 2.4 GHz band.

However, one of the other key attributes of UWB radio transmission is the fact that creating these pulses requires much less time and energy than encoding data on a traditional sinusoidal waveform. In order to transmit, a UWB radio goes through the following sequences:

**Turn on → Transmit → Turn Off**

Radio regulations require that the sinusoidal waveform required for encoding data must first be stabilized to fit within a specific narrow frequency band before transmission. Only then, can data be mixed into the signal. This process takes much longer and uses significantly more power than simply creating a burst of energy. Additionally, a traditional radio receiver (required for the acknowledgement) increases the power penalty. The receiver actually requires more power than a transmitter as shown in Figure 8.

A traditional transmitter goes through the following sequence:

**Turn on → Stabilize → Transmit → Turn Off**

Receivers usually utilize more power because their sequence includes wait for reception which could be milliseconds to seconds depending upon the protocol.

**Turn on → Stabilize → Wait for Reception → Receive → Turn Off**

Therefore tags that contain traditional narrowband two-way radios will use much more energy and have shorter battery life than a system that is strictly UWB.
Architectural Challenges (Continued)

Since these radios commonly operate in the 2.4 GHz band they must be frequency agile and find a clear frequency. This same 2.4 GHz band is very congested, being used for Bluetooth, ZigBee, Wi-Fi, and proprietary data feeds. Additionally, in most application environments end users require that Wi-Fi be given priority. The addition of this second radio link in the 2.4 GHz band increases the probability of interference on one of the system components essential for maximum RTLS performance with architectures utilizing such a control channel.

Systems using a control channel must also require that adjacent cells use different frequencies to communicate with the tags in each cell so as not to cause self interference. As a result, the system must cycle through multiple channels to find the correct channel for that cell. This probe-and-response mechanism requires more power because the transmission and reception cycle must be performed on each frequency until the correct one is found for the new cell. Additionally, the system must assure that the tag switches to the proper cell, and not one that is adjacent to the intended new cell.

Since these narrowband radios had to be included for regulatory purposes, other uses were found for them including changing update rates, turning on LED’s (more power burned), and reprogramming a tag. Reprogramming takes a lot of power and has a significant impact on battery life because the receiver must stay on to collect a lot of data and then reprogramming of a flash memory uses a lot of power. This is almost never used in normal deployments.

The addition of this second radio also complicates installation because the site survey must be performed for both the UWB band and the 2.4 GHz band. Different frequencies have varying characteristics with regard to blockage. While a sheet of metal is a complete blocker for any frequency, other partial blockers are affected by frequency. For example, a chain link fence can almost completely block low frequencies, while high frequencies with shorter wavelengths will pass through it transparently. Conversely, partial blockers with high moisture content can have a much more significant attenuating affect on high frequencies then lower frequencies. The bottom line is that:

1. Cell to cell handoff increases the chance of an incorrect location calculation, and
2. Installing two collocated radio systems at once is significantly more difficult and expensive than setting up one.

The final question is whether to design a system that utilizes proprietary technology, or an internationally accepted standard. The obvious answer to this question is standards based systems. Customers should have the freedom to choose products from multiple vendors, and have them operate heterogeneously. This fosters competitive pricing, innovation, and allows customers to choose “best of breed” for individual components. It also gives them assurance that when they want to expand or enhance their system there will be a vendor available to provide it at a competitive price. It is very disheartening and all too common to learn that a system that is providing good value has to be replaced because the vendor of that proprietary technology has discontinued production, or ceased to be a viable business entity. The IEEE 802.15.4 Work Group has developed standards for two modes of UWB modulation. Additionally, ISO/IEC has a working group that is completing the RTLS 24730-81 and -62 standards that have defined upper layers to use those physical (PHY) layers defined by the IEEE.

Optimal Architectural Choices

As shown above, there are many trade-offs that a system architect must consider in order to develop the optimum system for the broadest variety of applications. There is no doubt that particular design choices can be made for a specific narrow application, but for most applications, there are some clear advantages to certain design choices.

The first of these is to use systems designed with new generation, simple one-way beacon architecture. This saves tag cost, and greatly reduces downtime and maintenance costs by virtually eliminating battery changes. The complexity of having a second traditional radio can be eliminated with very small losses in function by adding a simple low frequency Exciter function. An exciter is a low frequency electromagnetic field (EMF) device with very short, well-defined area of coverage, for which receivers can be made which consume extremely low power. Exciters do not require data connections and have been used in RTLS systems for over 15 years. The receiver side in the tag operates on micro-amps of current and does not have a significant impact on battery life. This technology can be used to create a transactional event in areas where there is only presence detection, and they can also be used to reprogram blink rates.

An architectural design that utilizes contiguous cells can create an uninterrupted field of coverage. The radio design of the receiver on the sensor can be optimized to provide the maximum margin and allow a choice of multiple antenna patterns. This allows the site designer/installer to choose the best combination of both directional and omni-directional antennas. If the sensor receiver is designed to use omni-directional antennas, and provide only slightly less range then directional antennas, then in multi-cell installations 1 sensor with an omni-directional antenna can replace 3 to 4 sensors for all interior reception points as shown in Figure 9. Sensors with antenna options may be more expensive than sensors that only host directional antennas, but this is much more than compensated for by reducing the total number of sensors (and required cabling).

The choice of a continuous architecture utilizing multiple antenna types eliminates cellular handoff delays and saves significant cost if complete areas are covered. The entire facility can be covered and tags will not be out of sight between cells.

Although utilizing single point omni-directional antennas to provide continuous coverage will not support Angle of Arrival AoA locating, this is an easy tradeoff to make given the low confidence level of AoA locates. In fact, the large savings in infrastructure density from the 1-to-4 sensor tradeoff can easily allow additional sensors in suspected trouble spots such as areas with mobile or multiple blockers. This will result in locates throughout the facility with minimum variation in accuracy.

One of the attributes of the discrete cell architecture that is claimed superior is the ability to have a single sensor in a cell fail without affecting other cells. It should be noted that if the cable to the timing generator is damaged, then the entire cell is affected which creates a complete blackout.
Optimal Architectural Choices (Continued)

An installation using continuous cell architecture can be made much more robust than this by employing good site design techniques. The continuous cell architecture simplifies installation by using one CAT5 cable to supply power, timing, and data return to the sensors. However, there are multiple chains of these cables that are used to distribute the three functions. A customer should select a system that supports the maximum number of these chains in order to minimize the length of any chain. Therefore, by designing the installation to use the maximum number of chains; the minimum sensor count per chain; and cable runs designed to reach out to the widest dispersion area possible, a system using continuous coverage architecture can provide a completely soft failure. A system deployed in this manner will allow the entire system to continue to operate even if an entire chain of sensors fail. In this case there would be a slight loss of precision in immediate areas of the failed sensors, but the entire facility would continue to have location capability. Additionally, the architecture can allow failover from a primary to a secondary location/time server so that an entire server can fail without causing a failure of the entire system.

Comparison of an Installation

Shown below in Figures 10 and 11 is a comparison of the same size installation in an aircraft manufacturing area.

Figure 10 shows that installing the discrete cellular architecture using only directional antennas requires 15 more sensors than the continuous coverage model using a combination of directional and omni-directional antennas. This represents a 71% increase in components. The addition of these additional sensors not only adds component cost, but also cabling cost, installation cost, and introduces more potential points of failure. These factors combined with inherently shorter tag battery life significantly increases the long term cost of ownership.

Conclusions

Simple beacon architecture based on international standards with continuous areas of coverage provides the best solution for a high reliability, cost effective RTLS solution. It provides the four key requirements:

- Continuous and Constant Locating Coverage
- Increased Interoperability Through Use of Standardized Hardware
- Better Price Performance Through Reduced Cost of Coverage and Installation
- Lowest Long Term Cost of Ownership

Bibliography

1. Ref: “Location Tracking and Ubisense”  
Univ. Prof. Dr. Alois Ferscha  
Universität Linz, Institut für Pervasive Computing  
Altenberger Straße 69, A-4040 Linz  
ferscha@soft.uni-linz.ac.at  
October 2010