APS003 APPLICATION NOTE

REAL TIME LOCATION SYSTEMS

An Introduction

Version 1.1

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1 INTRODUCTION

Real Time Location Systems (RTLS) describe a class of ***Systems*** that provide information in ***Real-Time*** about the ***Location*** of objects, animals, people or just about anything you care to imagine.

Let's examine these terms in a little more detail: -

Real Time: Information on the location of the relevant object / person is available now or with a very short latency.

Location: The system provides information on the position of an object / person in a form that can be used to relate them to their environment: -

- as a symbol overlaid on a map or a floor plan
- as an audible tone that indicates the proximity to the object
- some other method that provides meaningful information to the users of the system

System: This information is gathered, processed and delivered using a collection of hardware and software technologies in an organized and structured way

The most pervasive example of an RTLS is GPS. Just about everyone has heard of this satellite based technology that you can use, assuming you have the appropriate hardware and software, to find your way in a foreign country on roads you've never driven on before or navigate in waters you've never sailed in previously. This is a truly remarkable system that has irrevocably changed the face of commercial and personal navigation. The problems begin when you go indoors however. GPS doesn't work indoors so all the tracking and location functionality that GPS provides suddenly disappears. This has led to people asking for indoor location capability.

But long before the advent of GPS people across a broad range of industries were examining their business processes and they began to realize that with accurate location information they could, in many cases, transform those businesses or at the very least make considerable improvements in costs, service and profits. Since then people have been searching for reliable, accurate location technology that could be applied to their business process.

The advent of cost-effective wireless technology has led to many attempts to apply it to RTLS some more successful than others.

This note examines some of the basic use cases and implementation methods for RTLS.

Other notes on www.decawave.com examine the application of RTLS to specific market areas such as Healthcare, Agriculture and Logistics

2 RTLS Use Cases

Real Time Location means different things to different people depending on the proposed application. We'll look at a few of the most common types here before considering how they might be implemented and how DecaWave's DW1000 technology brings previously unheard of performance and cost benefits to these systems.

2.1 Proximity

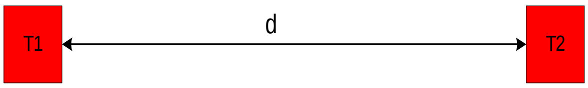
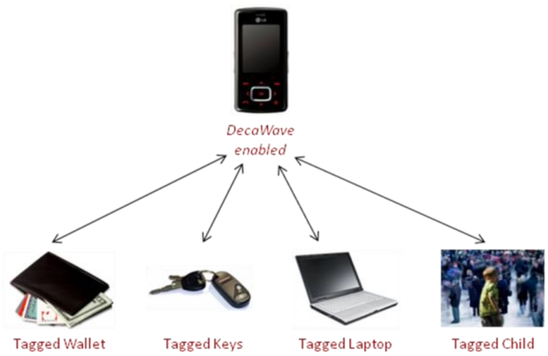


Figure 1: Proximity

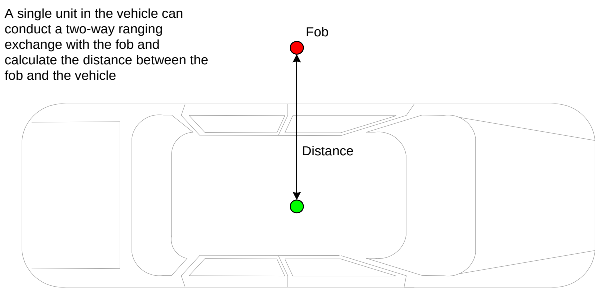
This is the simplest form of RTLS where the requirement reduces to the need to determine the distance between two items. Nodes establish how far apart they are from each other and take action accordingly.

Obviously this function can also be implemented as part of a full 2D or 3D RTLS system.

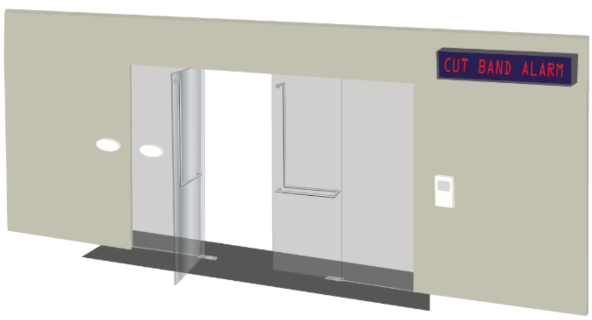
Possible examples of a "proximity" type application include: -



A mobile phone's separation from a laptop or other personal possession – the "find my stuff" application. All items involved would need to be DecaWave enabled.



The proximity of a key fob to its associated automobile



The proximity of an Alzheimer's patient or infant to an unlocked door through which they are not authorized to pass

2.2 *Absolute Location using Fixed Infrastructure*

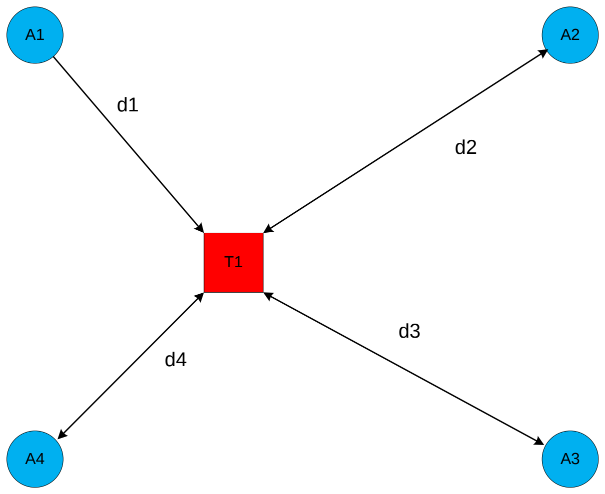


Figure 2: RTLS with fixed infrastructure

This is the “traditional” RTLS scheme.

The location of tagged objects is established using a number of fixed anchors in known locations around the area in which the tagged objects are located.

These anchors can be separate units or can be incorporated into Wireless Access Points

There are a number of implementation schemes possible here which we’ll discuss in the next section.

Typical examples of this type of RTLS include: -

The tracking and location of assets and patients in healthcare providing: -

- Significantly improved patient care,
- Increases in efficiency and
- Reductions in operating costs

The tracking and location of pallets, packages and items in warehousing and logistics applications leading to: -

- Reductions in wait time
- Improved customer service
- Reduction in operating costs

The tracking and monitoring of farm animals leading to: -

- Improvements in animal health and yield
- Reduction in operating costs

- The tracking of Inventory, Work in Progress and Finished Goods in manufacturing environments
- The tracking of which components have been assembled to other components
- The monitoring of tool movements to ensure manufacturing sequences are carried out in the correct order

2.3 Relative Location Among a Group of Nodes

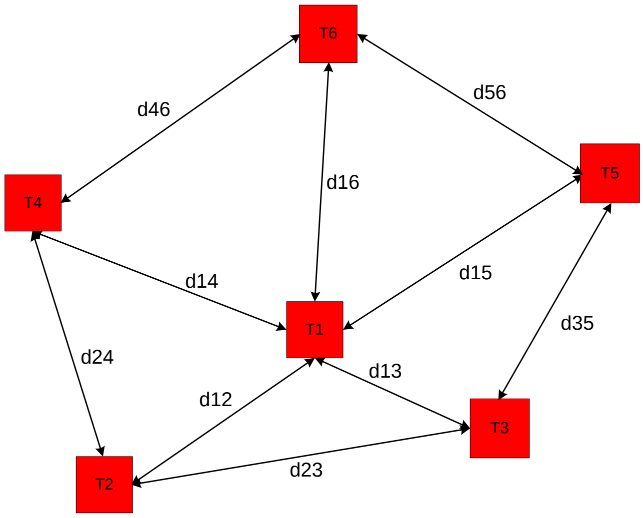


Figure 3: Relative location among a group of nodes

In this situation there is no fixed infrastructure so nodes must establish their location relative to other nodes in the network.

You might find this kind of scenario in first-responder situations, for example, where emergency services arrive at a building that is not equipped with RTLS infrastructure but yet they need to track the progress of their personnel as they enter the building.

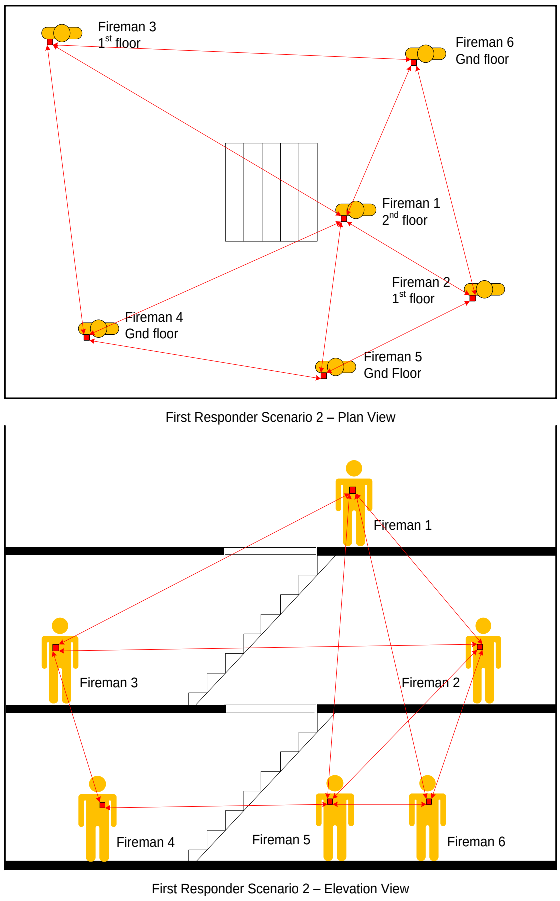


Figure 4: First responder scenario

In this scenario the building has no RTLS infrastructure – only the first-responders are tagged. Nodes establish their location relative to other nodes in the network.

In order for this information to be available to the command centre, one or more of the first responders will need to be linked wirelessly to the command vehicle outside the building.

If absolute location is required then at least two nodes that are in known locations relative to the building are required. These would need to be "dropped" by the first responders or their support crew on arrival at the building and their locations noted.

Relative location on its own is useful in that it tells team members where they are relative to other team members however for maximum usefulness absolute location is also required.

3 Implementation Methods

To determine the absolute position of a tagged object in 2D or 3D space it is necessary to determine how far away it is from a number of known points denoted as anchors. With this knowledge and with some (conceptually in any case) relatively simple mathematics it is possible to calculate the location of the object.

There are a number of different methods of implementing RTLS using wireless schemes but they effectively devolve into two basic types of scheme: -

- Those based on radio signal strength – commonly referred to as Received Signal Strength Indication or RSSI schemes.
- Those based on the measurement of Time – where the time it takes the radio signal to travel between transmitter and receiver is measured using one or more of a variety of different techniques and then knowing the speed of light the distance can be calculated.

3.1 Signal Strength Based Schemes

These schemes involve measuring the signal strength of the arriving radio signal at the receiver. Knowing the power at which the signal was transmitted from the transmitter, the propagation characteristics of that particular radio signal in air and with some a priori knowledge of the environment it is possible to calculate approximately where the transmission originated based on how attenuated it is at the receiver.

These schemes are perfectly adequate in certain circumstances but, generally speaking, where high levels of accuracy are required they need to be augmented with additional technologies (choke points, infra red, ultrasound etc.) to provide the necessary levels of accuracy.

We will not consider these schemes any further here since time-based schemes using Ultra Wideband can achieve a far more accurate result.

3.2 Time Based Schemes

For our purposes there are three main methods of determining a tagged object's location in an area. These are: -

- Time of flight
- Time Difference of Arrival
- Phase difference of Arrival

These are all referred to as time-based schemes because they are all based on the accurate measurement of the propagation time of a radio signal from one location to another or the difference in arrival time of a radio signal at different locations.

3.2.1 Time of Flight

All time of flight based systems work on the basis of determining the time it takes for a radio signal to propagate from a transmitter to a receiver. Once this time is known accurately then the distance between the transmitter and the receiver can be determined since the speed of propagation of radio waves in air is known.

To implement a full RTLS the distance between the tagged object and a number of anchors in known locations must be measured. In Fig 5 we can see that anchor P1 calculates the distance between itself and the tag B as r1. This locates the tag on a circle of radius r1 from P1. Similarly, P2 calculates the distance as r2 putting the tag B on a circle of radius r2 from P2 and finally P3 calculates the distance as r3 putting the tag on a circle of radius r3 from P3. Calculating the point of intersection between these three circles (tri-lateration) gives the position of the tag B. If the absolute location of the anchors is know in 2D or 3D space then the absolute location of the tagged object is also known.

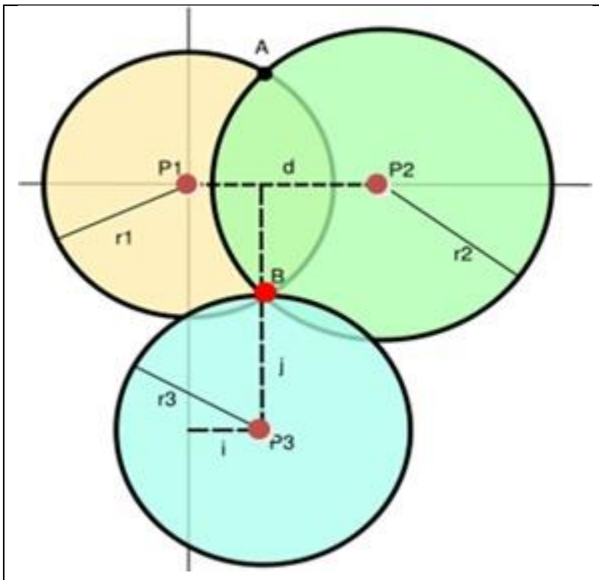


Figure 5: Time of flight scheme

There are a number of ways you can implement such a scheme: -

3.2.1.1 Time Synchronized Transmitter and Receiver

In this case the tagged object (transmitter) and the Anchor (receiver) are synchronized in time. In this scheme the tag (B) broadcasts a message to all of the anchors simultaneously (P1, P2 & P3) at a known time (or with the transmit time embedded in the message). Each anchor receives the message and because it knows when the message was transmitted, when it was received and because all times are relative to a common time-base it can calculate the time of flight and therefore the distance.

The drawback with this system is that it requires all elements of the system to be time synchronized. This is difficult enough in the case of anchors, as we'll see later, but is extremely difficult to do in the case of mobile tags. For that reason, this system is seldom used.

3.2.1.2 Unsynchronized Transmitter and Receiver

In this case the tagged object communicates with each of the fixed anchors in what's called a two-way ranging exchange. The tag and each anchor exchange timing information so that the anchor can calculate the time-of-flight of the signal from the tag to the anchor without the necessity for tag and anchor to be synchronized in time. Once each anchor has this information, a location engine can calculate the position of the tagged object.

This requires that the tag be capable of receiving as well as transmitting which means that this method generally consumes more power than the Time Difference of Arrival solution we'll see in the next section.

In this scheme the tag (B) communicates individually with each of the three anchors (P1, P2 & P3). Each anchor calculates the time of flight of the transmission from the tag.

In order to calculate the distance between the tag and an anchor the tag and the anchor communicate and exchange information with each other.

So, this scheme involves a two-way exchange of messages between the tag and each anchor. A very simplified version of what happens is as follows: -

- The anchor transmits a message to the tag and records the time the message left its antenna (let's call it t_1).
- The tag receives the message and sends back a reply.
- The anchor records the time it receives the reply (let's call it t_2)
- The anchor then calculates the time difference $T_r = t_2 – t_1$
- The anchor then calculates the distance using the formula $d = cT_r/2$, where c is the speed of light.

This is what's known as **Two Way Ranging.**

In reality we also need to account for the processing delay in the tag and there are various methods that can be adopted to both take this delay into account and to minimize it.

The total time between the two time-stamped values can therefore be expressed as: -

$$T_T = 2T_t + T_{TA}$$

Where T_T is the total time
T_t is the time of flight of the signal
T_{TA} is the turnarond time in the tag

There are various physical effects such as clock drift from which this simple scheme suffers and that can be corrected by a more advanced scheme known as Symmetric Double-Sided Two-Way Ranging (SDS-TWR) [1]. This scheme needs 4 instead of 2 messages. Also an additional message is generally needed to send measurements from one side to the other, so that the calculation of T_{TA} can be completed.

Consideration also needs to be given to where the final result is required. In most cases this is at the anchor since, in general, an infomation system of some sort extracts the distance information from multiple anchors to perform tri-angulation. It is also possible for the tag to perform these calculations once the distance to 3 anchors is known and the fixed locations of those anchors are known to the tag – for robotic control applications for example.

Returning to the simple case you can see that there are a number of stages involved that all contribute to the total time required to calculate the distance between the tag and the anchor before the anchor can range to another tag: -

Operation	Description	Symbol	Typical Value
Tag transmits message	Tag transmits message and notes transmit time-stamp	T_{TXTAG}	Depends on architecture of the tag, processor used etc.
Message Flight time – Tag to Anchor	Time taken for message to travel from Tag antenna to Anchor antenna	T_t	Depends on the chosen premable length, data-rate, message length etc
Anchor receives message, processes it and transmits reply	Anchor receives message, processes it, constructs and transmits reply	T_{TA}	Depends on architecture of Anchor, processor used etc.
Message Flight	Time taken for message to	T_t	Depends on the chosen

[1] *Nanotron is the owner of the intellectual property rights of the SDS-TWR scheme. The relevant Nanotron patents are EU EP1815267B1 and USA US7843379B2*

Operation	Description	Symbol	Typical Value
time – Anchor to Tag	travel from Anchor antenna to Tag antenna		premable length, data-rate, message length etc
Tag processes received message and calculates distance	Tag receives message, notes time stamp and calculates distance	T_{RXTAG}	Depends on architecture of the anchor, processor used etc.

Table 1: Stages in Simple Two-Way Ranging Scheme

Note that we have constructed the transaction in this way so that the Tag instigates the exchange. This means that the Tag does not need to “listen” for Anchor transmissions and so saves power. However, if the Anchor needs to know the range to the Tag then the Tag must either send the result to the Anchor or the transaction must be instigated by the Anchor which requires that the Tag must be listening for Anchor transmissions and as a result will consume more power.

3.3 Time Difference of Arrival (TDoA)

In this scheme three or more readers are positioned in known locations around the area in which tagged items are to be located. Each of these readers is time synchronized to the others.

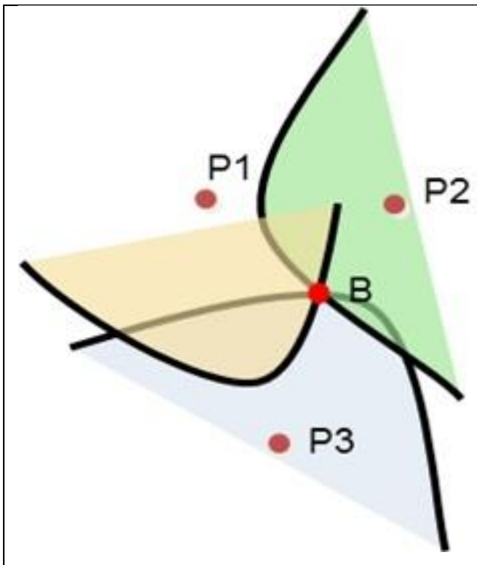


Figure 6: TDOA scheme

As shown in Figure 6 a tagged object (B) transmits a message that is received by all the readers (P1, P2 and P3 in the diagram shown here). Because radio waves travel at a constant speed, depending on the position of the tagged object, the message will arrive at some of the anchors before others. The time of arrival of the message at each reader is noted by the reader.

Since all three readers are time-synchronized, the difference in the time of arrival at each of the three readers gives information about the location of the tag B

Using a mathematical technique known as multi-lateration it is then possible to derive the position of the tag

Since the tag only transmits and does not receive, this is also known as **One Way ranging** but is not possible with only one reader since it relies on the difference in the arrival times at several readers to calculate the location

The most important system issue here is that the anchors must be synchronized in time. Any error in the synchronization of time in the anchors translates directly to an error in the reported location. When you think that 1ns = approx 30cm then it’s clear that synchronization needs to be to the sub-nanosecond level. Traditionally this has been achieved by wiring clock signals from a central clock distribution point to all the anchors and

compensating for delays in the distribution cabling. As you can imagine this makes system installation very expensive.
DecaWave have developed a wireless synchronization scheme that allows the anchors to be synchronized to the required level of accuracy without extra cables.

3.4 Phase Difference of Arrival (PDoA)

Phase Difference of Arrival concept is used to determine the range or distance an Anchor (aka node) is from a tag and additionally the x,y location of the tag relative to the node.

This scheme is generally implemented using an array of antennas in the anchor. The time of arrival at the first antenna in the array is measured and compared with the time of arrival at the second antenna and so on. See Figure 7 below.

If the tag is directly perpendicular to the antennas in the array then the incident signal arrives at all of the antennas simultaneously and there is no difference in arrival times.

If the tag is at some angle to the array then the incident signal will reach one antenna in the array first followed by the next and so on.

Assuming these arrival times can be measured accurately then a measure of the phase difference of arrival can be made and the location of the tag derived.

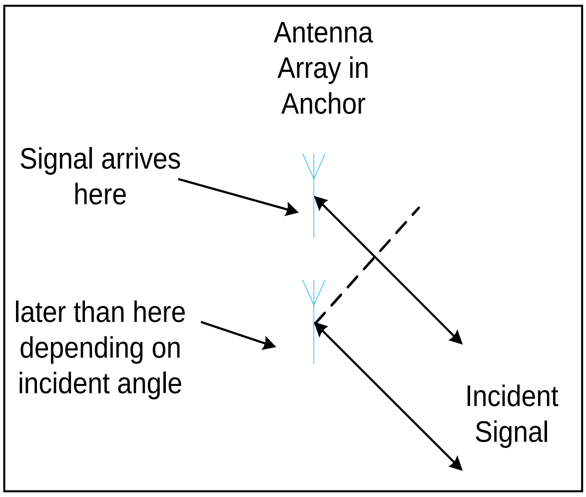


Figure 7: PDoA antenna array

PDOA schemes don't deal particularly well with multipath propagation between the transmitter and the receiver antenna array and so are best suited to Line of Sight scenarios.

Obviously adding antennas adds cost to the system so the cost of an PDoA solution can be higher than others.

4 How Well Does DW1000 Handle The Requirements?

DecaWave's DW1000 is a family of wireless semiconductor products that use Ultra Wideband radio technology, are compliant with the IEEE802.15.4-2011 standard and are implemented using CMOS technology. For more information on DW1000 see the DecaWave website www.decawave.com

Looking at the three different application scenarios discussed above let's look at how DecaWave's DW1000 technology addresses the main requirements of each: -

No	Parameter	Proximity	Real Time Location using fixed Infrastructure	Relative Location among a group of Nodes	What DW1000 brings?
1	Location accuracy	As accurate as necessary for the application	As accurate as necessary for the application	Application dependent but needs to be accurate enough to answer the "which side of the wall" problem for emergency personnel	**Best in class accuracy +/- 10cm**
2	Node power consumption	Application dependent but generally as low as possible	Application dependent but generally as low as possible	Application dependent but for mobile nodes as low as possible	**Very efficient packet transmission and reception leading to power savings over alternative schemes**
3	Anchor power consumption	Application dependent; if anchor is fixed (door) or powered from a large source (car battery) then consumption is not such a major issue. If anchor is another mobile node then see above.	Application dependent but generally not as big an issue as Node Power consumption because anchors are usually powered	No anchors in this scheme	

No	Parameter	Proximity	Real Time Location using fixed Infrastructure	Relative Location among a group of Nodes	What DW1000 brings?
4	Node density	Generally low – unlikely to have more than a single figure number of tagged people approaching a given door / looking for a particular lost item	Application dependent. May be relatively few nodes as in hospital environment or very many nodes in warehousing environment but system should be designed such that system overhead is minimized to leave as much bandwidth as possible for dealing with nodes	Generally low	**Due to its high data rates and short packet times DW1000 can handle many more nodes than will be found in a practical situation**
5	RF performance	As long a NLOS range as possible	NLOS performance should be as high as possible to minimize number of anchors required and thereby reduce system cost	As long a NLOS range as possible to maximize geographic node area	**Up to 290m Line of Sight (LOS) and 45m Non Line of Sight (NLOS) in demanding indoor environments**
6	Ability to deal with multipath propagation	Absolutely vital to be able to detect first path correctly	Absolutely vital to be able to detect first path correctly	Absolutely vital to be able to detect first path correctly	**Use of Ultra Wideband allows individual multipath signals to be resolved at the receiver**
7	System Architecture		The ability to wirelessly synchronize the anchors is vital otherwise the cost of cabling clocks to anchors makes the overall system cost very high		**DW1000 supports Wireless Synchronization of Anchors**

Table 2: Meeting RTLS Requirements with DW1000

5 FURTHER INFORMATION

Decawave develops semiconductors solutions, software, modules, reference designs - that enable real-time, ultra-accurate, ultra-reliable local area micro-location services. Decawave's technology enables an entirely new class of easy to implement, highly secure, intelligent location functionality and services for IoT and smart consumer products and applications.

For further information on this or any other Decawave product, please refer to our website www.decawave.com.