Real-Time Locating Systems in Agriculture: Technical Possibilities and Limitations

Lasanthis Ayoma Karunaratne
Abstract

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With the increasing world population the demand for the agricultural products should also increase. Mass production is one solution for a better yield by monitoring the production process more precisely. The current trend is the automation of crop and livestock production, which leads to precision agriculture and results in low-cost quality products. Real-time locating is essential for the automation of many systems. Many automated systems already exist, even in agriculture. But agricultural automation still has a long way to go, specially the crop production. This thesis describes the technical details and pros and cons of many real-time locating systems in brief and their present state of development. Then, how these technologies can be useful for various livestock and crop production systems is discussed. Furthermore, a simple case-study is examined and possible solutions are listed.
Preface

This thesis project is initiated by JTI - Swedish Institute of Agricultural and Environmental Engineering. There are two parts of this project and this is the second part.
Acknowledgements

I want to thank you, Anna Rydberg, Professor Mikael Sternad and Professor Anders Rydberg for your help, guidance and encouragement.
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1. Introduction
It is important to know the location in real-time. Locating people, tracking equipment and its usage, managing supplies and observing animal behaviour are just few of the many examples where it is important to know the location in real-time. With the technological advances today it is possible to make these measures of location in real-time. Real Time locating Systems (RTLS) are the electronic systems which enable to locate anyone or anything in real-time. The use of RTLS is still increasing due to the reduction in price and size of the equipment used in the system.

The first location tracking systems were implemented using RFID technology. Many RTLS today are based on the RFID technology. There are some other technologies than RFID, such as Wi-Fi, Ultra Wide Band, Infrared Ultrasound, Zigbee, GPS, and GSM [5](20 Real Time Locating Systems 2009-2010, TechEx Ltd). If there is existing wireless communication infrastructure (e.g. 802.11, GSM) in the area, RTLS systems can be built using them without purchasing much equipment. There are many systems in the market today that are based on a hybrid of several technologies, such as RFID with Infrared (e.g. the system for studying the behaviour of Norway lobster [115]).

1.1. Background
In agriculture there are many applications where a real-time locating system can be applied, such as tracking animal behaviour, tracking equipment and agricultural products, precision agriculture etc. With the advances in technology, methods used for agriculture have also changed. The farms are expanding and use precision agriculture and loose-house systems which becomes difficult to manage without RTLS for efficient production. The ongoing research in this area too needs systems that can automatically transfer various sensor data from exact positions in the field to a computer.

1.2. Objectives
The objective of this project is to find the most suitable technologies that can determine the position under the environment and quality needs listed by the parallel project. The parallel project explores where the RTLS systems can become useful in agriculture. It discusses the applications of RTLS systems in agriculture both at present and in the future mainly in the areas of livestock and crop production. The suggested future applications are based on the Scandinavian agriculture.

Various RTLS systems are possible with the existing technology. Such a broad range of technologies are available mainly because the characteristics of electromagnetic waves changes with its frequency. Therefore the parameters of RTLS systems changes from one system to the other according to the frequency and the technology used for the wireless communication. To select the technology suitable for an application, we need to compare the needs of the application to the parameters of the technology. When the application needs become more complex, several technologies can be merged to obtain a better RTLS system. This project suggests the most suitable technologies for the agricultural RTLS applications, according to its needs.

1 These words are described in the Section 8 (Definitions).
1.3. Scope

This project considers only the technical qualities. The requirements of the costs of the systems are not taken into account. The types of the tags and the location sensors fulfilling the requirements are compiled.

The number of applications of RTLS in Agriculture is quite large and system parameters are unique to each and every case of application. In order to overcome this complexity of the applications, it is studied how each technology can be used in Agriculture.
2. Present Technologies of RTLS

2.1. Structure of an RTLS

Tags, location sensors, location engine, middleware and application are the parts of an RTLS system [5].

![Figure 1: A Simple RTLS (1-tag, 2-location sensor, 3-location engine, 4 middleware and application software) [80]](image)

2.1.1. Tags

A tag is usually a small device most of the time comprised of silicon chip that stores information and an antenna to send and receive data. Tags are attached to a moving asset or a person which is to be tracked. The RTLS location sensors locate these tags in order to find the location of the tagged item. In most cases the tag is a small Integrated Circuit(IC). But there can be different kinds of tag technologies such as SAW, Wi-Fi, GPS/3G etc. The shape and the material of the tag depend on its application. For the use of tracking an animal a tag can be e.g.: ear tags, rumen bolus, collar transponder's or injectible transponders [10].

Many of the tags types are active and contain a battery. The lifetime of the battery is a critical parameter when selecting the suitable technology for some applications. When the communicating frequency of the tag with the reader is higher, the consumption of tag battery power also increases. Sensors may also be used in conjunction with the tags to monitor the asset's physical condition, including ambient temperature or humidity.

2.1.2. Location Sensors

The position of location sensors on or within the tagged assets is usually known. The locations of the tagged assets or people are tracked by locating the tags attached to them.

2.1.3. Location Engine

The location engine is the software used for the communication between the tags and the location sensors to locate the tags. Using software algorithms, the data collected from the tags are used to determine the item’s location as precisely as the tag technology permits. Then the location engine sends the information to the middleware and applications.

There are several methods used by the location engine to calculate the location of the tags. Such as:
• Angle of Arrival (AOA)
• Received Signal Strength Indication (RSSI)
• Round Trip Time (RTT)
• Time of Arrival (TOA)
• Time Difference of Arrival (TDOA)
• Triangulation/Trilateration
• RF Fingerprinting
• Proximity to several points

2.1.4. Middleware
Middleware is the software which lies between the location engine and the application software. The middleware is invisible to the end-users of the system. These programs provide messaging services so that different applications can communicate.

2.1.5. Application
Application software is the software which the end-users directly interact with. It communicates with the RTLS middleware and interprets the data for the end user in a manner which helps to perform specific tasks the user needs.
<table>
<thead>
<tr>
<th>RTLS Technology</th>
<th>Common Frequency</th>
<th>Commonly used areas at Present</th>
<th>Reading Range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RFID</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Frequency (LF)</td>
<td>30 kHz</td>
<td>Access control</td>
<td>Passive 10 m [111] Active 100 m [112]</td>
<td>1-3m</td>
</tr>
<tr>
<td></td>
<td>125 kHz</td>
<td>Animal identification</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>134.2 kHz</td>
<td>Lot identification</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>300 kHz</td>
<td>Chemical process Distribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Frequency (HF)</td>
<td>3 MHz</td>
<td>Logistic warehouse management</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.56 MHz(ISO 15693)</td>
<td>Automotive manufacturing and tracking</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 MHz</td>
<td>Retail</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hospitals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Baggage check</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Library management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Parcel tracking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Security</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Smart cards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultrahigh Frequency (UHF)</td>
<td>300 MHz</td>
<td>Retail</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>433 MHz</td>
<td>Toll roads</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>866 MHz(Europe)</td>
<td>Logistics: Inside a factory and through the supply chain</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>915 MHz(US)</td>
<td>Long-range applications</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Item tracking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microwave Frequency</td>
<td>2.45 GHz, 5.8 GHz</td>
<td>Long-range applications Item tracking Freight tracking</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>RuBee (IEEE 1902.1)</strong></td>
<td>131.072 kHz</td>
<td>military and medical asset tracking</td>
<td>15m [110]</td>
<td></td>
</tr>
<tr>
<td><strong>Surface Acoustic Waves (SAW)</strong></td>
<td>2.45 GHz</td>
<td>Livestock tagging Food supply chain traceability and monitoring [69]</td>
<td>10m</td>
<td></td>
</tr>
<tr>
<td><strong>Infrared (IR)</strong></td>
<td></td>
<td></td>
<td>10m</td>
<td>5-10 m [82]</td>
</tr>
<tr>
<td><strong>Ultrasound</strong></td>
<td>&gt;20kHz</td>
<td>Tracking patients in hospitals</td>
<td>Several meters</td>
<td></td>
</tr>
<tr>
<td><strong>Power Line Positioning (PLP)</strong></td>
<td>10 – 500 kHz</td>
<td>Still at early stages</td>
<td>3 m -90% 1 m -67%</td>
<td></td>
</tr>
<tr>
<td><strong>Wi-Fi (IEEE 802.11)</strong></td>
<td>2.45 GHz, 5 GHz</td>
<td></td>
<td>100m</td>
<td>1-5m</td>
</tr>
<tr>
<td><strong>Zigbee (IEEE 802.15.4)</strong></td>
<td>2.4 GHz</td>
<td></td>
<td>10-100m</td>
<td>1m</td>
</tr>
<tr>
<td><strong>Bluetooth</strong></td>
<td>2.4GHz</td>
<td>Tracking assets in rooms</td>
<td>10m</td>
<td>2m</td>
</tr>
<tr>
<td><strong>Ultra Wideband (UWB)</strong></td>
<td>3.1 – 10.6 GHz</td>
<td>Tracking people and assets indoors</td>
<td>30 m [36]</td>
<td>0.01 m</td>
</tr>
<tr>
<td><strong>Computer Vision</strong></td>
<td></td>
<td>Drowning-detection systems Unusual event detection Human tracking Vehicle tracking and traffic surveillance</td>
<td>A few cm</td>
<td></td>
</tr>
<tr>
<td><strong>Acoustic Locating Systems</strong></td>
<td></td>
<td>Underwater wireless sensor networks Gunfire Detection</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cellular RTLS</strong></td>
<td>*800 MHz, *1.9 GHz</td>
<td>Locating People</td>
<td>50-200 m</td>
<td></td>
</tr>
</tbody>
</table>
Location-based advertising

<table>
<thead>
<tr>
<th>Technology</th>
<th>Services</th>
<th>Range</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>WiMAX (IEEE 802.16)</td>
<td>Locating People, Tracking Shipments, Location-Based Advertising</td>
<td>50 km</td>
<td>50-200 m</td>
</tr>
<tr>
<td>GPS</td>
<td>Logistics, Transport, Manufacturing, Healthcare</td>
<td>5 m+</td>
<td>5 m</td>
</tr>
</tbody>
</table>

Table 1: A Short Summary of the Technologies (*Licensed Frequencies)

2.2. Radio Frequency Identification (RFID)

At the moment RFID is the mostly used RTLS technology in the agriculture applications. It is attracted by the farmers because of its low cost. RFID is a very old technology, which was first implemented during the First World War. It can be divided into several categories according to the carrier frequency band.

There are two main components in an RFID system; the RF reader (base-station or interrogator) and the RF tag (or transponder). To identify objects, the RFID tag can be attached to it so that the RFID readers could identify using radio frequency communication. RFID tags contain antennas to enable them to receive and respond to radio-frequency queries from an RFID reader or interrogator. RFID is a very popular technology at present, in areas like automation, manufacturing, purchasing and distribution logistics and anti-fraud systems. Non-line-of-sight nature of RFID technology has become a significant advantage.

Radio frequency waves can disturb other receivers and also be difficult to block. Federal Communications Commission (FCC) is the agency in United States which controls RF spectrum usage. Radio spectrum is a limited public resource so the governments apply regulations for its use. The technological developments have increased the portions of the spectrum being used and the data rate sent using the same bandwidth. But the number of telecommunication services also has increased which exceeds the available spectrum. So, policies are required to assign the spectrum. There are various kinds of methods being used for assignment of spectrum [12] (ICT Industry and Markets). The RF spectrum is divided into two: Licensed and Unlicensed frequencies. Most RFID systems use the unlicensed spectrum.

**Licensed spectrum**

One must pay to use a licensed frequency band. Licensed bands are designated by the government regulators to be used by individual license holders. These License holders are permitted to use their part of the band over an assigned geographic area [13](Motorola, 2007). In Sweden, the Swedish Post and Telecom Agency (PTS) allocates the radio spectrum.

**Unlicensed spectrum**

Unlicensed spectrum is the portion of the RF spectrum which is set aside for used without a radio license. So it does not always provide an exclusive use of the band. Unlicensed radios and antennas are less expensive and band is not restricted to a specific geographic area.
<table>
<thead>
<tr>
<th>Unlicensed Frequency</th>
<th>Frequency Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Frequency (LF)</td>
<td>125-134.2 kHz</td>
</tr>
<tr>
<td>High Frequency (HF)</td>
<td>13.56 MHz</td>
</tr>
<tr>
<td>Ultra High Frequency (UHF)</td>
<td>• 865.5-867.6 MHz (Europe)</td>
</tr>
<tr>
<td></td>
<td>• 915 MHz (U.S.)</td>
</tr>
<tr>
<td></td>
<td>• 950 – 956 MHz (Japan)</td>
</tr>
<tr>
<td>Microwave</td>
<td>2.45 GHz</td>
</tr>
</tbody>
</table>

Table 2: The Unlicensed sections of the spectrum used by the RFID systems

**Low Frequency (LF) – 125-134.2 kHz**

Low frequency systems offer an operating range between 0-1m. This is because near-field coupling is used for both the power supply and the data communication. The two types of coupling at low frequencies are capacitive and inductive coupling. In *capacitive coupling* the transfer of energy from one circuit to the other is by means of the mutual capacitance between the circuits. In *Inductive coupling*, the energy transfer is by means of mutual inductance between the circuits.

Capacitive coupled systems can operate at ranges between 0 and 1cm, the frequency can be from DC to 30 MHz because no power is radiated. It also provides greater amounts of available power, so a microprocessor can also be used. These systems are used in high security applications with a low operating range, such as electronic door locking systems, contact-less smart cards with payment functions [10].

Inductively coupled systems operate up to 1m. Most of the RFID systems used are of this type and most transponders are passive. All the energy needed to operate the micro-chip of the tag is supplied by the reader.

Smaller reading range is a major problem in many RFID systems, thus when a larger antenna is used to collect more power from the tag the reading range can be improved [4].

In the inductively coupled systems when the frequency is increased, a higher operating range can be achieved because it takes the advantages of the far-field propagation characteristics. The boundary between the near-field and the far-field lies at about \( \frac{\lambda}{2\pi} \) meters from the reader antenna (\( \lambda \) is the wavelength of the RF carrier). In the far field, the electromagnetic field strength attenuates according to the relationship \( d^{-1} \) (\( d \) = the distance to the tag from the transceiver). But in the near field the field strength attenuates according to the relationship \( d^{-3} \).

Usually the systems having read range higher than 1m use electromagnetic waves for communication. These long-range systems operate using UHF and microwave range frequencies.
2.2.1. **Tags**

The RFID tags can be categorized in to three main groups as below:

- *Passive tags*
- *Active tags*
- *Semi-passive tags*

Another classification is:

- *Read-only (RO) tags*
- *Read-write (RW) tags*

**Read-only (RO) tags**

These tags can only be read. So, the communication between the reader and the tag is unidirectional. The tags’ unique identity numbers are encoded to the tags at the manufacturing or initial setup time.

**Read-write (RW) tags**

In addition to the capabilities of the RO tags, the RW tags provide the ability for the reader to send (write) information to the tag at any time. The RW tags contain a memory space used to store the information sent by the reader which can vary from just a few bytes to hundreds of kilobytes [10].

2.2.2. **Readers**

The readers transmit and/or receive the radio frequency waves used to communicate with the tags.

2.2.3. **Passive RFID**

There is no built-in power source in passive RFID tags. So, the identity cannot be actively broadcasted and needs to be queried by an external reader. The tag draws small amounts of power from the magnetic field associated with the radio waves created by the reader, when it passes through the RF signal emitted from an RFID reader. These small amounts of energy temporarily energise circuits in the tag. The tag then sends the information encoded in the tag's memory, often using a different frequency to the one used to energizing the chip.

The main advantages and disadvantages of passive RFID tags relative to active tags and other frequencies are:
<table>
<thead>
<tr>
<th>Frequency</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive Low Frequency (LF)</td>
<td>The tag is readable for a very long time</td>
<td>The tag can be read only at very short distances, typically a few feet at most although some modern tags can operate up to 3m if care is taken with tag orientation</td>
</tr>
<tr>
<td></td>
<td>Generally more resistant to corrosion and physical damage.</td>
<td>Limits the future extensions such as temperature and motion monitoring [6]</td>
</tr>
<tr>
<td></td>
<td>The tag functions without a battery; these tags have a useful life of twenty years or more.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The tag is typically much less expensive; you can typically expect to pay between 10cents and a few dollars.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The tag is much smaller and it can be easily concealed</td>
<td></td>
</tr>
<tr>
<td>Passive High Frequency (HF)</td>
<td>LF is not affected by surrounding metal or liquids. Also it works in the environments with mud, dirt or snow.</td>
<td>Doesn’t support simultaneous reads of large number of tags. It can only read 10-20 tags per second.</td>
</tr>
<tr>
<td></td>
<td>LF can penetrate water and body tissue. So it is useful for animal and fish identification. LF also can be used for underwater or underground.</td>
<td>The read lowers in noisy environments containing power transformers, improperly grounded electrical devices, switching power supplies, lighting dimmers, lighting controls, electrical devices etc.</td>
</tr>
<tr>
<td></td>
<td>The data transfer rate is low because of the low frequency.</td>
<td>The tags are large and complex because they need larger antennas compared to higher frequencies. It is complex because of the number of turns needed in the induction coil</td>
</tr>
<tr>
<td></td>
<td>LF signals do not penetrate or transmit around metal.</td>
<td>LF signals do not penetrate or transmit around metal.</td>
</tr>
<tr>
<td>Table 3: Advantages and Disadvantages of Passive RFID [2]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.2.3.1. Passive Ultra High Frequency (UHF) RFID

Ultra high Frequency (UHF) includes the radio frequency from 300MHz to 3 GHz. The read distance of UHF is larger than LF or HF. At the moment there is no universally accepted standard for UHF RFID. But there are international, national, and industry level standards. These standards can include specifications for transponder format, communication protocols, frequency of operation and the code ID. Two available standards are EPC Global initiative and the ISO 18000 standard. The ISO only includes standards for the air interface but EPC also includes the data structure of the ID.

The parts of a passive UHF system are: UHF tags, an antenna, and an interrogator. The high data throughput and the fast *anti-collision scheme* used provide higher read rates than LF and HF. The cost of a UHF transponder is less than the HF transponder because of the simpler manufacturing process [5]. The read range of UHF is higher than HF read range and is around 10 meters [109].

2.2.4. Active RFID

The active RFID have a small battery built-in to the tag which works as an internal power source. Because of this on-board power source, active tags can operate at higher frequencies such as 455 MHz, 2.45 GHz, 5.8 GHz etc. The active RFID broadcasts its identity by itself. Frequencies between 100MHz -1GHz give the best performance for active RFID in crowded (with a large number of tags) environments [3]. The batteries can sometimes be replaceable or the unit will be replaced after certain time, normally between 1 year and 7 years.

![Figure 2: An Active RFID tag [22]](image-url)
The advantages and disadvantages of active tags can be summarised as follows:

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>More information can be read and written to the tag</td>
<td>The active RFID tag cannot function without battery power; therefore they have a limited lifetime.</td>
</tr>
<tr>
<td>Read and write distances are much greater than for passive tags</td>
<td>The active RFID tag is typically more expensive, costs typically start from $10 to $20 per tag</td>
</tr>
<tr>
<td>The read rates are better than the passive read rates in a noisy environment</td>
<td>The active RFID tag is physically larger than the passive LF because of the battery and its circuitry. So, it can be more fragile and prone to damage</td>
</tr>
<tr>
<td></td>
<td>The battery life is about 2-5 years</td>
</tr>
</tbody>
</table>

Table 4: Advantages and Disadvantages of Active RFID [2]

2.2.5. Semi-Passive RFID

Semi-passive tags contain an onboard battery like the active tag. This battery is not used if the tag is not activated by a reader. After this activation, the tag can behave exactly as an active tag. A semi-passive tag can have a longer battery life-time than an active tag because it does not transmit a beacon on a regular interval.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longer read ranges than passive tags but generally at a lower cost than an active tag</td>
<td>The costs becomes nearer to active tags when many of the features with active tags such as memory are incorporated to the tag</td>
</tr>
<tr>
<td>Because a battery is attached to the tag, additional sensors can also be attached</td>
<td>A battery is needed to be attached to the tag. The life time is around 10 years</td>
</tr>
<tr>
<td></td>
<td>Tags cost higher than the passive tags because of the additional battery</td>
</tr>
<tr>
<td></td>
<td>Size of the tag is also larger than passive tags because of the battery</td>
</tr>
</tbody>
</table>

Table 5: Advantages and Disadvantages of Semi-passive RFID [2]

2.2.6. Microwave

Frequencies from 1GHz to 300 GHz are called microwaves. There are few RFID systems that use the microwave spectrum to operate. 2.45 GHz and 5.8 GHz are two widely used microwave frequencies. Even though high data rates can be achieved with microwave RFID, it is the most expensive RFID system at the moment and has a limited read range up to 1m [14]. 2.45 GHz frequency is largely attenuated by the presence of water. So, RFID systems should not be used in the environments that are close to liquids or very damp.

Microwaves include the UHF and EHF (Extremely High Frequency-millimeter waves). Radar is a technology which uses the microwave frequency to detect characteristics of remote objects.
2.2.7. **Usability of RFID RTLS in Agriculture**

Many of the RTLS systems used in the livestock production are RFID systems. And there are also systems for irrigation purposes which use RFID tags ([62] G. Vellidis). In the system developed in [63], they adapt the Wherenet® [43] system with RFID tags which was originally made for spatially tracking inventories. But they find many disadvantages of using RFID tags and replace them by *Mica2 mote*®s manufactured and sold by Crossbow® Technology Inc. The disadvantages were:

- unidirectional transmitting
- receiver costs
- capable of only transmitting from the tag to the receiver

There was another wireless sensor array prototype for scheduling irrigation in 2007 [72]. This system used active RFID tags to transmit sensor data to the receiver. The receiver was connected to a laptop computer. They have used Watermark® soil moisture sensors and thermocouple temperature sensors. The Wherenet® [43] RFID tags operated in the 2.4 GHz microwave frequency. Due to the transmission problems occurred at the beginning the RFID tags were removed from the ground level sensor electronics boards and were mounted on hollow flexible fiberglass rods about 1.2m above the ground level. The Wherenet® receiver used two *omnidirectional antennae*12 to receive the sensor node signals. Testing was done using 2.3 ha land of cotton plantation which was divided into two zones. Two different irrigation scheduling strategies were used in these zones: scheduling using traditional assessment of crop by a person and using the sensor array. The results have shown that the sensor array was able to successfully monitor soil water status and soil and air temperature for the entire growing season, compared to scheduling using traditional assessment.

2.3. **RuBee**

RuBee is also known as IEEE 1902.1. It is still emerging standard which expects to provide an alternative to RFID technology by overcoming many problems in those systems. RuBee also uses low frequency and consumes very low power. It is used for military and medical asset tracking and it is in use at many high-security government sites. Because each RuBee tag has a clock with date and time stamp, it has very high security. So, IEEE 1902.1 has met the highest possible standard for wireless data security ([15] IEEE 1902.1, 2009).

**IEEE 1902.1 Standard**

This standard defines the interface for radio tags which are designed to be used in visibility networks. A visibility network is a system for creating an inventory of tagged items that involves directly reading the presence of tagged items wherever they are, stationary or moving, in an area, in real time. The carrier frequency used in IEEE 1902.1 for the communications between the controllers and responders is 131.072 kHz and these communications uses near field, inductive coupling signalling in both directions. IEEE 1902.1 does not provide a backscattered mode of operation.

The two devices in an IEEE 1902.1 system are the controller and the responder. The controller initiates the communication and makes requests of responder devices while a responder performs the requested action and transmits the response to the controller.
are several design choices (communication modes, packet sizes etc.) which allow responder devices to have a very low power budget. There are choices which can have the power budget less than 10 microwatts average power. So, these devices can operate for more than 10 years when small coin sized lithium batteries are used.

The IEEE 1902.1 uses magnetic dipole antennas and communicates in the near field distances. At the 131.072 kHz frequency, the near-field/far-field boundary lies at 364 meters from the antenna in free space (IEEE Standard for Long Wavelength Wireless network Protocol, 2009[16]).

Visible Assets makes its own RuBee chips and licenses the technology to other vendors. Epson Seiko is another company making RuBee tags. SIG Sauer builds tags into guns for use with tracking systems ([60]RuBee Approved as New IEEE Standard, 2009).

2.3.1. Usability of RuBee RTLS in Agriculture

Because RuBee can be used as an alternative standard to RFID, it can also be used in livestock tracking. RuBee networks have already been deployed in smart shelves for high-value medical devices in hospitals and operating rooms, smart in-store and warehouse shelves for inventory tracking, agricultural visibility network[17]s for livestock, elk and other exotic animals [64]. In [65] a RuBee system (The Visible Assets, Inc. (VAI) RuBee IEEE P1902.1 protocol) was used for tracking deer activity. The major advantages of RuBee when applied to livestock applications are [65];

- Large read range compared to passive RFID tags
- Simple user installation using a RuBee network router
- No on-site computer required.
- Low cost, light weight tags - $2
- All software/reports are web browser enabled, easy to use and maintain.
- Daily activity monitor based on Eating, Drinking and Behaviour (EDB) index.

Twenty animals were tagged in [65] using RuBee VAI large ear tags (Figure 3 & 4).
2.4. **Surface Acoustic Waves (SAW)**

Low cost SAW technology can be used in manufacturing passive RFID tags in place of the integrated circuits (IC). SAW provides longer read ranges than the integrated circuit (IC) based systems. It can also work in harsh environments (Lin Wei, 2008, [17]). There is not much standardization work has been done with the SAW based RFID systems. But it is in progress at the moment. The SAW technology is also used in cell phones, pagers, TVs, garage door openers etc (Ajay Malik, 2009 [5]).

A SAW device consists of a piezoelectric substrate with metallic structures such as interdigital transducers (IDT) and reflectors.

Piezoelectric materials produce an electric current when it is under mechanical pressure. Piezoelectric effect is reversible and occurs only in non conductive material. Piezoelectric materials can be divided in to two main groups: crystals and ceramics. The most well-known piezoelectric material is quartz [19].
Working Principles of SAW RFID

When a SAW RFID tag enters the monitoring range of the reader, it receives an interrogative RF signal from the reader. Then the interdigital transducer (IDT) converts this signal into a surface acoustic wave. The SAW wave propagates along the tag surface with a smaller speed compared to the speed of the electromagnetic waves and the reflectors on the surface of the tag give rise to partial reflections of the interrogating pulse. After some time, when a reflected SAW reaches the interdigital transducer again, it is reconverted to an electrical signal by the IDT. It is then transmitted back to the receiver by the tag antenna as a RF signal. The signal transmitted by the tag antenna contains the information about the number and the location of the reflectors which can be used for extracting the number and/or certain sensing parameters (Lin Wei, 2008 [17]).

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAW RFID is passive and has a longer reading range than IC RFID</td>
<td>SAW RFID tags are read-only</td>
</tr>
<tr>
<td>Can withstand high temperatures, x-rays and gamma rays where IC devices are useless</td>
<td>There is no complete anti-collision solution at the moment for the transmission between the tags and the readers</td>
</tr>
<tr>
<td>Can identify objects with high moving speed because a readout procedure only require few microseconds</td>
<td></td>
</tr>
<tr>
<td>Inherent sensor capability</td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Advantages and Disadvantages of SAW RFID [5]

SAW RFID tags can be used for sensing parameters such as: temperature, pressure, torque, current, chemical content etc. The propagation of the SAW wave depends on the geometry of the substrate. When the environmental conditions change, the material parameters of the substrate can also change which can also affect the propagation of the SAW wave. Comparing the reflected RF signal against the original signal and a previously calibrated scale the sensor reading of the parameter can be calculated.

2.4.1. Usability of SAW RTLS in Agriculture

SAW based RTLS works as same as an IC based RTLS, so it can be applied in to agricultural sector. There is a SAW tag for livestock at RF SAW Inc [69]. Still it is not as popular as IC tags. SAW tags have not been tried out for crop production applications. There are research studies and commercialized wireless and passive of several SAW sensor networks for reading temperature, pressure, torque, humidity etc. Recently there was one SAW RFID system developed for asset management in an office environment, which gave good results [70]. Reference [71] describes a sensor network with SAW-id tags. SAW RFID systems can be applied to crop production, but for large fields several transceivers should be used because the maximum read range is around 30 m. One major advantage of SAW tags in agriculture is that it does not require any battery power.
2.5. Infrared

Infrared is also electromagnetic radiation and has wavelength longer than visible light but shorter than RF. Because the infrared waves does not go through opaque barriers and reflect off the ceilings, walls, and most other objects in a typical room enclosure, it can be used for room-level locating.

IR transmissions can be characterized as two main types:

**Direct IR:**

Direct infrared is characterized principally by the need for a line of sight (LOS) between the transmitting and receiving devices. Direct IR is point-to-point and (typically) one-to-one communication. Most consumer electronics, from camcorders to stereo equipment, include infrared remote controls. Video and audio apparatus, computers, and modern lighting installations often operate on infrared remote controls as well.

**Diffused IR:**

A diffused infrared device floods the room with an IR signal and then uses the reflections from the ceiling, walls, floors, and other natural surfaces to maintain robust optical communication. Diffused IR allows many-to-many connections and can be unidirectional or bidirectional. Diffused IR can create communication links at distances of 10 meters or more, depending on the emitted optical power.

For an RTLS, diffused infrared is typically used because it eliminates the need for LOS (line of sight) with the infrared receivers to receive the IR signal from tags. Diffused IR provides exceptional robustness against shadowing and behaves like radio-frequency (RF) waves within the enclosure in which they operate. The IR receivers used for an RTLS system are highly sensitive, because only a small part of the transmitted signal power reaches the receiver due to signal absorption and multiple refraction which causes the signal to be attenuated. There is not much standardization work has been done for standardizing IR for the purpose of RTLS.

IR can be used to build RTLS that are low cost and safe. It is safe because IR does not penetrate body tissues. Because infrared can achieve high data rates, the RTLS can have a large number of tags or can store a large amount of data. One problem is that the read range is only several meters. So, if the RTLS is deployed in a larger area, multiple infrared location sensors must be used (Ajay Malik, 2009[5]).

2.5.1. Usability of Infrared RTLS in Agriculture

The ARS (Active RFID Systems) [104] Read/Write Bi-directional Infrared Tags can be used for precise location information. It has 10 year battery life and 2 m read range [105]. Versus Information System (VIS) is an RTLS system developed by Versus Technology [106], Inc which uses infrared (IR) and active RFID technologies. At the moment there cannot be found an Infrared RTLS system being used in agriculture.
2.6. Ultrasound

Sound frequencies greater than the upper limit (about 20 kHz) of human hearing is Ultrasound. Ultrasound is good for room level locating because it cannot penetrate walls. There is not a lot of research regarding applying ultrasound for RTLS has been done. It is being used at some hospitals at the moment.

At user-defined times, the ultrasound tag which is attached to something transmits its unique identification signals using ultrasound waves. Ultrasound do not leave the room. Then the waves are received by the receivers (microphones). The receivers use wired or wireless LAN to transmit these signals to the location engine in digital form. Ultrasound can be used to locate accurately inside a room [5].

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasound signals does not penetrate walls so there is a guarantee of accuracy in ultrasound RTLS in room-level locating</td>
<td>No global regulations</td>
</tr>
<tr>
<td>The cost is low because the receiver is just a microphone</td>
<td>The effective range of ultrasound is few meters. When locating in a large area several readers will be required. Then it becomes more expensive</td>
</tr>
<tr>
<td>Does not interfere with other devices in adjoining rooms because ultrasound waves does not penetrate walls</td>
<td>Reception suffers from severe multipath effects caused by reflections from walls and other objects</td>
</tr>
<tr>
<td>Ultrasound does not require line-of-sight</td>
<td>If there are other equipment which emits ultrasound inside the room, it interferes the ultrasound RTLS</td>
</tr>
<tr>
<td></td>
<td>Due to lack of standards the users have to purchase all the tags and receivers from the same vendor</td>
</tr>
</tbody>
</table>

Table 7: Advantages and Disadvantages of Ultrasound RTLS

2.6.1. Usability of Ultrasound RTLS in Agriculture

There is no commercial ultrasound RTLS system available for agricultural purposes. Sonitor [40] Indoor Positioning System (IPS) which uses ultrasound can locate any object in real-time inside a room or corridor. This system is used at several hospitals in US and Europe. As an ultrasound RTLS can only be used in an indoor environment it is not useful for crop production. But there is a possibility of using ultrasound RTLS in Livestock tracking systems, when the animals are staying indoors.
2.7. Power Line Positioning (PLP)

Powerline positioning can be used for room level locating. In powerline communication (PLC), the data is carried though the same conductors which are also used for electric-power transmission. So, if electric power is already available on the building then the same wiring system can be used for implementing the RTLS system.

There is no location sensors required for a PLP RTLS. Tone generators are connected to selected electrical outlets. These tone generators emit their signals over the powerline continuously which emanate to the rest of the building from the outlets of the powerlines. The PLP tags have specially tuned tone detectors which can sense the signals sent from the tone detectors. Then the tags transfer this information to the location engine using a wireless network such as Wi-Fi. To calculate the location of the tags, the location engine compares the signal levels received from the tag with the prerecorded database and finds the best match.

A PLP system is based on the wire-finding technique used by many electricians to locate or trace hidden wires behind a wall or underground. In this technique the electrician connects an exposed end of the wire to a tone generator (which can range from 10-500 kHz) and locates the hidden wire using a handheld tone detector. Some detectors use LEDs to indicate the tone strength and others play an audible sound. The approximate location of the wire is found by the electrician by scanning the area for the loudest tone. The path of the wire can be found by following the presence of the tone [78].

The database is created at the deployment stage of the RTLS. When the tone generators send their signals, each area in the building will have unique signals characteristics such as unique amplitude, phase etc. These characteristics which are called signature\(^{10}\)s or fingerprint\(^{11}\)s are recorded and stored in the database, accessible by the location engine. The location accuracy depends on the number of unique entries in this database.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needs limited infrastructure additions to the building and needs no cabling</td>
<td>Need of extensive fingerprinting as a part of the setup process because a power PLP RTLS is based on fingerprinting</td>
</tr>
<tr>
<td>The cost is low because it needs only a few inexpensive tone generators</td>
<td>PLP uses low-frequency RF signals which brings up many of the problems in a LF RTLS system</td>
</tr>
<tr>
<td></td>
<td>Interference by nearby systems, transistors, rectifiers, transformers, AC-DC converters etc.</td>
</tr>
</tbody>
</table>

Table 8: Advantages and Disadvantages of Powerline RTLS [5]

2.7.1. Usability of PLP RTLS in Agriculture

PLP RTLS systems are still at its early stages. A PLP indoor locating system is presented by Shwetak N. Patel et al [78]. In this first system they experiment the system for tracking multiple household objects simultaneously which did not require installation of new infrastructure. Two small plug-in modules were used at the extreme ends of house which were used to inject a low frequency, attenuated signal throughout the electrical signal of the house. Then the positioning tags listen for these signals and wirelessly transmit their positioning readings back to the environment. The experiment was tested in various kinds of houses and was compared against 802.11 and GSM. The figures below show the equipment used in the system.
There was recent research which was called PL-Tags was carried out for testing battery-less PLP tags in 2009 [79]. The major advantages of this system compared to the earlier system are, reduction in tag size and longer tag lifetime.

As there is electric power available inside the barns, a PLP system can be used for tracking animal inside the barn. But PLP is not developed enough to be used at the moment. To be applied in crop production there must be an underground electric power supply available at the field. There are still no commercial PLP systems available at the market.
2.8. **Bluetooth**

Bluetooth is a low cost, low power, short range radio technology, originally developed as a cable replacement to connect devices such as mobile phone handsets, headsets and portable computers. Bluetooth operates in the 2.4 GHz band as same as Wi-Fi. Even though Bluetooth was not designed as a locating technology, it is suitable for locating because devices those are Bluetooth-enabled contain a mechanism to identify their neighbors and communicate with other devices in the area.

Bluetooth tags can be in the following types:

- Standalone tags
- Built-in features of computers, PDAs, cell phones and other devices
- Expansion cards that can be added to other devices

It is required to have Bluetooth access points installed 10-15m apart. When it is needed to locate a Bluetooth tag, the location engine instructs the access points in one of the following methods. Using these methods the location engine receives the tag’s RSSI from the access points. Then the location engine calculates the location using proximity, trilateration or fingerprinting [5].

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>There are standards for Bluetooth devices. So the devices have the interoperability between the devices made by different vendors which results in lower prices</td>
<td>Access points are needed to be installed every 15-20 meters because the Bluetooth range is short</td>
</tr>
<tr>
<td>Low power consumption</td>
<td>Bluetooth is vulnerable to security attacks such as jamming and denial-of-service attacks</td>
</tr>
<tr>
<td>The accuracy is relatively high because the access points are placed closed to each other</td>
<td>There is a positioning delay of about 15-30 seconds because of the Bluetooth inquiry process</td>
</tr>
<tr>
<td>Electronic devices that have built-in Bluetooth increases, so these assets can be tracked without attaching tags to them</td>
<td>Bluetooth infrastructure provides additional services such as remote monitoring and control</td>
</tr>
</tbody>
</table>

**Table 9: Advantages and Disadvantages of Bluetooth RTLS**

**Inquiry (Discovering) Procedure**

The location engine finds all the nearby tags using the Bluetooth inquiry procedure. This is the procedure which enables a Bluetooth device to find which devices are in the range and then determine the address and clocks for them. Using this procedure the Bluetooth access point is given the ID of all the Bluetooth devices or tags in the range within 5-10 seconds, when requested.
Paging (Connecting) Procedure

When the location engine needs to find a specific tag, then it uses the Bluetooth paging procedure. To find this specific tag, the access point first sets up a connection with (page) one or more of its discovered neighbor Bluetooth devices or tags using the paging procedure. This takes only 1-2 seconds but requires a previous knowledge about the tag’s ID and clock information [5].

2.8.1. Usability of Bluetooth RTLS in Agriculture

Bluetooth is a short range technology. So it is mainly used for indoor tracking systems. Blueon [101] provides several Bluetooth systems for few applications. The “BodyTag BT-002” is a Bluetooth tag which can be used for tracking and positioning a person, an animal or any asset [102]. Blueon “iQueue Solution” is used for airport terminal performance monitoring and reporting and. Bluelon “iTrack Solution” can be used as a traffic monitoring system. Miguel Rodriguez et al have also presented a Bluetooth locating system [103]. A Bluetooth RTLS system can be used for positioning animal indoors.

2.9. Ultra-Wideband (UWB)

Any radio technology that has a bandwidth higher than 500 MHz is called Ultra Wideband (UWB).

A UWB RTLS have tags and UWB receivers. These tags send UWB pulses, which are short and have low repetition rates (about 1-100 mega pulses per second). UWB receivers collect the timing information from the UWB signals emitted from the tags and send them to the location engine to compute the locations. The location engine uses the following methods to compute the location:

Angle of Arrival (AOA)

When AOA is used by the location engine, the location is estimated by measuring the angle between the signal of a given tag and different UWB receivers.

Time Difference of Arrival (TDOA) or Time of Arrival (TOA)

Because of the very large bandwidth of UWB, compared to RF the accuracy is high when these methods are used [5].
<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can have very accurate locating (up to few centimeters)</td>
<td>Needs line of sight or timing cables for time synchronizations</td>
</tr>
<tr>
<td>Locations can be produced in three dimensions</td>
<td>Interference from signals from multiple tags and other UWB applications</td>
</tr>
<tr>
<td>Performs well in environments which contain high metal content such as manufacturing plants because of its short low-duty-cycle pulses</td>
<td></td>
</tr>
<tr>
<td>No interference with other RF systems</td>
<td></td>
</tr>
<tr>
<td>UWB is not susceptible to multipath fading because its pulses are narrow and occupy the entire UWB bandwidth</td>
<td></td>
</tr>
</tbody>
</table>

Table 10: Advantages and Disadvantages of UWB RTLS

2.9.1. Usability of UWB RTLS in Agriculture

UWB RTLS are still at the developing stage. Time Domain [44], Ubisense [41] and Tagent [87] are involved in making UWB RTLS systems. Recently Ubisense and SMARTERFARMING introduced a commercial RTLS system which uses UWB technology called CowDetect [88]. The accuracy of the CowDetect system is 15 cm and it can track over 1000 cows per second [89] and it can also observe animals in 3D. UWB works well indoors but its performance is not good outdoors [36]. So it is not suitable for tracking outdoor crops.

The Talon™ RTLS system made by Tagent [87] will be available to purchase in 2010. This system can be applied to Pathology sample location & tracking, Tracking early in manufacturing, Pharma item/unit level tracking. There are no specific Talon™ components developed for Agricultural purposes. A Talon™ tag is 2 mm × 2mm in size and it is passive. The accuracy of the system is 250 mm and read range can be up to 10 m [92] [93].
2.10. **Wi-Fi (Wireless Fidelity)**

Wi-Fi is also called 802.11 networking. 802.11 is a set of Wireless local Area Network (WLAN) standards developed by IEEE. Many devices today use 802.11 wireless networks like wireless industrial equipment, PDAs barcode scanners etc. If anything needed to be tracked which doesn’t have inbuilt 802.11, then Wi-Fi tags can be used.

**Frequency spectrum used:** 2.45 GHz

**Methods used for determining the location:**

- Radio Signal Strength Information (RSSI)
- Time Difference of Arrival (TDOA)

**Average Accuracy:** up to 1 meter. The quality of location data varies depending on frequency of tag transmission.

<table>
<thead>
<tr>
<th><strong>Advantages</strong></th>
<th><strong>Disadvantages</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>The deployment cost decreases if there is an existing 802.11 infrastructure.</td>
<td>Battery life is a problem as in all active tags when the tag cannot draw power from the device it is tagged. It depends on the transmission interval.</td>
</tr>
<tr>
<td></td>
<td>When there is no adequate signal there will be null spots where there cannot be made a connection between the tag and the receiver.</td>
</tr>
</tbody>
</table>

*Table 11: Advantages and Disadvantages of Wi-Fi RTLS*
2.10.1. Usability of Wi-Fi RTLS in Agriculture

Most of the Wi-Fi systems are used indoors. Moen et al. have developed a Wi-Fi based locating systems for outdoor environments [97]. Several test scenarios were carried out to test the performance of their system. A real-time test scenario was also carried out to check whether the system supports real-time services for highly mobile systems.

Ekahau deploys RTLS systems which uses Wi-Fi technology. Most of their commercial systems uses existing Wi-Fi infrastructure. A new Wi-Fi network must be established when it does not exist. Wi-Fi RTLS system can be used for locating animal.

A Hybrid of Wi-Fi and RFID has been tested for warehouse management in 2009 [99].

2.11. ZigBee

ZigBee which originated in 1998 is based on the IEEE 802.15.4 standard and created by ZigBee Alliance, which is formed by several companies interested in defining low/cost, low/power, wireless networking standard. ZigBee can support large number of nodes providing a low cost global network. The IEEE defines only the PHY and MAC layers in its standards and ZigBee defines the network and the application layers, application profile and the security mechanism. Because of this design, the power consumption is low so the battery lifetime is longer [7].

The devices in the IEEE 802.15.4 wireless network are called Full Function Devices (FFDs) and Reduced Function Devices (RFDs). An FFD is capable of performing all the duties in the IEEE 802.15.4 standard and accept any role in the network. But an RFD has only limited capabilities. The RFD devices are used for very simple applications, which result in less processing power and memory size than FFD devices.

Following are the three unlicensed frequencies that ZigBee operates [5].

- 868.3 MHz: Channel 0 (Europe, Australia, New Zealand, America)
- 902-928 MHz: Channel 1-10 (Europe, Australia, New Zealand, America)
- 2405-2480 MHz: Channel 11-26 (worldwide)

The data rate of ZigBee is slower than 802.11b (11 Mbps) and Bluetooth (1 Mbps). They are; [9]

- 250 kbps (at 2.4 GHz),
- 40 kbps (at 915 MHz),
- 20 kbps (at 868 MHz)
2.11.1. Usability of ZigBee RTLS in Agriculture

ZigBee is used in many RTLS systems today. Hyuntae Cho et al. presents a RTLS System based on ZigBee Technology [94]. They use ZigBee compliant tags and transceivers. The results of this setup showed an accuracy within 3m.

A company called ZigBeef has developed an RTLS for tracking cattle using ZigBee in 2008 [95]. Awarepoint [33] has also developed commercial RTLS/WSN systems based on ZigBee for use in hospitals [96].

2.12. Computer Vision

Computer-vision is typically used when it is not possible to attach a tag to the asset or person needed to be located. To determine the location of something, the locating systems based on computer vision, process image data typically obtained using live cameras (still image cameras or video cameras). Image data can be in following forms:

- Still images
- Video feeds
- Views from multiple cameras
- Data from medical scanners

The image data are sent to the location engine. There are no tags needed. Then the received images from several cameras are analysed by the location engine or application software to find specific patterns. Image resolution and environment conditions are two factors which cause accuracy to vary [5].

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>No need to use tags because information about the tracking object is extracted by the image</td>
<td>Accuracy depends on the environmental conditions because quality of the image changes with the environmental condition</td>
</tr>
<tr>
<td>Can locate long ranges</td>
<td>A large number of cameras might be needed depending on the requirements and specifications of the application</td>
</tr>
<tr>
<td></td>
<td>Large network bandwidth will be required for transferring high-resolution images or videos from cameras to the location engine</td>
</tr>
<tr>
<td></td>
<td>A computer-vision RTLS is expensive to deploy because it involves high-resolution cameras and high-performance computers for real-time processing of the images received</td>
</tr>
</tbody>
</table>

Table 12: Advantages and Disadvantages of Computer Vision
Acoustic locating systems work based on sounds. These systems can detect sound events at long ranges and do not require line of sight because sound waves can travel a mile or more from the source and they can bend. If the object being located creates sound itself, then a tag that works as a source of sound is not required. The sensors continuously listen to the sound and report any acoustic anomalies or patterns to the location engine. Gunfire detection is one of its uses. To find the location of the sound source, the location engine performs acoustic trilateration based on the acoustic sensor locations and volume of the sound [5].

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>If the locating object can make sound itself, then no tag is needed</td>
<td>Can be only used to locate things which make special sound. Because the environment is already contain various sounds</td>
</tr>
<tr>
<td>No line of sight needed</td>
<td>Can be used only when there are only a limited number of sound sources to locate</td>
</tr>
<tr>
<td>Can detect sound events from long distances more than 1 kilometer</td>
<td>Attaching tags that make sound is not much suitable for tracking people or assets</td>
</tr>
</tbody>
</table>

Table 13: Advantages and Disadvantages of Acoustic Locating Systems [5]

2.13.1. Usability of Acoustic Locating Systems in Agriculture

There is no RTLS system using Acoustic signals in the market. Acoustic locating system is simple if each animal has a unique distinguishable sound and makes that sound all the time. But no animal makes sound always. So, to use Acoustic waves in the RTLS in both livestock and crop, tags which make sound at the required time are required. But there cannot be found such tags readily available in the market. Even if acoustic waves are used in locating crops, it is not suitable for tracking animal, since the noise made by the tags will disturb the animal.

There is some research work on Acoustic locating systems. In [29] (Raja Jurdak, 2004) the authors experiment an acoustic location system by using a PC microphone and Speakers in an office room. They used multiple frequencies and used those frequencies to send encoded data to the speakers.


By using a satellite navigation system, a person with a receiver can find out his position at any time by using the signals from a constellation of several satellites. The United States Global Positioning System (GPS) and the Russian GLONASS system are two operational Satellite navigation systems. Europe is developing a third independent global system, named ‘Galileo’ which was initially planned to be operational by 2013 [84]. But now it has been delayed to 2014 [113].
All the satellite navigation systems use the same principle as GPS. GPS provides 24 hour, all-weather, worldwide coverage with position, velocity and timing information. The system uses 24 operational satellites to provide a receiver with at least six satellites in view at all times. A minimum of four satellites in view are needed to allow the receiver to compute its current latitude, longitude, altitude and time. Parameters such as velocity and acceleration of a user can be calculated using this information.

A GPS user receiver calculates its location on the earth's surface using the known positions of the satellites being tracked. When the distance to each satellite is measured, the position is calculated by using Time Difference of Arrival (TDOA). The three-dimensional position of the receiver can be obtained with only four satellites in view. Position accuracies in the order of 20 meters can be achieved by using one receiver [84]. GPS is the mostly used RTLS technology at the moment. It is also a widely used technology in the Agricultural sector.

Some Satellite navigation applications are [84]:

- air traffic navigation and control;
- management and tracking of ship and land vehicle fleets;
- rental and personal car navigation systems;
- automation of container location and tracking to increase the efficiency of ports;
- navigation systems for remotely piloted air, land and water vehicles;
- road and rail traffic monitoring;
- dispatch and monitoring of emergency services;
- automated car and truck guidance systems;
- automated guidance of agricultural equipment for efficiency improvements in crop spraying and harvesting
- recreational guidance for hikers, boaters, cyclists and explorers;
- aerial, seismic, and land surveying;
- large structure monitoring (such as dams, bridges, buildings, etc);
- accurate timing systems for communications and commerce; and
- earthquake and tsunami detection and warning systems.
### Advantages

| There is no cost for using GPS signals from the satellites | Attacks such as jamming, blocking and spoofing can happen against GPS |
| The positioning accuracy is from a centimetre to few meters | The tag location is computed by the tag itself. So if the location information is needed by another application, then another networking technology (back end network) is required to send the information to the location engine |
| Clear lines of sight with four or more satellites are required by a tag to calculate its position. But satellite signals don’t travel through objects like mountains, thick jungles etc. | GPS tags sometime won’t be able to locate themselves in an urban canyon area with skyscrapers |
| A GPS tag consumes a relatively large amount of power | Does not work well indoors where there is no line of sight to the satellites |

Table 14: Advantages and Disadvantages of Satellite Navigation Systems

### 2.14.1. Usability of Satellite Navigation Systems in Agriculture

Many RTLS systems used in crop production use GPS. It is also used with tracking terrestrial animals and birds. Recently GPS tracking has been used for tracking diving marine species such as turtles and seals [76].

Manon G. Guillemette et al. have built an RTLS using a hybrid of GPS and RFID which can track human resources both indoors and outdoors [97].

### 2.15. Cellular

The increased use of mobile phones has made the cellular network-based positioning systems possible. All the cellular phone networks use the Ultra High Frequency (UHF) portion of the radio frequency spectrum.

A cellular network consists of the following components:

- Mobile station (MS): A device used to communicate over the cellular network.
- Base station transceiver (BST): A transmitter/receiver used to transmit/receive signals over the radio interface section of the network.
- Mobile switching center (MSC): The heart of the network which sets up and maintains calls made over the network.
- Base station controller (BSC): Controls communication between a group of BSTs and a single MSC.
- Public switched telephone network (PSTN): The land based section of the network.
The cellular structure is used in a cellular network which consists of cells. The coverage area is divided into cells as in Figure 3. The diameter of a cell can vary from several kilometers to dozens of kilometers. Neighbouring cells use different frequencies while the cells which are further apart can use the same frequency.

Table 15: Advantages and Disadvantages of Cellular RTLS

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular networks are widely available in many parts of the world today</td>
<td>Accuracy is low which depends on the size of the cell and density of cells. It is difficult to achieve accuracy better than 50-200 m</td>
</tr>
<tr>
<td>Can be used to locate indoors</td>
<td>High battery usage</td>
</tr>
<tr>
<td>Tags are needed only to track assets, people do not need tags because they already have the cell phones</td>
<td></td>
</tr>
</tbody>
</table>

2.15.1. Usability of Cellular Systems in Agriculture

Cellular RTLS systems are still not popular in agricultural applications. Poor accuracy could be one reason. At the moment people are concerned in using cellular networks in traffic management [114].
2.16. WiMAX

WiMAX (Worldwide Interoperability for Microwave Access) is also known as IEEE 802.16 which is a wireless digital communication system. A WiMAX tower and WiMAX receivers (tags) are the two major components of a WiMAX system. The receiver antenna can be contained in a tag or built in to a cell phone [5].

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>A single WiMAX tower can has a communication range of 50 kilometres</td>
<td>WiMax networks are not widely available at the moment</td>
</tr>
<tr>
<td>Can be used to locate in urban and indoor areas</td>
<td>Consumes a lot of battery power</td>
</tr>
<tr>
<td>Based on standards. So no need to use one WiMAX provider</td>
<td>Cannot reach accuracy higher than 50-200 m</td>
</tr>
</tbody>
</table>

Table 16: Advantages and Disadvantages of WiMAX RTLS

2.16.1. Usability of WiMAX RTLS in Agriculture

WiMax is mainly used outdoors. VistaMAX system which is developed by Vecima Networks uses WiMAX technology [100]. There is no commercial WiMAX RTLS system for Agriculture available at the moment. It is still at the developing stage. WiMAX can be used for monitoring and locating crops and animal outdoors if the suitable WiMAX compatible tags are available.
2.17. Locating Cattle in the Shade

This section shows an example application of RLTS in agriculture and the possible RTLS solutions. Many applications in agriculture are more complex and require individually designed RTLS systems to achieve better results.

In some applications it is required to monitor how much time a specific cow spends under the shelter.

Required results from the RTLS:
- Whether the cow is in the range of 6m radius of the shade.
- Lifetime of the battery should be more than 6 years because the lifetime of the cattle is around 6 years.

Problem Description:
In this RTLS, animals that come inside the 6m radius should be detected. There is no existing structure to mark the 6m-shadow area. If batteries are used in the tags then lifetime a little more than 6 years is sufficient. Only ID of the animal is needed to be stored.

Solution 1:
One suitable RTLS for this problem is a passive Ultra High Frequency (UHF) RFID system with one interrogator at the centre of the tent. Because there is no sensor data to be transferred to the location sensors, passive tags are sufficient but the reading range is too small for Low and High Frequency RFID. When correct size of the antenna is installed, the tags can be read from the 6m range.

Solution 2:
ZigBee is a fast emerging technology which can also be used in this application. Today the advanced ZigBee Technology can provide a reading accurate up to 1m [5]-1.5m [8]. To locate the cattle in this application, a ZigBee Gateway can be fixed on the centre pole of the tent and distance from the cattle can be fed to the server at a nearby location. The ZigBee data rate is low, around 20-250 kbps which is enough for this application because only the location and the ID of the cattle need to be known. At the central server a suitable program should be used to show the cattle within the 6m radius of the shade.

Solution 3:
Global Positioning System (GPS) has become the most popular system for outdoor localization. But due to higher energy consumption, higher cost and frequent satellite connection loss it is difficult to apply in practical farming [6].

Solution 4:
A UWB RTLS can also be used as one solution. But the price of one UWB tag is higher than the price of a passive RFID tag. Since the required read range is 6 meters and the read range of UWB is 30 meters, this system will be more expensive.
3. Conclusions
Many technologies are at their early stages. Specially Agricultural applications are still developing. RFID and GPS are the mostly used technologies in Agriculture at present. There is a high potential of some technologies to be used as Agricultural RTLS. SAW, IR, WiMAX, Bluetooth and UWB are some examples. The performance of RTLS can be improved by using better localization techniques and protocols for transfer of data between the reader and the tags and vice versa. The value of RFID technology for Agricultural RTLS is not decreasing with the appearance of many other technologies. The possibilities of combining other technologies with RFID are also experimented and there exists such hybrid locating systems in the market today. This results in new RTLS systems with absence of several disadvantages of RFID alone. The developing technology will also introduce more powerful, effective and smaller batteries and electronic circuitry in the future so the tags and readers will become friendlier to the man, assets and the environment.
4. References


[109] “UHF RFID Chip Extends Reading Range To 10 Meters”,
[111] “RFID Read Range: Just how far can RFID track something?”,
[112] “Reading distance for active RFID?”,
[113] “Commission awards major contracts to make Galileo operational early 2014”,
5. Abbreviations

AC-DC – Alternating current to Direct current
BSC – Mobile Station Controller
BST – Base Station Transceiver
DC – Direct Current
DoS - Denial of Service
GPS – Global Positioning System
GSM - Global System for Mobile communications: originally from Groupe Spécial Mobile
IC – Integrated Circuit
ID - Identification
IDT – Interdigital Transducer
IPS – Indoor Positioning System
LAN – Local Area Network
LED – Light Emitting Diode
LF – Low Frequency
MAC – Media Access Control sublayer of a Computer Network
MS – Mobile Station
MSC – Mobile Switching Center
PDA – Personal Digital Assistant
PHY – Physical Layer of a Computer Network
PLC – Powerline communication
PLP – Powerline Positioning
ppm – parts-per-million
PSTN – Public Switched Telephone Network
RF – Radio Frequency
RFID – Radio Frequency Identification
RO – Read-only
RSSI – Received Signal Strength Indicator
RTLS – Real Time Locating Systems
RW – Read-write
SAW – Surface Acoustic waves
TDOA – Time Difference of Arrival
UWB – Ultra Wideband
VAI - The Visible Assets, Inc
6. Definitions

1. **IEEE 802.11**: IEEE 802.11 is a set of standards carrying out wireless local area network (WLAN) computer communication in the 2.4, 3.6 and 5 GHz frequency bands. They are created and maintained by the IEEE LAN/MAN Standards Committee (IEEE 802) [77].

2. **Unlicensed spectrum**: The specific part of the spectrum set aside for use without a radio license.

3. **Data rate**: The data transmission speed in a network.

4. **Bandwidth**: Bandwidth is a measure of available or consumed data communication resources expressed in bit/s.

5. **Power budget**: The allocation, within a system, of available electrical power among the various functions that need to be performed.

6. **Near field**: The radiation from an antenna transits three regions as shown. The transitions between these regions are not distinct and changes between them are gradual. The reactive near-field region is the region close to the antenna and up to about 11 away from any radiating surface. In the reactive region, the energy decays very rapidly with distance. In the radiating near-field region, the average energy density remains fairly constant at different distances from the antenna, although there are localized energy fluctuations.

![Figure 15: Three regions of antenna radiation](image)

7. **Multipath effects**: Multipath fading affects most forms of radio communications links in one form or another. Multipath fading can be detected on many signals across the frequency spectrum from the HF bands right up to microwaves and beyond. It is experienced not only by short wave radio communications where signals fade in and out over a period of time, but it is also experienced by many other forms of radio communications systems including cellular telecommunications and many other users of the VHF and UHF spectrum.

Multipath fading occurs in any environment where there is multipath propagation and there is some movement of elements within the radio communication system. This may include the radio transmitter or receiver position, or in the elements that give rise to the reflections. The multipath fading can often be relatively deep, i.e. the signals fade completely away, whereas at other times the fading may not cause the signal to fall below a useable strength.
Multipath fading may also cause distortion to the radio signal. As the various paths that can be taken by the signals vary in length, the signal transmitted at a particular instance will arrive at the receiver over a spread of times [86].

8. **Tone generator**: A tone generator is also known as a signal generator. A tone generator is an electronic device that generates repeating or non-repeating electronic signals (in either the analog or digital domains). They are generally used in designing, testing, troubleshooting, and repairing electronic [23].

9. **Signature**: A pattern used for matching. Also called a fingerprint or definition.

10. **Fingerprint**: A physical or electronic pattern.

11. **Omnidirectional Antenna**: An omnidirectional antenna is an antenna system which radiates power uniformly in one plane with a directive pattern shape in a perpendicular plane. This pattern is often described as "donut shaped" [73].

12. **Mica2 mote**: Mica2 mote is one of the most popular and commercially available sensors which is marketed by CrossBow technologies. Applications for Mica2 motes are developed on an operating system called TinyOS [75].

13. **Transponder**: A radio transmitter and receiver for sending out a signal that triggers a transponder and for receiving and displaying the reply.

14. **Jamming Attack**: Jamming is one of many exploits used to compromise the wireless environment. It works by denying service to authorized users as legitimate traffic is jammed by the illegitimate traffic. A knowledgeable attacker with the right tools can easily jam the 2.4 GHz frequency in a way that drops the signal to a level where the wireless network can no longer function [81].

15. **Denial of Service (DoS)**: A denial-of-service attack (DoS attack) is an attempt to make a computer resource unavailable to its intended users. One common method of attack involves saturating the target (victim) machine with external communications requests, such that it cannot respond to legitimate traffic, or responds so slowly as to be rendered effectively unavailable [82].

16. **Anti-collision Scheme**: When two or more tags which are in the reading range of one reader, try to send messages to the reader simultaneously, the messages collide with each other and interrupt each other. An anti-collision scheme describes a set of procedures which can prevent collision between two messages sent simultaneously by two tags.

17. **Visibility Network**: A visibility network is a system which can create real-time inventories of the moving or stationary tagged items within an area [16].
7. Appendix A

7.1. List of Companies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Company</th>
<th>System Type</th>
<th>Special Features of the System</th>
<th>Applications of the system</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID</td>
<td>ConnecTerra</td>
<td>RFID Middleware</td>
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<td></td>
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<td>OAT Systems</td>
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<td></td>
<td>GlobeRanger</td>
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<td></td>
<td>WINMEC [28]</td>
<td>RFID products</td>
<td></td>
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<tr>
<td></td>
<td>GAO Tek Inc., Canada</td>
<td>UHF Passive ear tags for tracking pigs [27]</td>
<td>Perform reliably in high-reader density environments, Works in harsh environments, Programmable memory in the tag</td>
<td>Suitable for tracking of a range of medium-sized livestock like pig</td>
</tr>
<tr>
<td></td>
<td>RF Code Inc.</td>
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<td>Savi Technology [57]</td>
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<td>Intermec Tecnologies Corporation [58]</td>
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<td>IPICO</td>
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<td></td>
<td>Thing Magic</td>
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<td></td>
<td>Crossbow Technology Inc. [61]</td>
<td>Eko sensors for environmental monitoring</td>
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<td></td>
<td>Vilant Systems</td>
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<td></td>
<td>European</td>
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<td>AutoID Store</td>
<td>Visonic Technologies</td>
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<tr>
<td>Intelleflex [59][60]</td>
<td>Active RFID for crop</td>
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<td>Airgate Technologies</td>
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<td>WhereNet [43]</td>
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<tr>
<td>RuBee</td>
<td>Visible Assets, Inc. (VAI) [66]</td>
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<tr>
<td>Surface Acoustic Waves (SAW)</td>
<td>Airgate Technologies</td>
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<td></td>
<td>RFSAW [68]</td>
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<tr>
<td>Infrared</td>
<td>CenTrak [33]</td>
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<td></td>
<td>Versus and Radianse [39] (earlier had infrared RTLS) [33]</td>
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<td></td>
<td>Active RFID Systems, Inc. (ARS) [104]</td>
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<tr>
<td>Ultrasound</td>
<td>Sonitor Technologies [40]</td>
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<td></td>
<td>Sonitor Ultrasound IPS</td>
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<tr>
<td>Power Line Positioning (PLP)</td>
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<tr>
<td>Bluetooth</td>
<td>Blueon [101]</td>
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<tr>
<td></td>
<td>Bluetooth Based Tracking and Access Control Solutions</td>
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<tr>
<td>Ultra-Wideband (UWB)</td>
<td>UbiSense [41]</td>
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<td></td>
<td>Parco Wireless [42]</td>
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<td>MSSI-Zebra [43]</td>
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<tr>
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<tr>
<td>Time Domain Corp.</td>
<td>Tagent</td>
<td>[87]</td>
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<tr>
<td><strong>Wi-Fi (Wireless Fidelity)</strong></td>
<td>Aruba Networks</td>
<td>[32][45]</td>
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<td></td>
<td>Cisco Systems</td>
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<td>G2 Microsystems</td>
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<td></td>
<td>Motorola</td>
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<td>Newbury Networks</td>
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<td>Nortel Networks</td>
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<td></td>
<td>PanGo Networks</td>
<td>(InnerWireless) [52]</td>
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<td>Trapeze Networks</td>
<td>[53]</td>
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<td>Ekahau</td>
<td>[54]</td>
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<td><strong>ZigBee</strong></td>
<td>ZigBee</td>
<td>[95]</td>
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<td></td>
<td>Awarepoint</td>
<td>[33]</td>
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<td></td>
<td>MeshNetics</td>
<td>[30]</td>
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<tr>
<td></td>
<td><strong>ZigBee modules and software</strong></td>
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<td><strong>Computer Vision</strong></td>
<td>Vecima</td>
<td>[100]</td>
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<td><strong>Acoustic Locating System</strong></td>
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<td>WiMAX components</td>
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7.2. Frequency Ranges

- Passive UHF – 300 MHz – 3 GHz
- Passive HF – 3 MHz – 30 MHz
- RuBee – below 450 kHz often in 131 kHz range [5]
- Active Low Frequency – 30-300 kHz
- Low Frequency Passive – 30 kHz – 300 kHz.
- Diffused IR – Ultrasound – above 20 kHz
- Bluetooth – 2.4 GHz
- Microwave – 2-30 GHz
- ZigBee – 2.4 GHz

7.3. Accuracy

- Wi-Fi – 1-5m
- Bluetooth - 2m
- Passive LF, HF - 1m
- Passive UHF – 10m [11]
- Active RFID – 1-3m
- Ultra Wideband – 30cm – 1m
- ZigBee – 1m
- Computer Vision – a few cm (depends upon the application)
- Acoustic locating - 25cm
- Building Illumination – 1 –3m
7.4. Read Ranges

- Surface Acoustic Waves (SAW) - 10 m

A SAW tag can be read up to 30 m and located with high accuracy [5].

- Passive UHF – 3-6 meters
- Passive HF – 1 meter
- RuBee – 1-30 meters
- Active Low Frequency – few inches to few feet
- Low Frequency Passive – few centimetres to couple of meters
- Diffused IR – 10 meters (30 feet)
- ZigBee – 10 – 100m
- Ultra-Wideband (UWB) – 10m
- Bluetooth – 10m
- Wi-Fi – 100m
- Ultrasound – several meters
- Microwave – Up to 10m