NōdeNs medical

SEVEN STATE-OF-THE-ART RTLS TECHNOLOGIES

Khalid Z. Rajab
Technology Director
NodeNs Medical Ltd

Real-time location sensing (RTLS) technologies have been rolled out in hospitals across North America, and are starting to find their way into the European and Asian health services sector. Prime among the reasons has been a desire to automate asset allocation (beds, equipment) and monitor staff and patient movements. This promises to save staff time, reduce running costs, and ultimately improve patient health outcomes. The operational aspects of RTLS and its potential benefits are covered **here**.

What are the key indoor location sensing technologies on the market? The seven main technologies each have their own features and capabilities, such as:

- Tracking accuracy. How accurately can a target be tracked? This can be as accurate as a few centimetres, allowing highly refined monitoring of complex tasks or monitoring whom an infected patient has come into contact with. The least precise systems can only track to roughly 10 m, which may just be sufficient to identify which room a target is in!
- Polling rates (continuous to 1 minute intervals). How often does the sensor update a target's location? Continuous tracking[1] would allow hospital analysts to identify hand sanitisers use by tracking proximity to its location and length of time spent at the unit. It would also support accurate logging of staff interactions with patients. Less frequent polling would not.
- Tagging technologies (tagless, passive, or active). The majority of RTLS solutions use active tags, which send out a signal used to find its location. However they require batteries, which add complexity, require charging, and increase costs. Passive tag technologies are cheaper but have traditionally been less accurate. Can tagless tracking provide an accurate, robust RTLS solution?
- Infrastructure requirements. Ideally a system would be plug-and-play, where you connect up the RTLS anchors[2] and with minimal configuration they're working together transmitting locations to the central server. A more unwieldy system may require complex wiring, ward shutdowns, and inevitably high costs.

Most (but not all) of these solutions lie in the radio frequency (RF) and microwave space, primarily because these waves can accurately track objects and signals over a range of distances, and also because of the existence of currently available technologies that can be used, either directly (e.g.

[1] Technically, what we call continuous would also have a polling rate, albeit one that is fast enough rate (up to 10 Hz, or 10 times per second) that it is practically indistinguishable from continuous, and certainly so for RTLS applications.
[2] Anchor: a fixed unit, or node, with an RTLS unit. It is used to sense target locations and transmit these locations back to a central server.

Wi-Fi or Bluetooth) or as part of a custom-designed system (e.g. RFID). A new and patent pending[3] technology, developed by NodeNs Medical and based on millimetre waves (mmWaves), is also described.

Without further ado:

1. **Wi-Fi positioning systems (WiPS/WFPS)** use received signal strength indicators (RSSI) to estimate a device's location through knowledge of existing Wi-Fi hotspots. Using existing Wi-Fi infrastructure makes this straightforward to implement, but it nevertheless suffers from poor accuracy due to the complexity of the Wi-Fi signal and propagation characteristics, and because Wi-Fi beacons typically have low priority in the layer stack; so precision is normally as poor as ~10 m, and frequently worse. The very narrow channel bandwidths available, in conjunction with the heavy usage of these bands fundamentally restricts the ability to improve performance through signal processing methods. Furthermore, the tracked assets must actively broadcast their location, which increases the cost and complexity of tags (or otherwise necessitates the user to have a Wi-Fi-enabled device, such as a smartphone).

   Advantages:

   - Very easy to implement, without significant infrastructure changes.

   Disadvantages:

   - Poor accuracy; typically around 10 m, lucky to get 5 m.
   - Unreliable if not implemented correctly (beacons may not have priority in the network stack).
   - Active tags must transmit location, requiring batteries and further circuitry. This reduces polling times (can't track in real time) or requires frequent battery charges.

2. **Bluetooth low energy (BLE) beacons** make use of the development of low energy transmit-only devices that were incorporated into the Bluetooth (BT) 4.0 standard. The more recent Bluetooth 5.0 allows angle-of-arrival (AOA) estimation through IQ processing[4]. These beacons send out identifying and other relevant information, but do not waste power on listening for other devices (and therefore do not require pairing). While they do – by design – require active tags, their low energy consumption allows tag battery life measured in months. However as with WiPS, and for similar reasons, they currently suffer from poor positioning resolutions. While AOA estimation improves accuracy and usefulness, antenna array sizes set limits on precision.

[3] Patent application PCT/GB2018/051230.

[4] IQ stands for in-phase (I) and quadrature phase (Q). This is used to represent signals orthogonal, or at 90° to one another; in other words it can be used to detect time delays. A very useful application of this feature is to use time delays between antennas to estimate angle-of-arrival, for more precise location sensing accuracy.

Advantages:

- Easy to implement, only requiring installation of Bluetooth anchors.
- More recent iterations can detect angle-of-arrival.
- Tags can be embedded with additional sensors, with location and data transmitted together.
- Long tag battery life, measured in months if infrequent polling is used.

Disadvantages:

- Poor accuracy (albeit better than WiPS); typically 1-5 m. Recent improvements with AOA in Bluetooth 5.0, but precision is still limited.
- Signal robustness has historically been an issue with BT, with dropped connections being a common occurrence. However this is improving with more recent standards.
- Active tag technology.
- If faster polling rates are used to approach continuous tracking, battery life seriously degrades.
- Anchors for angle-of-arrival systems will require multiple antennas, which at this frequency can be quite large

3. **Ultra high frequency (UHF) radio-frequency identification (RFID)** is among the most ubiquitous technologies in current RTLS use. Most frequently operate at around 900 MHz[5] using passive or active tags.

Passive tags can be extremely cheap (on the order of around £0.10 or less), and are useful for room-level localisation in a gated system, where a tag is detected as it passes under an anchor (frequently mounted above a doorway).

State-of-the-art active tag systems typically use a number of anchors around a room, for joint identification and tracking of tags. These typically quote, quite optimistically, accuracies of ~1 m. A shortcoming of this system is that many walls are transparent to UHF waves, so tags may appear to 'jump' between one room and the next. And as with the other ISM band methods presented previously, this limitation is due to the narrow bandwidths and fading effects, both of which fundamentally restrict performance and can only be overcome through processing to a limited extent. Furthermore, the requirement for multiple spatially-diverse antennas and transceivers, along with synchronisation and processing units, adds significant cost to the system.

In summary, while UHF RFID works very well for certain RTLS applications in which multiple tags must be tracked with relatively low accuracy, it is fairly restrictive for high accuracy use-cases, and when installation and infrastructure costs must be kept low.

Advantages:

- Well understood, widely used technologies.

[5] Most system work in the 900 MHz industrial, scientific and medical (ISM) band (more precisely: 865 to 868 MHz in Europe, 902 to 928 MHz in North America).

- Passive tags are very cheap.
- Active systems can track many tags robustly, to moderate accuracy (1-3 m).

Disadvantages:

- Passive systems have only room-level accuracy.
- UHF can ‘see through’ walls, so tags may appear to be in neighbouring rooms.
- Multi-path effects and reflections (fading) could lead to ‘ghost’ tags appearing and inaccuracies in localisation.
- Active systems may require costly wiring and have high infrastructure costs. In hospitals this may necessitate ward closures.

4. **Ultra-wideband (UWB)** technologies have recently been proposed as a solution to the bandwidth limitations of the earlier technologies. UWB in general covers the bands from 3.1 to 10.6 GHz, although channels typically span only 0.5 GHz, and regional policies may restrict use of some channels or sub-bands.

The development of a UWB chipset by Irish company **Decawave** has led to a wave of startups using their technology in the RTLS space. While these products promise accuracies ranging from around 10 to 50 cm, they require bulky and costly active tags with short battery life. Additionally, careful calibration of the anchor transceivers is required to maintain precision, and large antennas are required to maintain bandwidth at these frequencies.

24 GHz systems, originally developed for automotive radar applications, are also available with bands of around 0.5 GHz. However this band is being deprecated, and has not been used for health services applications.

Advantages:

- High tracking precision (up to 10 cm).
- Virtually continuous polling.
- Tags can be integrated with other sensors (temperature, accelerometer, etc.).

Disadvantages:

- Active tags; relatively complex circuitry and requiring batteries. Expensive if used throughout hospital.
- Multiple (at least 4) anchors required per room.
- Large antennas required to maintain bandwidth at this frequency.
- Only around 500 MHz of the full band is used, which restricts precision.

5. **Infrared (IR)** scanners have had widespread usage for hospital RTLS applications, as they are a mature technology and are relatively robust. Scanners are placed at strategic points around a room (for example surrounding a hospital bed, or group of beds), and an active tag – either user-

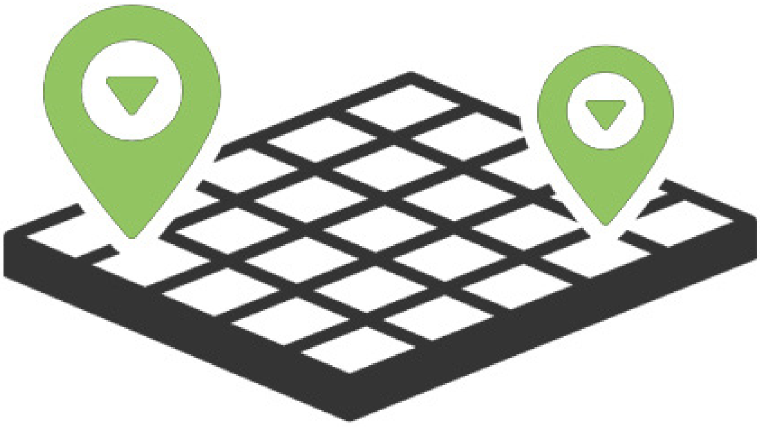
worn or attached to an asset – would be detected when in close proximity to the scanner. An advantage of this technology is that detection is localised to individual rooms as the infrared light is fully reflected by walls; this is in contrast to the previously presented RF/microwave techniques, in which the waves may quite easily propagate through the walls, causing false readings. However this has its own disadvantage, in that the method is most implementations of IR RTLS are reliant on line-of-sight between the scanner and the tag, so if a ward gown were to cover the tag for example, it may not be detected.

Advantages:

- High polling rate (multiple times per minute).
- Tracks multiple tags.
- Well understood technology.
- No cross-room interference.

Disadvantages:

- Active tags; bulky and expensive.
- Loss-of-signal due to blockage, for example by a bedsheet or ward gown.
- Costly infrastructure requirements; multiple anchors per room, each requiring wiring in ceilings. Ward shutdowns necessitated.



6. **Ultrasound** RTLS technology is predicated on the use of ultrasonic waves, which travel far slower than the speed of light, but which still have short wavelengths. While they are generally quite accurate, they are slow and can have quite poor polling rates, and have not gained much traction for RTLS applications.

   Advantages:

   - High polling rate (around 1 Hz).
   - High accuracy (around 50 cm).
   - No cross-room interference.

Disadvantages:

- Requires line-of-sight, and signal can easily be blocked.
- Multiple anchor points required to cover a ward.
- Performance highly dependent on air temperature and humidity (although this is not typically an issue in hospitals).

NodeNs Medical have developed a mmWave RTLS technology which has the potential to disrupt the healthcare RTLS space by providing tagless tracking, with market-leading accuracy

7. **Millimetrewave** spans the frequencies from around 30 – 300 GHz. While this technology has not yet been used for RTLS applications, NodeNs Medical is developing a platform to take advantage of the unique capabilities afforded.

   A number of leading semiconductor chip manufacturers (such as Texas Instruments) have recently released chipsets in the 60 GHz and 77 GHz bands. The technologies were initially targeted at automotive radar, but show great potential for indoor tracking. In addition, the recent development of technologies such as MIMO radar, which leverage the great improvement in processing power described by Moore's law, enables extremely high tracking resolutions.

   A number of unique advantages exist: the bandwidth (up to 4 GHz) is much larger than the earlier technologies, allowing much higher precisions; higher frequencies mean smaller wavelengths, and thus smaller devices; and there is even potential for tagless tracking, and features such as vital sign monitoring!

   Advantages:

   - Market-leading tracking precision (better than 5 cm).
   - Plug-and-play capabilities: plug the anchor into a wall, and with minimal configuration it will transmit tracking data. No rewiring or ward shutdowns required.
   - No cross-room interference, but can still 'see' through many objects such as textiles, wood, glass, and plastics. So targets are localised to a room, but not blocked by other objects.
   - Only one anchor required for localisation, and will cover most rooms.
   - Small anchor size: because of the high frequency an array of antennas will now take less room than a single UWB antenna!
   - Tagless tracking (in certain scenarios).
   - Potential for additional features, such as tagless vital sign monitoring.

Disadvantages

- Nascent technology, so still room for improvement.
- Not yet tested in a healthcare environment.
- Currently, target identification possible only through a hybrid approach (such as with passive RFID tags).

Table 1. Comparison of primary features of RTLS methods

Features	mmWave	Wi-Fi	Bluetooth BLE	RFID	UWB	IR	Ultra-sound
Tracking accuracy	● Excellent	● Poor	● Poor	● Good	● Excellent	● Excellent	● Excellent
Measurement robustness	● Excellent	● Poor	● Poor	● Excellent	● Excellent	● Good	● Good
Track tagged/untagged assets	● Excellent	● Poor	● Poor	● Poor	● Poor	● Poor	● Poor
Infrastructure	● Excellent	● Excellent	● Excellent	● Good	● Poor	● Poor	● Good
Cost	● Good	● Excellent	● Good	● Good	● Good	● Poor	● Good

Excellent ● Good ● Poor ●

Conclusions

Six current RTLS technologies have been summarised with their respective advantages and disadvantages. An additional nascent RTLS technology – millimetrewaves – developed by NodeNs Medical, has the potential to disrupt the healthcare RTLS space by providing tagless tracking, with market-leading accuracy and at low cost.

E-mail: khalid@nodens.eu www.nodens.eu