

HORIZONS IN COMPUTER SCIENCE RESEARCH

VOLUME 14

THOMAS S. CLARY
EDITOR

NOVA

HORIZONS IN COMPUTER SCIENCE

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SCIENCE RESEARCH**

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Chapter 6

DETECTING MOVEMENT WITHIN INDOOR ENVIRONMENTS USING PASSIVE AND ACTIVE TRACKING TECHNOLOGIES

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ABSTRACT

The ability to track the real-time location and movement of items or people offers a broad range of useful applications in areas such as safety, security and the supply chain. Many systems that track subjects in real-time outdoors such as GPS and mobile phone triangulation have severe limitations when tracking individuals in a smaller area, such as a room, building or garden. GPS devices require line of sight with satellites to be tracked correctly, meaning devices cannot be tracked indoors or in some areas surrounded by tall buildings. The degree of accuracy to which GPS provides location information is also inadequate for applications that monitor areas with specific boundaries between where an individual is allowed and where they are not. Mobile phone tracking is expensive and works only in more developed areas in the range of multiple cell towers. Position estimation, to within an average of fifty metres, is much too inaccurate to track subjects over a small area. Implementing a location determination system using received-signal-strength (RSS) has the

advantage that the system can work indoors, however the cost of implementation is rather high and the complex network infrastructure may need constant maintenance. Radio Frequency Identification (RFID) is an automatic identification technology which has seen increasingly prominent use in tracking, however problems also exist here with regards accurate tag location determination. WLAN fingerprinting is arguably the most successfully used technique in systems on the market now. This chapter provides an overview of common techniques and commercial products used in tracking people and objects within indoor environments.

Keywords: movement detection, device free passive localisation, presence detection, smart phone activity detection

1. INTRODUCTION

There is a substantial amount of work in determining the location or activity of an individual over time inside a building with wireless tracking. Movement detection is important for many scenarios such as asset tracking, health care, games, manufacturing, logistics, shopping, security and tour guides. Indoor localisation systems can be classified into active and passive systems. Using Wireless signals is an attractive and reasonably affordable option to deal with the currently unsolved problem of widespread tracking in an indoor environment. Location estimation has become an important component in many applications (Furey et al., 2008a). Various implementations of location estimation systems which can estimate/track the position of people or objects exist (Bekris et al., 2002). A localisation system is chosen based on the accuracy and precision required for a specific application. Indoor location estimation systems are classified into active and passive systems. Active localisation requires the tracked people participate actively, while passive localisation is based on monitoring changes of characteristics dependent on human presence in an indoor environment. Active participation means that a person is required to carry electronic devices or tags which send information to a localisation system that infers that person's position. In many cases the devices/tags used by the localisation systems can also process recorded data. The results are sent to an application server running the localisation algorithms for further processing. Passive localisation estimates the position based on the variance of a location dependent measured signal or video process. Thus, the system is not using any electronic devices to infer the person's location. Device Free Passive Localisation (DfPL)

approaches can identify human presence by monitoring variances of the signal strength in wireless networks (Deak et al., 2010). This is since human body contains about 70% water and it is known that water's resonance frequency is 2.4 GHz. Most common wireless networks use the 2.4GHz frequency, thus the human body behaves as an absorber attenuating the wireless signal. The use of indoor location determination technology could be utilised in several applications namely:

- **Prisoner Monitoring** - A system using tamper-proof Wi-Fi tags can be worn by prisoners for instance to restrict prisoners to certain areas of the prison by notifying prison wardens if prisoners enter restricted areas. This will also help to prevent escape attempts and allow prison guards to monitor prisoner whereabouts always.
- **Child Safety** - A Wi-Fi based system could be used by children in a school, crèche or theme park environment, some commercial wireless location tags have a call-button which a child could activate if they were distressed or in need of help. The system could be configured to notify the nearest teacher, carer or park staff about the issue.
- **Indoor gaming** - A large scale version of Pac-man could be played with people equipped with tags playing the roles of Pac-man and the Ghosts.
- **Security** - If valuable equipment is no longer detected in its normal area this action could activate an alarm for the security staff and then allow them to track and find it while it is in the range of the WLAN.
- **Supply Chain** - Wi-Fi tags could be attached to product in a warehouse to enable stock or inventory level tracking.
- **Healthcare** - Patients could wear wristband tags that allow them to be tracked throughout the hospital. If a patient tries to leave without being discharged, nurses are alerted to the situation and can get them and return them to their ward. This would be particularly useful for patients suffering from dementia or Alzheimer's disease. Additionally, important staff may wear tags so that in an emergency they can be quickly located.

The remainder of this chapter outlines common implementations of active and passive indoor location tracking technologies.

2. DEVICE FREE PASSIVE LOCALISATION (DfPL) TRACKING

Device Free Passive Localisation (DfPL) is tracking human subjects when they are carrying no electronic devices in the localisation aspect. This can work as the human body causes a noticeable distortion to the wireless medium (unless the environment is very ‘noisy’). Location tracking techniques for active localisation require tracked personnel to participate actively however passive localisation is based on monitoring changes of characteristics dependent on people’s presence in an environment. By participating actively, we mean that a person carries an electronic device which sends information to a positioning system helping it to infer that person's position. In the passive localisation case, the position is estimated based on the variance of a measured signal or video process. Thus, the tracked person is not carrying any electronic devices to infer the user's position. The implementation of person tracking for active localisation systems is relatively straightforward with the aid of electronic devices such as tags or sensors. The challenge however is implementing Device-free Passive Localisation (DfPL) systems as no devices are carried on the person to provide movement detection (Furey et al., 2008b; Curran et al., 2011).

DfPL is based on monitoring the variances of the signal strength in a wireless network. The human body contains about 70% water and it is known that waters resonance frequency is 2.4 GHz. The frequency of the most common wireless networks is 2.4GHZ, thus the human body behaves as an absorber attenuating the wireless signal. This technique was the focus of earlier research where a DfPL scenario was deployed on a minimum number of wireless nodes with the help of a principle component analysis (PCA) based intelligent signal processing technique with results demonstrating that human detection and tracking are possible to within 1m resolution with a minimal hardware infrastructure (Vance et al., 2010; Vance et al., 2011). This DfPL research builds on previous research concerned with the development of a more accurate algorithm for Wi-Fi positioning in an indoor environment as Indoor positioning systems suffer from high levels of inaccuracy due to the distortion of radio signals or they require a lot of extra infrastructure to be installed. A novel system to overcome these difficulties was developed called HABITS (Curran et al., 2007), that employed artificial intelligence methods based on movement history to provide higher levels of tracking accuracy. The core algorithm used the history of movement of users through a building as a

means of predicting the most likely paths that they will travel in the future thus overcoming RF signal black spots where other systems fail. HABITS used the same radio signals and equipment as other systems but also enabled positioning and continuous real time tracking with accuracy levels that were not previously possible. This individual DFPL identification led to further investigation into the problem of identifying multiple people in a room using simply RSSI measurements and the application of smoothing algorithms to filter the RSSI recordings (Furey et al., 2008a). Smoothing the RSSI signal made it easier to detect or observe changes in the environment due to the presence of a person in the room where a Wireless Sensor Network was deployed. Previous work done at Ulster University was testing the accuracy, precision and robustness of indoor location detection systems in the field of robotics (Curran et al., 2009) and consultancy for industries connected to tracking hospital patient records and tracking people in shopping malls. Another project improved the accuracy of 802.11 WiFi location sensing systems by combining the strength of WiFi signals and the user activity recognized from accelerometer data (Furey et al., 2010). This focused on recognizing basic activities from accelerometer data, such as standing still and climbing upstairs with the output of the activity recognition then fed into the existing WiFi location sensing system to improve the accuracy of the estimation of the user's location.

2.1. Device Free Passive Localisation on Mobile Phones

Nearby movement can be detected using mobile phones where software on the phone detects variations in the received signal power thereby allowing decisions to be made on whether a person is moving near the mobile phone (Deak et al., 2014). This opens the possibility of a multitude of applications making use of knowledge which can determine if a person is moving in the vicinity. This idea can also be transferred to other wireless devices such as laptops but the mobile phone is the more obvious candidate. At present the only way to determine human presence in a room equipped with a mobile phone would be to run some application which works through the camera on the phone. This would be a heavy drain on the phone battery as image processing is intensive. The camera on the phone also must be orientated in a certain way and would only have a specific viewpoint. The other option might be sound recognition but this is processor intensive and prone to repeated failure should the person(s) speak no words. The mobile phone detects

variations in the strength of the wireless signal received at the device and uses these variations to determine movement of a person. The device detects variations in the amplitude of the signal. For example, the device may detect the Received Signal Strength Indicator (RSSI) values for the received wireless signal and monitor how these vary. Movement may be determined to have occurred when the detected RSSI amplitude varies above a first threshold and/or below a second threshold. Motion is only determined to have occurred if the amplitude of the RSSI values rises above the first threshold and/or falls below the second threshold a predetermined number of times in a predetermined duration of time. This technique identifies movement without the need for the person to speak. Using mobile phones in a 'device-free technique' is different in that we are not attempting to 'track' an individual from a remote location but rather apply the principles of radio interference through the presence of a human so that a nearby phone can track the movement of a person for all manner of alerts and subsequent actions. Here the mobile phone is the 'access point' and the device which detects movement. This would allow app developers to incorporate this unique technique of detecting movement into their existing apps. One simplistic example could be alarm clock apps which detect the person being awake and moving in the room and thus cease to sound the alarm tone. This technique is also useful in allowing a mobile to 'be ready' as it detects movement e.g., screen of the mobile phone may turn on if movement is detected. The phone does not need to be docked and the threshold of detection can be adjusted so that disturbances by animals do not lead to false positives. The resolution of detection is room level ideally at less than 1 meter (Curran et al., 2007).

Currently, there are a limited number of means for a mobile device to detect the presence of a person nearby. One method is to use the phones camera. Thus, movement detection can be achieved by running a software application that receives images from the camera of the phone. However, this technique requires image processing and therefore demands a significant amount of power, which drains the battery on the phone relatively quickly. The camera on the phone must also be orientated in the optimum direction and even then, it only provides a specific viewpoint. The nearest competitors therefore are around camera based motion detection. One such popular app for Android is called Motion Detector Pro which is a camera surveillance app that uses the built-in camera to detect movements in the surrounding area. If it detects movement it sends an email or a text message with a picture link to another cell phone, allowing a person to remotely monitor an area using an Android phone. Yawcam is another motion-sensing security app which uses

the phones camera to detect movement. It is enhanced with features which allow the usual automatic FTP uploading, emailing, or just saving captured images to a hard drive. Other apps include motion detector (BFrontier), MySnapCam, Motion Detection Alarm (DevDroisSP) and inView (Shenzhen Corp). There are iPhone apps which simply detect movement through the iPhones accelerometer and can sound out warnings such as "Back away from my iPhone." One example is Motion Alarm (Maplewoods Associated Ltd). Similar apps exist for other mobile platforms as well but they have limited usage and solely rely on the phone moving. Another option for the detection of a person using a phone is sound recognition. Again, this requires intensive processing and would also be prone to failure should the level of noise created by the person be too low to detect effectively. Therefore, a DfPL solution is a much-improved method of detecting human motion using a portable electronic device. The WiFi is generally turned on and sensing internal networks. There is little overhead in the detection of movement using our unique technique. It is also less intrusive than camera based detection techniques.

Future applications of detecting movement could be around gaming where movement plays a part or apps which can be used for finding a smartphone or preventing phone theft. If movement is detected, an app can be directed to take a picture and send it to an email or another phone. This can also be used for watching a business/home or keeping an eye on pets. The images could also be stored on the cloud or locally on the phones SD-card. A DfPL mobile phone technique is also useful in a broader sense. For instance, it can be used to get the mobile phone 'ready' as it detects movement nearby. For example, the phone may change from a standby mode where it is running on low power and performance to an active mode where it is running on higher power and performance such that it is ready to be used by a user. An example is that the screen of the mobile phone may turn on if movement is detected. Another application is to turn off an alarm that is sounding if movement is detected nearby. For example, a wake-up alarm may be sounding and movement of the person woken by the alarm may deactivate the alarm without the person having to go to the phone, pick it up and switch the alarm off. The present invention is particularly advantageous with phones and smart phones since they are so widely used and software may be readily downloaded to convert the phone or smart phone into a motion detector. Similarly, a myriad of software applications that can use the motion detection software may be readily downloaded to the phone or smart phone. Although the present invention is beneficial to smart phones, less preferred embodiments are also contemplated wherein other portable electronic devices may be used such as a

laptop. Other potential applications reside in the healthcare domain where a mobile phone can be used to detect movement of patients and in some cases, form an alert system. There are several areas where movement detection on existing off-the-shelf smart phones can lead to inexpensive solution for remote monitoring.

3. THE TECHNOLOGY BEHIND PINPOINTING USERS INDOORS

Received Signal Strength Indicator (RSSI) is the most crucial parameter in the localization of WLAN devices (Furey et al., 2011e). At the laptop, it shows the signal strength received from an access point, where the stronger signal received by the WLAN card, the closer the position of the card to the access point. This corroborates a natural observation that there is a dependence between RSSI and the distance from the source of the signal, though the actual relation is not needed in the non-parametric localization algorithm used in this project. For localization purposes, the RSSI parameter must be measured between the device of interest and many APs. One of the most important factors in the measurement of RSSI is the power attenuation due to distance; however, absorption gradient also affects the RSSI measurement. Sudden changes in signal absorption, due to walls for example, introduce discontinuities into the dependence between RSSI and distance which is normally considered a smooth function (Nafarieh and How, 2008). In addition to walls, the presence of humans, the direction of the antenna, and the types of WLAN cards influence the absorption of the RF signal energy. The RSSI values can be reported by the device driver as a non-dimensional number or percentage and sometimes is converted to dBm through some nonlinear mapping process (Bardwell, 2005). However, the means of conversion are different from one WLAN card to the other. Although there is a formula for each specific card, some cards like Cisco cards follow a table for conversion with higher granularity, and some like Atheros cards use lower resolution (Bardwell, 2002). Since the RSSI measurements are dependent on different laptop/antenna positioning (e.g., height of the mobile card), antenna orientations were controlled. The average of all data in all directions was used to create the vector for the measurement point. We found that the antenna orientation could cause a variation in RSS level of up to 10 dBm. This effect cannot be ignored when considering the impact different orientations have on

RSSI measurements reliability and eventually on the localization accuracy documented here (Furey et al., 2008a). Another source of error for localization is the presence of humans in the environment. The frequency used by 802.11b, g standards is 2.4 GHz and the resonance frequency of water is at the same frequency. Therefore, water and anything containing water can be problematic because it absorbs RF signal and attenuates it significantly. Since the human body consists of 70% water, the received signal strength is absorbed when the user obstructs the signal path and causes an extra attenuation (Carlin and Curran, 2014). The deployment of different wireless NICs during the training phase and the actual localization phase, can also cause discrepancies in measurements. Also, the collected RSSI data on laptops are percentage-based while at Access Points they are in dBm. Since the conversion methods and their accuracy depend on the type of WLAN cards, the actual RSSI readings in the localization algorithm may be interpreted in erroneous ways, resulting in different RSSI data for the exact same environment. The error caused by different types of WLAN cards can be around 20% which is a considerable error value (Furey et al., 2010b).

4. RFID TRACKING

Radio Frequency Identification (RFID) is a technology which is in widespread use in areas like asset management and stock control. Radio signals are transmitted between a reader and a tag. An RFID tag consists of an antenna, a transceiver and a small amount of memory. An RFID reader has more functionality than a tag and in addition to an antenna and a transceiver it also contains a power supply, a processor and an interface to connect to a network. The tags may be either active or passive. The passive tags have no power supply and are activated by the signals scanning them. The active tags have a small power supply and this enables them to have a range of several meters when compared to less than 1 meter for most passive tags. RFID tags enable positioning by placing the readers at doorways or other such points of human movement. The network can then track people when the tag they are carrying, passes through a doorway. This information can be sent by the reader to a central server which can display the tag's location graphically. Active RFID tags have a much higher signal strength, as opposed to passive tags with a low signal strength that are depending on the RFID readers to power them. Active tags for a project tracking people could be set to have a range of approximately 20-30 meters which should give room level visitor information.

An active RFID tag has a unique identifier which can be continuously tracked with approximately 1 update per second as long as its signal reaches an RFID reader. The range of an active RFID tag is up to 200 meters. In order to save battery life and reduce the number of updates sent to the system, tags that only broadcast when moved can be used. Active tags however cost significantly more than passive tags. Therefore RFID tags must be handed out and linked to individuals or otherwise be available to for example, the shoppers and collected again when leaving the centre. This requires shoppers as well as the centre to take action for the system to work, thereby lowering the penetration of the system.

Communications from active tags to readers is typically much more reliable than from passive tags due to the ability of active tags to conduct a "session" with a reader. Active tags, due to their on board power supply, also may transmit at higher power levels than passive tags, allowing them to be more robust in "RF challenged" environments with humidity and spray or with dampening targets (including humans, which contain mostly water), reflective targets from metal (shipping containers, vehicles), or at longer distances: generating strong responses from weak reception is a sound approach to success. In turn, active tags are generally bigger, caused by battery volume, and more expensive to manufacture. Many active tags today have operational ranges of hundreds of meters, and a battery life of up to 10 years. Active tags may include larger memories than passive tags, and may include the ability to store additional information received from the reader. Semi-passive tags, also called semi-active tags, are similar to active tags in that they have their own power source, but the battery only powers the microchip and does not power the broadcasting of a signal. The response is usually powered by means of backscattering the RF energy from the reader, where energy is reflected back to the reader as with passive tags. An additional application for the battery is to power data storage. Semi-passive tags have greater sensitivity than passive tags, possess a longer battery powered life cycle than active tags and can perform active functions (such as temperature logging) under its own power, even when no reader is present for powering the circuitry. Whereas in passive tags the power level to power up the circuitry must be 100 times stronger than with active or semi-active tags, also the time consumption for collecting the energy is omitted and the response comes with shorter latency time. *The battery-assisted* reception circuitry of semi-passive tags leads to greater sensitivity than passive tags, typically 100 times more. They have the ability to extend the read range of standard passive technologies, to read around challenging materials such as metal, to withstand outdoor environments, to

store an on-tag database, to be able to capture sensor data, and to act as a communications mechanism for external devices.

4.1. CoreRFID - RTLS

CoreRFID has over 14 years' experience in the technologies that support track, trace, audit and control applications. Technology provided by CoreRFID is used to support applications in areas as diverse as asset management, logistics and delivery Tracking and security and access control. CoreRFID's customer base includes organisations like the BBC, Capita, Nokia, Thames Water and Norwich Union. CoreRFID has strategic partnerships with providers of Ultra High Frequency components, making it possible for CoreRFID's clients to exploit this technology. The systems outlined here will require UHF tags. UHF tags offer good read ranges and the ability for a number of tags to be read simultaneously. It is best to buy tags from the same suppliers as the readers as they will have experience with previous clients as to which work best. Some leading UHF tag suppliers are Confidex, Xerafy and Omni-ID. ETSI tags are for the UK. CoreRFID provide a Xerafy UHF Metal Tags Test Pack (see Figure 2) which consists of 14 UHF Class Gen 2 tags. The pack costs £47 and is a good way of determining which tags work best. This is especially useful if placing on metal shopping trolleys. Each Metal Tag Test Pack includes 2 pieces each of the following Xerafy tags: PICO X II, NANO X II, MICRO X II, Cargo Trak, Versa Trak, Global Trak and Data Trak.

4.1.1. Impinj Speedway UHF RFID xPortal

The Speedway xPortal (see Figure 1) is an integrated reader/antenna/housing for portal applications. It builds on the capability of the Speedway Revolution family by packaging a reader together with the necessary antennas in an easy to install casing that allows for portal installations in office buildings, retail premises or stock rooms. The xPortal exploits the Speedway Revolution's adaptive configuration facilities to deliver superior read performance. Power-over-Ethernet allows single cable connectivity, further simplifying installation. It broadcasts at frequencies 865-868MHz (ETSI), uses wired ethernet (10/100), supports EPC Global Class 1/Gen 2 ISO18000-6C tags and has "Autopilot" adaptive configuring including Max throughput modes. The S/W platforms for interfacing with it is Windows (.Net), In fact, the Speedway xPortal uses the LLRP standard - XML messages passed to and from the reader on a TCP port so developers can

develop on any platform that supports TCP based sockets. The Speedway xPortal is usually configured with Power-over-Ethernet.



Figure 1. Impinj Speedway UHF RFID xPortal.



Figure 2. Xerafy UHF Metal Tags Test Pack.



Figure 3. ThingMagic Astra UHF RFID reader and antenna.

4.1.2. ThingMagic Astra Integrated UHF RFID Reader and Antenna

ThingMagic's Astra integrated UHF RFID reader and antenna¹ (see Figure 3) offers an enterprise level, high performance, low cost EPCglobal Gen2 RFID solution. Astra is ideal for commercial and enterprise environments that require unobtrusive deployments with a minimum of cabling, readers and antennas. The Astra includes network management and security features, such as DHCP for configuration and firmware management, and SSL/SSH-based security. Astra supports power over Ethernet (POE), or when AC-powered is available with an option for Wi-Fi backhaul. It broadcasts at frequencies 865-868MHz (ETSI) and has 1 external antenna port plus integral antenna. The host interface is wired Ethernet (10/100) or WiFi (802.11 b/g). The S/W development platform is Java, .Net (C#). The max tag read rate is over 190 tags/second and max tag read distance is just over 30 feet (9M) with integrated 6 dBi antenna (36 dBm EIRP) parts. Applications to control the Astra reader, and all ThingMagic Reader products, can be written using the high level MercuryAPI. The MercuryAPI supports Java, .NET and C (for on-reader applications) programming environments. A fuller description can be found in this Developer's Guide². The MercuryAPI Software Development Kit (SDK) contains sample applications and source code to help developers.

4.1.3. CoreRFID Development Kit

CoreRFID have a *Development kit/entry level system for active tag based Real Time Location System*. This active tag based real time location system identifies in real-time where a tag is. CoreRFID claim that the readers determine the position of tags through the timing of return signals the RTLS allows the location of tags to an accuracy of about 1m. This package can be used for development of an entry level or pilot system. It provides 6 RTLS reader/anchor units (one with Ethernet), 6 power adaptors, mounting kits and tripod stands, 10 RTLS asset tags. Accessories include power adaptors and mounting kits for reader/anchors and access to downloadable SDK, demo programme, user's manual, programmer's manual and installation guide. The reader/anchor family allow the creation of a series of location cells; the Ethernet connected unit acts as the systems' master. The read range is up to 100 metres between tag and reader/anchor. In addition, CoreRFID software solutions are developed using the Microsoft .Net Framework making it easier

¹ <https://www.thingmagic.com/index.php/integrated-readers/astra-ex>.

² http://www.corerfid.com/rfid%20shop/thingmagic/MercuryAPI_ProgrammerGuide_Jan12.pdf.

to integrate track, trace audit and control applications with other back office systems.

4.2. 3M

3M have a proven track record in delivering tracking systems throughout the world. 3M's Track and Trace business is built around systems. These systems, whilst consisting of a number of component parts, are - in the vast majority of instances - sold as solutions rather than disparate hardware and peripherals. 3M can however provide an RFID based solution for the tracking of people. Their RFID based solutions utilise High Frequency (13.56 MHz) RFID. Seeking a solution where people 'walk' through a portal requires an Ultra High Frequency RFID and/or possibly Active/Powered RFID. A 3M RFID tag (which is guaranteed for the life of the file) (see Figure 4) is attached to a shopping trolley or any other device. They are not that expensive. The tag is then tracked around the centre by passing by strategically placed portals (see Figure 5). These portals are able to track multiple files all at once. They connect to existing PCs and feed information on the person's location to the 3M file tracking software. Every PC in the systems is able to use the software to see the location of a person.



Figure 4. Tag.



Figure 5. Reader.

3M tend to operate through value added resellers in this area, whereby 3M provide all hardware and software to a third party who deliver a solution including consultancy and user training.

4.3. ODIN Technologies Ireland

ODIN³ is a world-wide RFID company that has more than 500 successful RFID projects under its belt and over \$50 million of R&D invested in a patented RFID-specific software. ODIN have a strong track record of high accuracy, scalability and integration with third party back-end systems. ODIN is one of the leading RFID companies in UHF. ODIN is headquartered near Washington, DC with offices in Boston, MA, Budapest, HU, Dublin, IRL and full-time resources in Toulouse, France and Geneva, Switzerland. EasyTAP is a locationing engine that manages the reader infrastructure and turns the data into meaningful asset movement information for an application layer to consume. AM is the software application layer, and is an enterprise web solution.

4.4. Trolley Scan

The RFID-radar⁴ system from Trolley Scan is an RFID based location determination system that they claim can track up to fifty tags and locate their location within a few seconds. The system has three main components, the reader, the antenna array and the tags (See Figure 6). The reader measures the distance of the signals from the tags from the antenna array which also energises the tags. The RFID radar works by measuring the distance the signal travels to two of the antenna then calculating the angle from each and movement can be detected by repeating this process. Trolley Scan determines the range of the transponder based on its received transmission. The reader has a location accuracy lower than 0.5 m, a pointing accuracy of 1 degree and can cover a maximum range of 100 m depending on the tag used with the reader. RFID-radar takes a relatively long time to determine the exact position therefore it is better suited to static situations where transponders are relatively stationary.

³ <http://odinrfid.com/>.

⁴ <http://www.rfid-radar.com/>.



Figure 6. RFID Radar out of the box contents.

A problem with RFID systems is that they need an external antenna which is 80 times bigger than the chip. Further, the present costs of manufacturing the inlays for tags have inhibited broader adoption, but as silicon prices are reduced and more economic methods for manufacturing inlays and tags are perfected in the industry, broader adoption and item level tagging may make RFID both innocuous and commonplace much like Barcodes are presently. The RFID-radar by Trolley Scan, makes two measurements on each signal received from each transponder in its receiving zone: a range measurement and an angle of arrival. The angle of arrival measurement is virtually instantaneous and used in conjunction with range gives a 2D positioning system from a single measuring location. It also measures range with narrow bandwidth (10 KHz). RFID tags come in three general varieties: passive, active, or semi-passive (also known as battery-assisted). Passive RFID tags have no internal power supply. The minute electrical current induced in the antenna by the incoming radio frequency signal provides just enough power for the CMOS integrated circuit in the tag to power up and transmit a response. Most passive tags signal by backscattering the carrier wave from the reader. This means that the antenna has to be designed both to collect power from the incoming signal and also to transmit the outbound backscatter signal. The response of a passive RFID tag is not necessarily just an ID number and the tag chip can contain non-volatile, possibly writable EEPROM for storing data. Passive tags have practical read distances ranging from about 10 cm up to a few meters, depending on the chosen radio frequency and antenna design/size. The lack of an onboard power supply means that the device can be

quite small: commercially available products exist that can be embedded in a sticker, or under the skin in the case of low frequency RFID tags. The transponders are low cost Tag-Talks-First type devices, capable of being produced cheaply. Trolley Scan also works with the Transponder-Talks-First Protocol which is suitable for fast moving tags which send their ID as soon as they have enough energy. The interference area is smaller than using RTF (Reader-talks-first) Protocol because the tags are less powerful than the receiver. Due to very low operating power, Ecochip tags can be mounted on either side of objects as they will still be able to operate even when the large losses caused by the differences in dielectric constants of the objects in the path are taken into account (see Figure 7). The range is reduced dramatically from the 13m air situation to around 4 to 6m depending on materials.



Figure 7. RFID Radar Supplied Ecotag claymore semi-passive RFID tag.

The CR2032 battery has a life of approximately five years. The power level is $0.6 \mu\text{W}$ and the minimum range is 5 m as transponders might overload and stop if they are too close to the energizing field. The maximum range is 40 m. The Claymore tags (Figure 7) have been developed to address the issue of sensitivity when attached to hard objects. The tag is mounted in a block of plastic which has a metal backing so that objects behind the tag do not influence the sensitivity. This means that the radiation pattern of the tag is more directional as it is intended to be attached to a hard object and does not need to radiate behind this tag. The long range stick Ecotag claims operating distances of at least 30m however when it is placed close to a hard surface, its performance degrades as the hard surface influences the sensitivity (the stick Ecotag has the radiation pattern of a conventional dipole). RFID readers that are in charge of the tags of an area may operate in *autonomous mode* (as opposed to *interactive mode*). When in this mode, a reader periodically locates all tags in its operating range, and maintains a presence list with a persist time and some control information. When an entry expires, it is removed from the list. Frequently, a distributed application requires both types of tags: passive tags are incapable of continuous monitoring and perform tasks on demand when accessed by readers. They are useful when activities are regular and well defined, and requirements for data storage and security are limited; when accesses are frequent, continuous or unpredictable, there are time constraints

to meet or data processing (internal searches, for instance) to perform, active tags may be preferred. Trolleyscan sell a Notetrack Management system. The client needs to supply the computer that will be used at the guard point. This system needs to have Win98SE/Win XP or Win Vista for an operating system. The administrator section of the software can be run on any existing computer. The package comprises of 1 UHF Trolley Scan fixed reader, 50 Ecochip tags, 1 Guard point software package and 1 administrator software package. Additional transponders and readers can be bought as needed.

5. WiFi TRACKING SOLUTIONS

802.11 Wi-Fi networks are available in most public buildings. The signals transmitted by the Access Points (APs) provide a readily available network of signals which may be used for positioning. The wide availability of existing Wi-Fi networks and of Wi-Fi enabled mobile devices makes WLAN positioning an attractive option due to the low roll-out and operational costs (Furey et al., 2011b; Deak et al., 2013). The majority of systems in use today rely on measurements of RSS, Signal to Noise (SnR) ratio and Proximity Sensing. Each beacon (AP) sends out periodic broadcasts on the up or down link (Carlin and Curran, 2014). Measurements are taken at the terminal device for RSS and SnR. Passive scanning is used to listen for the signals from the beacons. This is normally used to select the best signal for data communication. Each beacon emitted from an AP contains some information about the AP (Furey et al., 2011c). For positioning purposes, one of the interesting properties is the Basic Service Set Identifier (BSSI) which acts like an individual name for the beacon. These beacons are emitted periodically and the time delay can be configured but is usually in the order of a few milliseconds. With the information gained from these beacons a number of positioning methods may be implemented. The AP with the strongest signal is considered to be the location of the mobile device. If the Base Station's (BS) coordinates are known to be (x, y) , then with proximity sensing, the Mobile Device's coordinates are also considered to be (x, y) . WLAN fingerprinting is the most successfully used method in commercial systems available today. It is used in both the Ekahau system and the LA200 systems from Trapeze networks. There are two separate stages in the fingerprinting process, the offline and online stages. The offline stage involves calibrating the area where positioning is to be conducted. This can be a time consuming process and involves manually walking around a building with a Wi-Fi enabled device

which is constantly taking “RSS snapshots” of the signals that it can detect at each location from all the detectable APs. This must be done every few meters or so and at each location a full 360 degree rotation must be carried out as there can be a large variation in RSS values depending on orientation. This information is then stored in a database with the coordinates of each location corresponding to a different pattern of RSS values. Systems such as Ekahau display areas where calibration has been conducted with their RSS values denoted by the different colours graphically on a map. The online phase involves actually getting a position fix from a mobile Wi-Fi device at an unknown location in the test area. A number of approaches can be followed with either terminal, network or terminal-assisted being used. The detected RSS values at a particular location are compared with those in the database. The closest matching pattern with its corresponding location coordinates are given as the previously unknown coordinates of the mobile device. A number of different methods may be used to find which of these patterns is the closest as there will very rarely be an exact match. Disadvantages of this method include a time consuming calibration/training process. In addition, if some of the APs are moved then partial calibration needs to be redone (Furey et al., 2011d).

5.1. Ekahau

The current leader in Wi-Fi positioning systems is the Finnish Company, Ekahau⁵. The Ekahau Real Time Location System is a software suite that uses an existing WLAN network without the need for additional special network hardware to determine the location of a Wi-Fi equipped device. The suite has three main components namely the Ekahau Site Survey (ESS), the Ekahau Positioning Engine (EPE) and the Ekahau API that utilises the EPE system to create custom applications (see Figure 8). The EPE uses software based algorithms to calculate the position of a tag. However before the EPE can determine the location work it needs the site survey calibration information from the ESS. The ESS collects the information on the coverage and RSSI of each AP in the network across the area to be covered. The ESS gathers the calibration information by a person carrying the system and walking around the area to be covered. Ekahau provides an open API with support to integrate

⁵ <http://www.ekahau.com/>.

XML thus full visibility across geographically-dispersed campuses is available out of the box without the need to install software or hardware at remote sites.



Figure 8. Ekahau Components out of the box.

The Client communicates with the mobile device's Wi-Fi chip and retrieves the RSSI information and passes this along to the EPE. The EPE is a positioning server that provides the location coordinates (x, y, and floor) of the mobile terminal or Wi-Fi tag (See Wi-Fi tags in Figure 9). The Ekahau manager merges information from the EPE and the Client and also provides applications for site calibration (Ekahau Site Survey) and live tracking.



Figure 9. Ekahau Tags.

A noteworthy element of the Ekahau systems is their proprietary “Rails” software which allows for tracking to be carried out in a way that replicates human movement and eliminates the “jumping through walls effect” that is common with other RTLS. This gives a unique competitive advantage to the Ekahau solution. The Rails are added by an administrator to “teach” the solution where devices are able to travel.

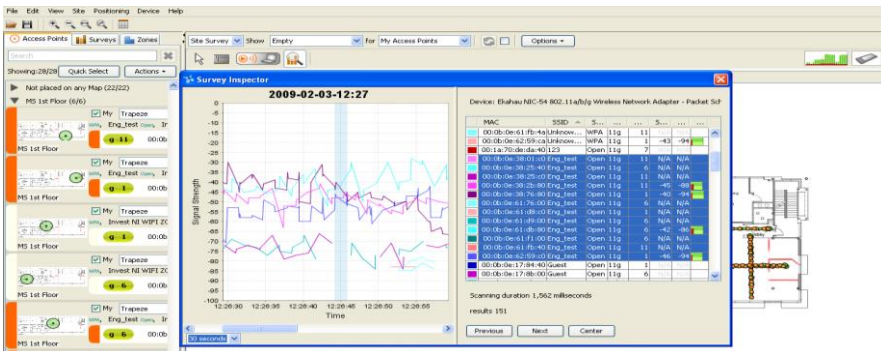


Figure 10. Ekahau Survey Inspector showing 30s fluctuations.

The software views the area where the rails are as a higher probability of true location. Ekahau can use a network, terminal or terminal assisted approach. It also comes with an Application Programming Interface (API) to enable custom applications to be developed. The Ekahau RTLS system facilitates all tracking of devices as it does not rely on proprietary infrastructure or readers in order to track devices. The existing 802.11 Wi-Fi network is used for all tracking with signal strengths being recorded as they are. Ekahau Site survey records RSSI data of the test area with all observable aspects of the WLAN being considered. RF characteristics e.g., multipath, reflection, are recorded and do not harm location accuracy or signal measurement. This survey data then facilitates building tracking models. The observed client data is recorded and each recorded location is assigned a probability based on this data (see Figure 10).

Ekahau uses its own probabilistic location detection algorithms which are computationally efficient giving 1-3 metres accuracy in ~ 5 seconds. Different Wi-Fi devices “hear” the network at different levels (RSSI readings) even when they are located at the same distance from the Access Point (AP). A process of normalization is applied which allows for the use of hardware from different vendors. Figure 11 illustrates how the rails tools in Ekahau can be used to designate areas such as hallways between rooms. The Ekahau Planner provides real-time visualizations for displaying RF coverage shown in Figure 12 and a variety of performance parameters. The software supports multiple different wall material types and antenna types for the best possible calculation of RF signal propagation.

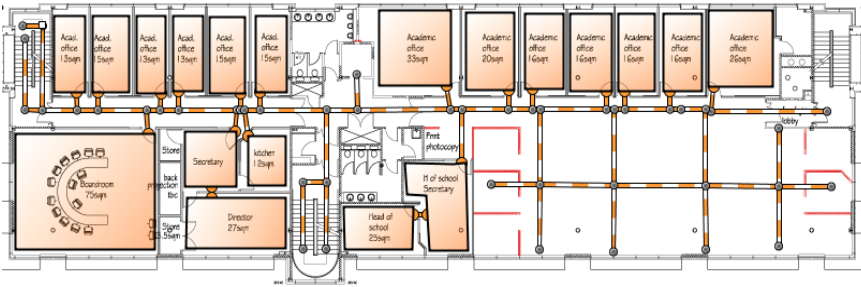


Figure 11. Rails and free space.

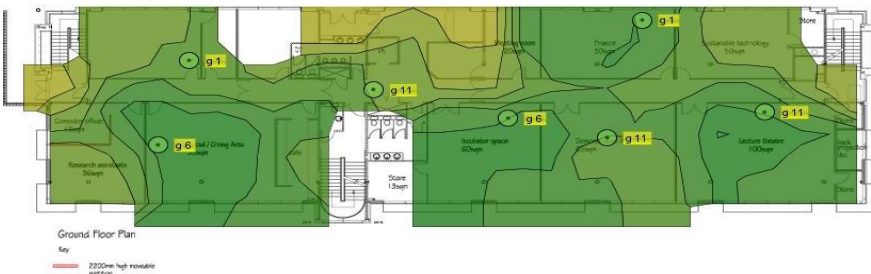


Figure 12. Shows RF coverage.

The Ekahau planner presents an innovative approach that streamlines Wi-Fi network design and deployment (Ekahau, Planner data sheet). It can be used to intelligently simulate the initial access point placement settings, walls, and thus predict the expected network performance, prior to installing any Wi-Fi infrastructure (Ekahau, Planner data sheet). An easy to use drag-and-drop GUI is included for access point and wall placement on a facility floor map (Ekahau, Planner data sheet). The Ekahau Planner provides real-time visualizations for displaying RF coverage and a variety of performance parameters. The Ekahau Software Development Kit (SDK) is an application that contains Java package, Javadoc, and code example for quickly connecting to the Positioning Engine.

5.2. Trapeze Networks

The Trapeze Networks Location Appliance LA-200 is a rebranded Newbury Networks Location Appliance. Newbury Networks strategic business

partners rebranded the unit under several different names namely the Meru Networks Meru RF Location Manager, the Nortel Networks Nortel WLE2340 and Trapeze Networks Trapeze LA-200 (See Figure 13). It will only be referred to as the LA-200 in this report.



Figure 13. LA200.

The LA200 uses server-side RSSI pattern matching techniques to locate devices or tags and claims the industry's highest performance for accuracy (i.e., claims to locate all devices to room level with accuracy at 99% with 10 meter precision in fewer than 30 seconds. It claims an ability to track up to 2,000 wireless devices without the need for specialized hardware or software on the tracked devices.

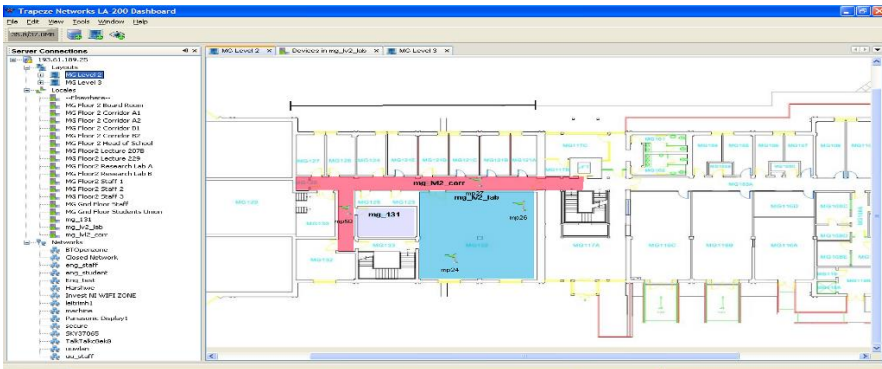
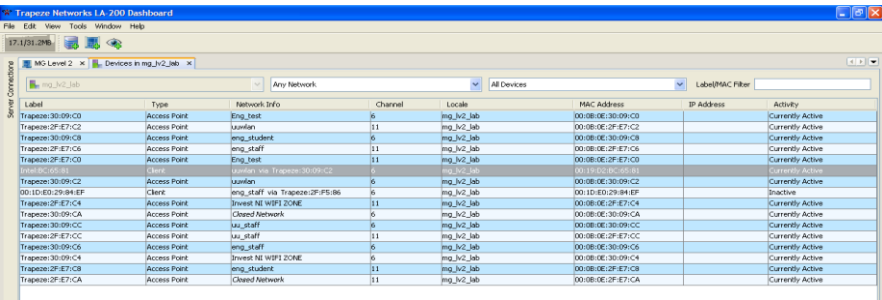


Figure 14. Trapeze Dashboard for the LA-200.

The LA200 is shipped with a dashboard application (see Figure 14) which allows the viewing of real-time movement of WiFi devices, people, and asset tags on each floor. It comes also with some scripting examples for the API which enables custom applications and business-process integration with location services. The system is also able to store location history for each tracked device for up to 30 days. The Trapeze Networks Location Appliance provides the ability in real time to quickly and accurately locate and track assets, people or practically anything that is attached to an existing Wi-Fi network. It provides the capability to run custom or enterprise applications that

require the ability to provide location sensitive content or security and track assets. The LA-200 is Wi-Fi compliant which allows the system to use the active Wi-Fi tags from other companies such as, AeroScout, Ekahau, Newbury Networks and Pango. A summary of devices connected can be viewed through the Dashboard and options are available to view devices by server, locale or network as shown in Figure 15. An image file containing a scaled plan of a building can be imported into the system and different locales added by the user.



Label	Type	Network Info	Channel	Locale	MAC Address	IP Address	Activity
Trapeze-30-09-C0	Access Point	Eng_test	6	mg_h2_jab	00-08-0E-30-09-C0		Currently Active
Trapeze-2F-E7-C2	Access Point	uunlan	11	mg_h2_jab	00-08-0E-2F-E7-C2		Currently Active
Trapeze-30-09-C8	Access Point	mg_student	6	mg_h2_jab	00-08-0E-30-09-C8		Currently Active
Trapeze-2F-E7-C8	Access Point	mg_staff	11	mg_h2_jab	00-08-0E-2F-E7-C8		Currently Active
Trapeze-2F-E7-C0	Access Point	Eng_test	11	mg_h2_jab	00-08-0E-2F-E7-C0		Currently Active
Trapeze-30-09-C2	Access Point	uunlan	6	mg_h2_jab	00-08-0E-30-09-C2		Currently Active
00-1D-E0-29-84-EF	Client	mg_staff via Trapeze-2F-F5-86	6	mg_h2_jab	00-1D-E0-29-84-EF		Inactive
Trapeze-2F-E7-C4	Access Point	Invest NE WSFI ZONE	11	mg_h2_jab	00-08-0E-2F-E7-C4		Currently Active
Trapeze-30-09-C4	Access Point	Chased Network	6	mg_h2_jab	00-08-0E-30-09-C4		Currently Active
Trapeze-30-09-C6	Access Point	uunlan	6	mg_h2_jab	00-08-0E-30-09-C6		Currently Active
Trapeze-2F-E7-C6	Access Point	mg_staff	11	mg_h2_jab	00-08-0E-2F-E7-C6		Currently Active
Trapeze-30-09-C8	Access Point	mg_staff	6	mg_h2_jab	00-08-0E-30-09-C8		Currently Active
Trapeze-30-09-C4	Access Point	Invest NE WSFI ZONE	6	mg_h2_jab	00-08-0E-30-09-C4		Currently Active
Trapeze-2F-E7-C8	Access Point	mg_student	11	mg_h2_jab	00-08-0E-2F-E7-C8		Currently Active
Trapeze-2F-E7-C4	Access Point	Chased Network	11	mg_h2_jab	00-08-0E-2F-E7-C4		Currently Active

Figure 15. Trapeze Dashboard Device List Screen Appliance.

The light blue area in Figure 16 represents the ‘MG122 locale. After the locales have been identified the actual physical fingerprinting is done. The points where fingerprints have been taken are represented by a green flag as shown in Figure 16.

The Dashboard application summary screen displays information on the system, network and devices visible to the network. By clicking on a particular device from the device list screen the system will display the recent activity of the tag. A MAC address and date range for a given time period of up to thirty days can be entered here and the system will display the location of that tag for the given date range. The system will also display the fingerprint information it holds for a particular fingerprint point. For example in Figure 17 fingerprint ‘mp24’ is shown. Figure 17 shows a screenshot from the web based Dashboard fingerprint section which shows a fingerprint location in a graphical representation using green and purple bars.



Figure 16. Dashboard fingerprint locations.

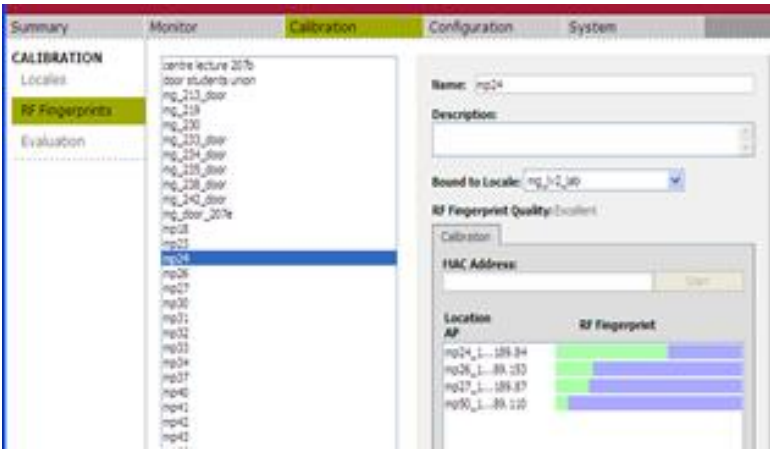


Figure 17. LA200 Web Configuration screenshot.

5.3. AeroScout

Aeroscout utilise standard WiFi networks to track the location, condition and status of assets both personnel and equipment. The use of standard WiFi networks helps to reduce installation costs. Aeroscout has attracted many Fortune 500 companies with its use of standard WiFi system meaning a lower overall COO and a higher ROI. Mounted exciters and choke points are used to

localise the active tags. There are two types of exciters in the system, the mounted exciter (Figure 18) and the choke point exciter (Figure 20). The mounted exciter will provide definitive location of people with the tag and provides the ability to make the LED in the tag (Figure 19) flash to determine its location in a heavily populated area. The choke point is set to scan for tags passing through every 200 milliseconds.



Figure 18. Mounted Exciter.



Figure 19. Active RFID Tag.



Figure 20. Choke Point Exciter.

The choke point enables large amounts of data to be acquired in a short space of time. It is particularly effective at doorways and in corridors. Tags that will be used with the system are Aeroscout TAG-2000. These tags have an outdoor range of 600m and indoors range of 180m. The tags operate on 802.11b/g @ 2.4ghz and have clear channel sensing to avoid interference with wireless networks. The transmission interval can be set between 128msec to 3.5 hours. The tags have 3.6 volts lithium ½ AA battery which is replaceable. The battery may last up to 4 years dependant on use. The mounted exciters are EX-3210. These exciters have a working range of 20cm to 3m. The power input is 12volts over POE (802.3af) hence the need for the POE switches. Choke point exciters are EX-2000B. These have a range of 50cm to 6m. They have an input of 24VDC POE (802.3af), again, as with the EX3210 these must be powered by the POE switches.

5.4. Motorola Proximity Awareness and Analytics

Motorola Solutions' Proximity Awareness and Analytics software module allows enterprises to detect, analyze and act on location information from Wi-Fi devices. Their solution enables the identification of customer proximity and supports interaction using rule-based push-to-deliver benefits like personalized messages, coupons or assistance. Their Analytical component provides customer insight with detailed statistics about customer activity (per store visit time, repeat customers, total customers in store, demographic profiles) and supporting programs to improve the customer experience. It allows target zone definition which supports capabilities like tailored assistance or zone-specific offers and allows tracking of Wi-Fi device location and path over time. This supports optimization of an enterprise environment, a retail store for example, to minimize congestion and improve product placement. It comes with an open API allows sharing of analytics data with third-party applications, creating a vendor-agnostic environment for development and delivery of location-based services which add value, improve service and build loyalty. The benefits are that the existing Wi-Fi infrastructure does not need replacing. The software based capability uses information from the existing WLAN network.

5.5. Insiteo

Insiteo provide an indoor location solution for smartphones that leverages the Aruba Wi-Fi beacons for position information. The smartphones collect position information from the Wi-Fi network and forward it to the hosted server, which then calculates the user's position. The central server can interface with added-value applications, which are then pushed to the user. For example, customer retention can be enhanced by pushing coupons for services to patrons that approach exits, or patrons can be guided to vendors that pay for enhanced exposure. Insiteo also delivers indoor geo-location services for smartphones. The solution combines indoor position location via Wi-Fi with a mobile application to locate the user's position and nearby points of interest – or directions to those locations – on a map. Target markets include large public venues such as shopping centres, airports, metro and train stations, convention centres, museums, and hotels.

6. BLUETOOTH TRACKING SOLUTIONS

There are a number of technologies available that use both Bluetooth to augment Local Positioning Systems. Most Bluetooth systems similar to WiFi and active RFID systems are made up of three major components the positioning server, the access points and the tags. The tags can be either special vendor specific Bluetooth tags or any Bluetooth equipped device such as a mobile phone. Some systems claim up to ninety five percent reliability accuracy to around two meters. Bluetooth tags are detected by several methods namely, using RSSI to triangulate the location, putting an access point in every room and using the nearest AP to the tag to indicate its location.

6.1. BlipTrack

BLIP Systems offer a range of solutions for tracking and mobile marketing. The BlipTrack solution brings real-time information about movement to achieve transparency, improved documentation and efficiency of daily management operations. They have installed it in a number of European airports. The Blip System, based on the Bluetooth radio technology, is able to track mobile units (e.g., phones) that have Bluetooth and are set to visible mode. It performs tracking by a number of Blip nodes, each of which is part of

a *Blip zone*; whenever a Blip node detects the radio signal from a Bluetooth unit appearing or disappearing, it sends a signal to applications using the Blip System. Applications can then provide location aware services, based on the zone information thus captured. A Blip zone is the area in which a mobile unit will be detected by a Blip node in this zone. The size of a Blip zone is determined by the signal strength with which the Blip nodes detect the mobile units, and can be changed by adjusting it using a system administration tool. Bluetooth addresses and other metadata. Bluetooth devices are very common in mobile phones, PDAs and laptops. Bluetooth transceivers are available in three classes, defining the maximum power output and thereby range of the signal. A class 1 transceiver has the highest power output and with it the longest range of up to 100 meters. Class 2 and 3 devices have a range of up to 10 meters and 1 meter, respectively. The range of class 2 and 3 devices can be slightly extended due to higher sensitivity by using class 1 access points. Most mobile phones come with Bluetooth modules, meaning that the best case penetration is nearly as high as for TMSI (used by Path Intelligence), but because they have to be activated to be seen, there is a moderate penetration rate when using this technology for tracking. BLIPs system queries for unique devices once per second. The Bluetooth system provided by BLIP is ready for communicating location and context specific content on the network. The range of a typical Bluetooth tracking system however is only around 20-30 meters. The short range requires many access points to be installed in order to cover the area. If the system should be upgraded to support triangulation, many more access points would be required. Due to the fact that most Bluetooth transceivers in mobile devices are class 2 transceivers and the signal output of different vendor Bluetooth modules varies greatly, their range is limited to approximately 10-30 meters with a precision of about 5-10 meters.

7. INDOOR MAP BASED SYSTEMS

A number of indoor solutions based on cell-tower triangulation or Wi-Fi network databases have appeared in recent years, the newest being one from Point Inside. By combining a proprietary location solution with indoor maps of major malls and airports, these systems offer guidance in places where Google Maps and others simply cannot. It is a rapidly growing area of localisation. Google, Yahoo, Microsoft, Nokia and a few standalone portable navigation device makers are well-entrenched with their efforts to dominate the indoor navigation space. An overview is provided here of the recent offerings in

creating indoor maps for large public spaces. Some of these systems use existing WiFi infrastructures to triangulate position. The key difference between these systems and the ones outlined elsewhere such as Ekahau and Trapeze is that you are reliant on the company or other users in having mapped the location beforehand. They are however very powerful and cheaper to utilise although there will be licensing costs to build your own apps with integrate with their API. Google and Apple are both in the positioning game and have both recently come into the news for collecting our personal data to improve their location abilities. They are gathering location information to build massive databases capable of pinpointing people's locations via their mobile phones. Generally, when companies have collected data from users it has been from personal computers. The data gathered through this medium can be tied only to a city or area code. The rise of internet-enabled mobile phones allows the collection of user data that is much more personal and can be tied to locations on a more granular scale.

7.1. Point Inside

Point Inside⁶ provide maps of indoor destinations for use with its mobile smartphone indoor positioning applications. It has just released an iPhone product. It is partnering with Meijer stores for a pilot program that will enable shoppers to “see the location of more than 100,000 items in a retail supercenter using their smartphones.” “Point Inside’s platform facilitates the aggregation of destination-specific content, adding the critical context of *location* to each item. This marrying of ‘*what*’ to ‘*where*’ enables shoppers to quickly find what they need at their destinations, whether it’s a specific department, service, like a fitting room or restroom, or even an individual product on the shelf.” If a location has been mapped by its software then it provides directions on a smartphone to easily navigate say from the GameStop to Lenscrafters. Point Inside says it now has maps covering over 100,000 stores, gates, kiosks, restrooms, elevators, and escalators in U.S. and Canadian malls and airports. And much like Foursquare, it offers retailers a geo-based way to provide promotions to a nearby consumer audience. Point Inside is actively soliciting for venues to use the Point Inside “Indoor Smart Map” technology. Malls and airports are just the lowest-hanging fruit for Point Inside. If the company can build up a large enough base of venue directories to mash up with its location

⁶ <http://www.pointinside.com/>.

solution — say, large office properties or sports venues — it could own the indoor navigation space. Point Inside is attempting to transform the shopping experience by enabling retailers to engage proactively with customers through their smartphones at every point along the purchase path. Point Inside's unique, patent-pending micro-location and indoor mapping technologies expand and enhance the value of smartphone apps by bringing location-based services into the store, letting retailers know which section and aisle their customers are in. Combined with understanding of the customers' purchase intents from the shopping list, purchase history and Point Inside's engagement technology, retailers can now connect customers with highly relevant messages while they are inside the store shopping. Combined with understanding of the customers' purchase intents from the shopping list, purchase history and Point Inside's engagement technology, retailers can now connect customers with relevant messages while they are inside shopping malls.

7.2. Google Indoor Mapping

Google also wants to map notable indoor locations like airports and retail stores to provide floor by floor navigation to users. It has just released a new version of Maps for Android that is fine tuned for indoor navigation. Google Maps is launching indoor navigation⁷ with floor plans for a few dozen airports and retail locations in the US and Japan. The list of supported locations in the States include Mall of America, IKEA, The Home Depot, select Macy's and Bloomingdale's. The newly added indoor maps do not offer turn-by-turn navigation but the provided layouts should help usher visitors along to the nearest bathroom, clothing shop or elevator. All of the positioning information is culled from the same set of data (including GPS) used for "My Location." It has even been optimized to detect movement along the z-axis so that with a feature called "Automatic Floor Detection" - it can keep track of your progress as you move about from escalator to escalator. Google's is also endeavouring to extend its indoor reach, opening up its mapping inventory with a self-service tool that will allow business owners to upload floor plans directly to Maps. Business owners to manually add floor plans to its map database at

⁷ <https://www.google.com/maps/about/partners/indoormaps/>.

maps.google.com/floorplans. A full list of buildings with Indoor Maps coverage is available at Google's Help Center.⁸



Figure 21. Google Indoor Mapping.

Google has just recently launched a crowd-sourcing Android app, the Google Maps Floorplan Marker, to allow users (i.e., business owners) to provide feedback about how accurate the Google Indoor Location service is for their venue. The app guides the user where to go inside the venue and do some WiFi scanning (and even Cell ID sniffing). This process collects the necessary data that Google needs to improve its indoor location service. Google is hoping these business users will help Google calibrate the Z-level (floor level) positioning challenge.

7.3. Wifarer

Wifarer⁹ is another company offering an indoor positioning technology app to steer users through large venues such as malls, airports, convention centers and museums. The free app, available for iPhone and Android users,

⁸ <http://www.google.com/support/gmm/bin/answer.py?hl=en&answer=1685827&topic=1685871>

⁹ <http://www.wifarer.com/>.

has an interactive location directory to help users find a specific store in the mall or terminal at the airport. Wifarer claim to pinpoint the user's location within 4-and-a-half feet, and draws a path to the location the users wants to go. The big hook here is the app will also show promotions and sales based on a user's location — providing advertisers a new way to catch an audience. Individual stores in a mall can control the ads customers are viewing. Once a customers steps in the store, the brand has complete control over what the app user sees. The store could provide inventory and directions around the store if they wanted. Most stores will likely use this control to target customers with advertising specific to their store. Interestingly, Wifarer is creating its indoor positioning systems by using each venue's pre-existing Wi-Fi, and then creating radio frequency fingerprints to infer users' locations. All locations at present are in the US and Canada.



Figure 22. Wifarer screens.

Wifarer's Indoor Positioning System still not disclosed but it seems to add features from the phone to supplement standard WiFi positioning. Otherwise it could not claim to outperform current positioning technologies by refining a location accuracy to an average of 1.3 metres. This works by firstly downloading the app at the Android Store and installing it on a smartphone. Next you need to get a floor plan of the location. Wifarer will then pinpoint a visitors location on the smartphone screen map. It automatically updates location on the map as they move. Its online management system allow you to

edit and update information in real time, which also appears on visitors smartphones instantly. Wifarer provides real time venue analytics. It anonymously gather visitors' smartphone data to produce heat maps and analytics. It offers insights into visitors behaviour in terms of where they go, how long they stay as well as their search and page view data regarding products. Users just need to download it once for free and can use it in any Wifarer certified venues in the world.

7.4. SenionLab

SenionLab¹⁰ seeks to improve navigation capabilities in environments where GPS systems are unavailable. It is intended to run on mobile phone platforms relying on sensors available in the phone. It is a cost efficient and easy to use, since it does not require that the buildings are equipped with infrastructure to determine the user's position. NavIndoors for iPhone is a pedestrian indoor navigation system for indoor environments such as shopping malls (see Figure 23). NavIndoors for iPhone is delivered as a separate software module together with a fully documented Application Programming Interface (API) that can be integrated into your location-based iPhone, iPad or iTouch application. It is fully compatible with iPhone 3GS, iPhone 4, iPad, iPad2 and iTouch. Navigation and positioning is based only on the sensors available on the mobile device. No additional hardware is required besides the mobile device for navigation and positioning.

NavIndoors for Android is also available with enhanced WiFi signal-based positioning capabilities for Android mobile phones. It is fully compatible with most of the Android based smart phones and comes with a documented Application Programming Interface (API) for easy integration with third-party location based application. Both apps allow users to be monitored in real time and user behavior related charts can be automatically extracted. The aggregation of shopper paths for a specified period of time produces a "PathDensity" map identifying relative shopper traffic throughout the store.

¹⁰ <https://senion.com/>.

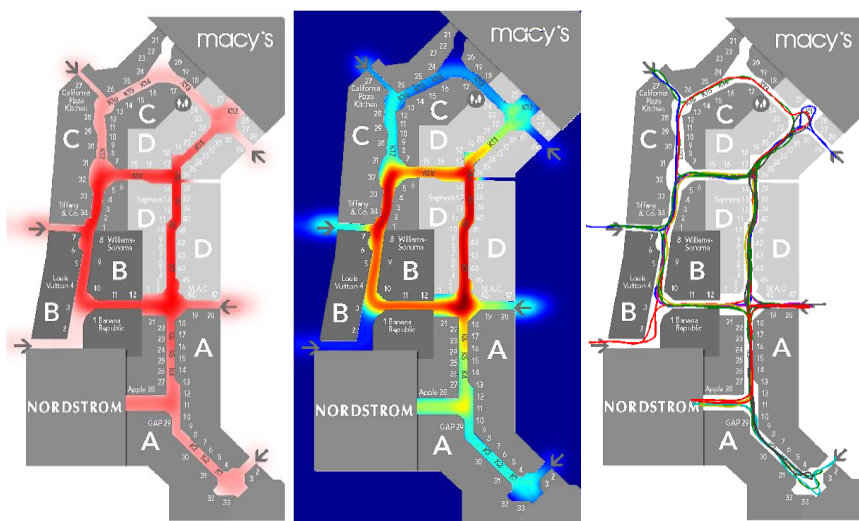


Figure 23. SenionLab Maps.

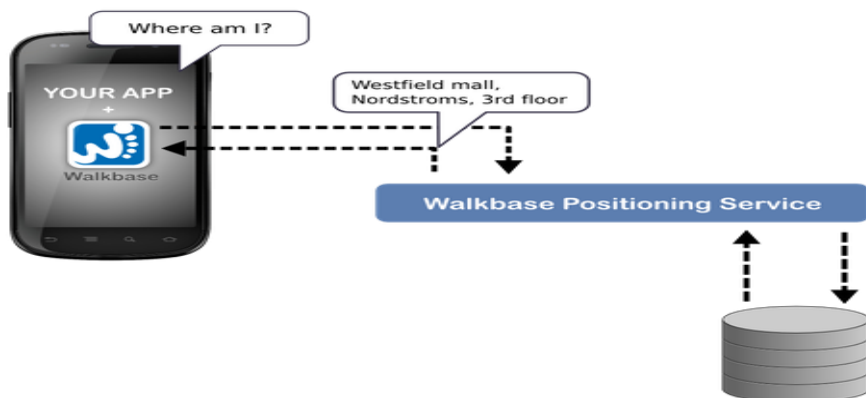


Figure 24. Walkbase.

7.5. Walkbase

Walkbase¹¹ have offices in Finland and the US. They allow developers to take measurements inside a building via the built-in WiFi chip on Android devices and upload the data to their servers. Then via an API call, the app will

¹¹ <http://www.walkbase.com/>.

compare its position to an online database of points of interest (POIs), which could be existing services like Foursquare or Factual or a proprietary database, and report back when it identifies that the device is in close proximity to one of the POIs. Rather than returning actual GPS coordinates, it returns a contextual message such as “inside the Wesfield Mall, Nordstroms, 3rd Floor.” It is difficult however to imagine how you would then display that information on a map. It is also Android only however the API is free to sign up for.

Walkbase offers a library that you can integrate with your mobile code to add indoor positioning capabilities for an Android application. The library provides developers with access to much improved indoor positioning that drives local room-level context as compared to what is possible with GPS only techniques. The library makes use of the built-in Wi-Fi radio chip most modern smartphones have. Measurements are performed using the chip and the obtained results are then sent to our servers. Instead of a physical location with longitude and latitude, the Walkbase Positioning Engine gives you a logical location (e.g., Starbucks, Radioshack) which is much more relevant and meaningful for most LBS apps. Once you have deployed an application with the Walkbase library embedded, you will immediately be able to see on a map where people are using your application. This will allow you to detect popular locations which in turn can help you refine the context. They say they are continuously developing analytics products in collaboration with the developer community. Walkbase allows registered developers to upload and maintain their proprietary location database at their servers. This ensures your location data works smoothly with the Walkbase library. In most use cases, it is their recommendation to use existing POI services like Foursquare or Factual. They, however, offer this option to support use cases where refined proprietary POI database is needed. A mobile application can still access proprietary POI database through their REST-interface. Walkbase Positioning Engine is free for non-funded start-ups and non-profits. Email is required to register. The service is free to try for commercial use as long as the total number of API calls stays under 50k/month. Once the total amount of calls per month exceeds 50,000, you will move to a monthly plan starting at \$40 for up to 200K/month.

7.6. Indoor Atlas

IndoorAtlas¹² provide a system that utilizes the anomalies of ambient magnetic fields for indoor positioning. IndoorAtlas offers a complete software toolbox for adding and managing floor plans, collecting data to create magnetic field maps, and an API to use IndoorAtlas' location service for mobile applications. IndoorAtlas' core technology is independent of external hardware infrastructures (such as radio access points) and is able to pinpoint the location inside a building within 0.1 - 2.0 meters. IndoorAtlas' cloud-based location service is illustrated in Figure 25. The application uses the IndoorAtlas API to communicate with the location service. The API sends processed sensor data to the location service, which computes the current location estimate and delivers the estimate back to the application's event listener method through the API. The location service connects to the map database, which hosts the magnetic field data collected from the building using the IndoorAtlas Map Creator application. The IndoorAtlas location service has been built on the top of Microsoft's Windows Azure cloud platform. IndoorAtlas' core technology is a software-only location system that requires, from the hardware point of view, only a smartphone with built-in sensors (no external hardware infrastructures, such as radio access points, are needed). They claim the accuracy in IndoorAtlas' technology in modern buildings ranges from 0.1 meter to 2 meters.

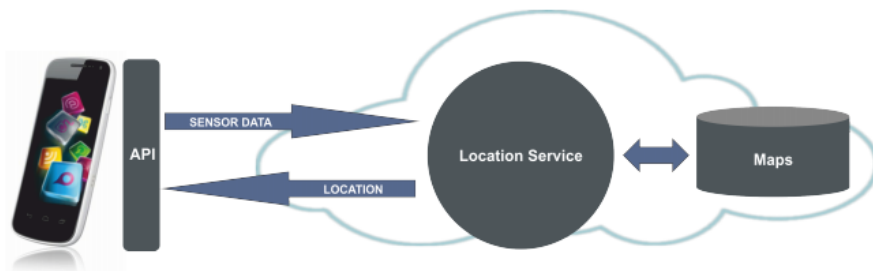


Figure 25. Indoor Atlas Cloud Location Service.

Before using the IndoorAtlas' location technology, a magnetic field map must be generated from the part of the building where the location service is going to be used. IndoorAtlas offers a complete software solution in adding and managing floor plans, collecting magnetic field data and using the location

¹² <http://www.indooratlas.com/>.

service API. The process of creating location awareness inside a building starts by adding a floor plan image to IndoorAtlas Maps. The Floor Plans web application is used then to align floor plans with corresponding geographic coordinates, enabling the use of the geographic coordinate system in application software. After opening the floor plan in MapCreator, the user marks the planned route (typically a straight line or a curved path) on the smartphone screen. The user walks along the path and records the magnetic field data. The Map Creator application connects with IndoorAtlas Maps, which generates the magnetic field map that will be used for indoor positioning. Next, a location aware application can begin using the IndoorAtlas API for accurate positioning.

A related technology is from Pole Star¹³ based in France who have developed their indoor positioning system based on existing WiFi infrastructure on-site. Their model appears to be to sell the solution to site-owners, allowing them to map their buildings and then make the information available to apps that implement their system. The offering is a complete service of coming out and taking readings round the building, creating a 3d map and preparing the whole thing to be inserted into an app.

7.7. CSR

Other players on the edge include CSR¹⁴ which are a UK technology company who specialise in wireless hardware. Chipsets they have designed are incorporated into thousands of consumer electronics products including cars, laptops, games consoles, digital cameras and, of course, mobile phones. Whilst traditionally focusing on such things as Bluetooth and audio streaming, they have recently made advances in the indoor location world, demoing their latest technology at Mobile World Congress in Barcelona. Their approach centres around a new chip which gathers real-time information not only from GPS signals, but also a whole range of other satellite and radio signals along with device sensors to such as accelerometers and gyroscopes. This data is then combined with external data such as mapping and WiFi hotspot location databases to come up with a form of “dead reckoning,” sufficient for the device to calculate its position indoors. Certainly one to watch as if these chips start to make it into the next wave of smartphones, and work as well as CSR

¹³ <http://www.polestar.eu/en/>.

¹⁴ <http://www.csr.com/>.

say they do, indoor location could quickly go mainstream. However, their systems are not something that can be leveraged right now for location estimation in retail.

8. MISCELLANEOUS TRACKING SOLUTIONS

This section describes some other widely used indoor or local area positioning systems. Each of these has their own advantages and disadvantages and while in widespread use, they cannot solve all problems.

8.1. Ultra-Wideband

Ubisense¹⁵ are a UK Company and one of the first to exploit Ultra-Wide Band for Real Time Location System (RTLS). Ultra wideband is precisely timed short bursts of RF energy to provide accurate triangulation of the position of the transmitting tag. Ultra-wideband (UWB) is a radio technology which can be used at very low power levels for short-range high-bandwidth communications (>500 MHz) by using a large portion of the radio spectrum (Knox et al., 2009). UWB transmissions send information by generating radio energy at specific time instants and occupying large bandwidth thus enabling a pulse-position or time-modulation. The information can also be modulated on UWB pulses by encoding the polarity of the pulse, its amplitude, and/or by using orthogonal pulses. Unlike conventional RFID systems, which operate on single bands of the radio spectrum, UWB transmits a signal over multiple bands simultaneously, from 3.1 GHz to 10.6 GHz.

In a UWB location system, small active tags are attached to the objects to be located, or are carried by personnel (Figure 27). The signals emitted by these tags are detected by a network of receivers surrounding the area. By detecting the signal at two or more receivers, the 3D position of the tag can be found. It is worth noting that two algorithms are employed. One calculates the time difference of arrival of a signal at two different readers and the other calculates the angle of arrival of the signal. The Ubisense RTLS solution utilizes battery-operated radio tags and a cellular locating system to detect the presence and location of the tags. The Ubisense Series 7000 sensor is a precision measuring instrument containing an array of antennas and ultra-

¹⁵ <https://ubisense.net/en>.

wideband (UWB) radio receivers. The sensors calculate the location of the tags based on reception of the detected UWB signals transmitted from Ubitags. Each sensor independently determines both the azimuth and elevation Angle of Arrival (AOA) of the UWB signal, providing a bearing to each tag. The Time Difference of Arrival (TDOA) information is determined between pairs of sensors connected with a timing cable. Sensors are administered remotely using standard Ethernet protocols for their communication and configuration. They work in standard wired and wireless environments, using networking infrastructures, such as 802.11 access points, Ethernet switches and CAT5 structured network cabling for communication between sensors and servers. The locating system is usually deployed as a matrix of sensors that are installed at a spacing of anywhere from 50 to 1000 feet depending on the site layout. These sensors determine the locations of the radio tags. Ubisense consists of *Tags* - designed to be mounted on assets or to be worn by a person; *Location Engine* software to install and tune a Ubisense sensor network and track tags in real time, through a series of configuration wizards and the *Location Platform* software which provides persistent storage and distribution of real-time location events for multiple clients in conjunction with real-time monitoring and notification of user-specified spatial interactions between objects. Ubisense claim that their systems (see Figure 26) require fewer readers than other systems which implement only the time-difference algorithm. Readers receive data from the tags (max distance 160 m) and send location updates through the Ubisense Smart Space software platform. Ubisense creates sensor cells each requiring a minimum of four sensors. It claims to achieve scalability to 1000's of sensors using low-cost off-the-shelf servers over Ethernet. The standard range covered by a cell is less than <160m and typically the range between a tag and a receiver is 10m-30m. Key limiting factors include the level of building obstruction between the two. Ubisense claim an achievable range accuracy of <15cm even within a complex indoor environment. Accuracy such as this would allow location aware applications to pinpoint particular devices being used in a room.

Ultra wide band systems work well indoors as the short bursts of radio pulses emitted from UWB tags are easier to filter from multipath reflections than conventional RF signals, however metallic and liquid materials still cause some signal interference. Ubisense however claim that this can be overcome through the strategic placement of sensors and UWB also possesses the ability to determine "time of flight" of the direct path of the radio transmission between the transmitter and receiver at various frequencies which helps overcome multipath propagation. UWB pulses are very short in space (less

than 60 cm for a 500 MHz wide pulse and less than 23 cm for a 1.3 GHz bandwidth pulse) therefore most signal reflections do not overlap the original pulse, and thus the traditional multipath fading of narrow band signals does not exist. Ubisense uses active tags named Ubitags which are manufactured by C-MAC and designed to be easily mounted on the side of vehicles and assets or worn by a person (Figure 27). Their update Rate is 0.01Hz – 20Hz. These tags have a unique 32-bit identifier and broadcast a beacon including their location as often as 10 times a second (essential for tracking people walking quickly through a monitored area) or as infrequently as once every few minutes. This rate can be changed dynamically over a wireless link while the system is running and in response to individual tag behaviour. If a tag is moving quickly, the update rate of its beacon can be programmed to increase, and if a tag is stationary, the update rate can be programmed to decrease. This feature is an attempt to conserve battery life. Ubitags are designed to last for approximately five years in typical use. The Ubitags can store up to 200 bytes of data, four of which are used to store the ID. Tag data can be changed over the network and individual tags can be paged. The Compact Tag is a small, rugged dust and water resistant device specifically designed for use in harsh industrial environments.



Figure 26. Ubisense out of the box contents.



Figure 27. Slim and Compaq tags.

8.2. Ultrasound Positioning

Ultrasound signals may be used as a method of positioning which works at room level accuracy. In nature bats use ultrasound signals to navigate and hunt, this has inspired the design of RTLS that work in a similar manner. Ultrasound signals have a frequency above the human hearing limit (approx. 20 KHz) which enables them to be used without people noticing. Commonly these systems consist of receivers and tags. The receivers are placed at known locations and are simply microphone sensors. The tags are inexpensive and emit an ultrasound pulse which is heard by the receivers. As these signals travel at the speed of sound (343 m/s), Time of Arrival (TOA) to the various sensors may be used and position calculated from this. The Active Bat positioning system, using ultrasound was designed by AT&T's Cambridge Research centre in the late 90's and was highly successful. While accuracy levels in the order of cm were achieved for 95% of estimates, to achieve this, 720 receivers fixed to the ceiling were required to cover a building of 1000 m². Thus, the system had low scalability and would not be suitable of widespread use. A more recent ultrasound RTLS is that provided by Sonitor Technologies¹⁶. A feature of this is that the ultrasound signals are confined to one room and do not pass through walls. These systems need to be combined with RF technology to synchronise and coordinate the receivers with one another. While ultrasound is much less expensive than using IR technology, its accuracy is of the order of centimetre as compared to millimetre for IR. A building wide implementation of an ultrasound positioning system would be

¹⁶ <http://www.sonitor.com/>.

extremely time consuming and complex and would therefore have very high overhead associated with it. It would however show how centimetre level accuracy is available if cost is not an issue. Ultrasound systems do suffer from interference for simple noise sources such as crisp packets or jingling keys.

8.3. Wireless Sensor Networks – Zigbee

Sensors are commonly used as a means of detecting an environmental or physical condition such as sound, light, pressure or temperature. When a large number of sensors are connected together for means of communication via RF a Wireless Sensor Network (WSN) is formed. Zigbee is a technology standard based on 802.15.4 which allows for control and communication in WSNs. Each sensor in the network is called a node. The nodes form a mesh network and due to the self forming and self healing architecture of WSNs it may be used as an infrastructure for positioning. A Zigbee tag may be localised upon entering the network by taking advantage of the way the network operates. Zigbee routers and tags, periodically or on demand, take TOA values from the signals received from one another. This information may be used by a Zigbee positioning engine to calculate the position of the mobile Zigbee device, given that the positions of the other Zigbee nodes (including routers) have already been calculated relative to one another. Many of the advantages of using Zigbee are similar to those of UWB systems as the underlying technology is the same. However, their best feature, which is unique to WSNs, is their high fault tolerance. If a network node fails, the network reconfigures and works without it in much the same way the internet does. Despite this significant strength however WSNs suffer from the same weaknesses that all RF technologies do like interference and security issues. The range is short and many nodes are required to give decent accuracy levels. Similarly to many of these proprietary technologies, the installation of a new RF network is unlikely to be popular with I.T. staff and leads to large roll out costs. Also, these new networks need to be troubleshot and maintained by a member of staff. These are costs that may not be apparent when first deploying an RTLS.

8.4. Infra-RED (IR) Tracking Solutions

Infra-Red (IR) based systems usually operate in one room or an open area. This is because the short range of the IR signals does not travel through walls

or doors. These systems usually need a direct Line of Sight (LOS) to the target device. Infrared (IR) systems operate by either the user taking some action to highlight their presence to a sensor or the light pulses worn by a user are detected by sensors. With IR technology, due to the fact that light cannot pass through walls, a sensor is required in every room, behind every blocking wall and in every corridor of a facility using this technology. These IR positioning systems work in a similar manner to RFID systems. Each user wears a tag that periodically emits a beacon containing some unique information about that tag and hence the person carrying the tag. IR sensors on the walls or ceilings detect the tags and give the location. This is usually a network-based positioning system. Olivetti research developed one of the first indoor positioning systems (ActiveBadge) in the early 90's using this technology. There are very few modern systems using infra-red tracking currently. It has been superseded by the other technologies mentioned earlier.

8.5. Camera Based

By far the best localisation method used by humans is using vision. By simply directing our eyes at a target (within LOS) we can instantly work out where it is and can make a fairly good estimate of the distance from ourselves to the target. Despite the high quality video technology and the powerful computers available today these operations, in general, cannot be performed with the same ease by an artificial vision system. Nevertheless, vision based positioning systems are very powerful if certain criteria are met. By using one or more cameras trained on an area, it is possible to track the location of a person or thing if (a) the computer knows what to look for, (b) conditions for viewing are suitable and (c) the computing engine has enough processing power to perform the complex analysis required for identification and tracking. A problem scenario would be trying to get a computer to spot a previously known person in a crowd who had changed their appearance somewhat. A beard or dyed hair, substantially changes the look of a person in the computers eyes, whereas for humans, the same person would be easily recognisable. Despite these difficulties, vision based RTLS are rapidly evolving and improving thanks to artificial intelligence techniques and more powerful computing engines. One of the greatest benefits of vision systems is that no tag is necessary. In this way localisation of a person or object doesn't require their cooperation. Locating engines look for specific patterns and can monitor an object in LOS over a large area and over a long timescale given

enough processing power. The United Kingdom is reported as having the highest per capita number of surveillance cameras of any nation in the world and is using vision based positioning systems to do it. Setting up an accurate vision based RTLS can be expensive, at least one camera is required per room (preferably more). High network bandwidth is required to transfer a stream of high resolution video between the network of cameras and the positioning engine, which must be a high end computer. These requirements mean that vision based positioning is not a viable solution where affordable ubiquitous localisation is required. If reductions in cost of vision systems can be made, then their readily understandable output and the fact that they do not require tags, could make vision based RTLS a very attractive option. Some of the more recent camera based systems are included here simply for completeness.

Prism¹⁷ is a cloud-based service that allows business owners to bring video feeds online, capture images from these feeds and share this data with consumers and the public. Most stores and restaurants have surveillance videos running 24-hours a day. Unless there is a theft or another crime that takes place in the establishment, this massive amount of surveillance video is unused. That's where Prism comes in. A business can download free software that detects cameras or video on a network and showcases a number of images of the space to the business. Similar to the way you can pull images from videos using a video editing software, Prism pulls relevant images of your establishment and builds insightful visualizations from these photos, while protecting customer privacy. For example, Prism can extract a visualization that will show the path that people are taking in a store (which can help owners gain insight into the performance of design or display), a heat map of bodies, a photo without any people in the store and more. Owners can gain insight about the performance of the store and the flow at certain times. Prism allows users to share and syndicate these photos directly from their platform to a business' Facebook page, Twitter stream, website and Yelp profile. Users can compare web analytics, social media traffic and more with traffic documented by the video images. For example, the startup says that a store could see how much foot and web traffic a Groupon or other daily deal could bring in and at what times the traffic is the greatest. Basically, Prism will be able to mashup data like Google analytics with the intelligence from the actual traffic in the store. The software integrates with point of sale systems as well. Another use case is the ability to post realtime pictures of how crowded a restaurant or bar is in realtime. So a restaurant could post pictures of how

¹⁷ <https://prism.com/>.

empty or full the space is to Twitter or Facebook so potential customers can see how busy an establishment is.

CONCLUSION

Common approaches to determining location were discussed. GPS (Global Positioning System) can show one's position on the Earth mainly in outdoor locations. GPS satellites, 24 in all, orbit at 11,000 nautical miles and float in geosynchronous orbit above the Earth. They are continuously monitored by ground stations located worldwide. GPS Receivers are cheap but the downside is that you need a line of sight to a satellite hence you need to be outdoors. Cellular Triangulation is a process by which the location of a radio transmitter can be determined by measuring either the radial distance, or the direction, of the received signal from 2 or 3 different points. The distance is determined by measuring the relative time delays in signals from the mobile set to 3 base stations. Most people carry mobile phones, however in reality most readings are quite coarse and can only be relied on to roughly pinpoint one to a geographical region. Wireless location determination systems consist of radio beacons, databases holding beacon location information and clients which estimate their location from the signal strength measurements. Leaders in the positioning field include Ekahau, Trapeze Networks and Ubisense. It is a useful method as access points now exist in many residential and public buildings but it can be difficult to achieve accurate readings and intense planning/fingerprinting needs to be performed. RFID has seen widespread use across many different applications with the clear majority of these applications only using the data contained in tags within the reader's zone, rather than the location of the tag at any given time. Tags are quite cheap but it is relatively new and the distance for measurements can be quite restrictive. Ultra Wide Band (UWB) is precisely timed by short bursts of RF energy to provide accurate triangulation of the position of the transmitting tag. Since the short time UWB signal is very broad in frequency spread (typically 1 to 2 GHz wide) the system can operate on a very low power output and is robust against interference. It can be accurate to centimetres but deployment can be expensive and many systems only work in limited wide area spaces.

Every location determination technology has its advantages and disadvantages in a number of areas namely; if they are designed to operate inside or outside, how they determine their position internally or via a network connection, their cost, their susceptibility to interference and their location

determination accuracy (Feng and Curran, 2009). This chapter has provided an overview into the various RFID, Mobile, Ultra wideband, Map based and Wi-Fi location determination methods and technologies and their uses and sought to provide an extensive and up-to-date market review of available position-sensing technologies ideally suited for tracking customers in retail environments. It could also be stated that the non-802.11 location tracking systems include ones such as ultra-wideband, active RFID, ultrasound and other RF-based systems for the most part require installation of proprietary and single-purpose antennas, and dedicated staff to deploy, manage and maintain. Some of these technologies such as active RFID, are problematic in certain scenarios because they can introduce possible interference with Wi-Fi networks and critical patient care equipment. 125 kHz chokepoints have been banned by many hospitals around the world because they can interfere with clinical equipment in hospitals and ZigBee can adversely impact a customer's existing Wi-Fi network that is used for primary voice and data communications. These aspects are not to be underestimated and may indeed strengthen the hand of the 802.11 location tracking systems in the future.

To successfully deploy a positioning or tracking system based on 802.11 WLAN, some aspects must be considered and planned carefully such as the number of access points. It is important to note that more access points do not enhance coverage. In relation to this, the locations of access points should be strategic. The distance between two adjacent calibrated locations should not be too large ~ 1-2 meters is fine and each location should have enough calibration samples (e.g., 200 to 300 samples). It can be important to give denser calibration locations to the areas which may be confused with other areas and finally to ensure that during the calibration/fingerprinting process that one walks slowly, stopping regularly for up to 30 seconds for increased accuracy.

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