Indoor Positioning Systems

By Ray Bernard, PSP, CHS-III

SECURITY INDUSTRY ASSOCIATION

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Introduction

This paper reports on modern *indoor positioning system* (IPS) technologies that utilize personal smart mobile devices, or non-personal non-smart mobile devices (object tags and beacons), for purposes of locating and tracking people and objects. The greatest attention is given to technologies that incorporate smartphones. Smartphones are of special interest to IPS manufacturers, because smartphone users are the largest user class for indoor positioning systems.

Examples of smartphone applications are in-store marketing, guided museum tours and hospital visitor way-finding. Systems that utilize smartphones are among the lowest-cost systems, as users bring their own personal equipment. One cloud-based system uses geomagnetic positioning (based on how the Earth's magnetic field is distorted by building structures); it requires no equipment beyond the personal smartphones of end-users that have the IPS application installed.

Indoor positioning capabilities are enabled by many different technologies, and most indoor positioning systems use a combination of technologies to accomplish their function. Some of the technologies are older, but have evolved over time. Some of the technologies were released as products only a few years ago, but are also rapidly evolving. There are hundreds of applications for positioning technologies, each with their own requirements. There is a lot of terminology involved in describing and explaining positioning technologies, and that terminology has also evolved over time. It is a complex picture.

To lessen the confusion and to provide progressive levels of understanding, this paper presents its information in the following order:

- Introduction to indoor positioning
- Business and security applications for indoor positioning
- Design and deployment considerations
- Positioning technologies used in IPS products

Purpose

There are many ways to apply indoor positioning, and many technologies to choose from. Indoor positioning is an area of emerging and evolving technology. This paper presents the most common indoor positioning applications and the types of technologies that enable them in a vendor-neutral manner, although helpful reference is made to a few well-known positioning device brands due to their familiarity. This paper explains the basics of how the indoor positioning technologies work. It provides information about relative accuracy, mobile device battery usage and other system performance factors to help support early IPS planning and preliminary product evaluation.

The purpose of this paper is to provide a basic understanding of indoor positioning applications and their use cases — along with the technologies that enable them — so that security specifiers, security systems providers and security practitioners can understand and productively participate in design, planning and deployment activities for indoor positioning system initiatives.

Growing IPS Adoption

Business applications are the primary driver for IPS adoption, whose purposes include increased revenue generation, reduced operating costs and improved customer satisfaction. The return on investment for business applications easily justifies their cost. The business applications are what drives the rapidly growing rate of IPS technology adoption, and often security applications can use the IPS infrastructure installed. This is easiest to do when security applications are part of the overall discussion right from the beginning.

IPS Security Value

Virtually all indoor positioning systems that use smartphones can be of security and life-safety value. This makes it important for security technology specifiers, security practitioners and security system providers to understand IPS technologies and their capabilities, so that the potential security benefits can be achieved as an integral part of a planned business IPS deployment.

Furthermore, the cost of a building-wide IPS can rarely be justified solely for security and safety reasons, except in cases where existing infrastructure can be utilized. Two technologies likely to enable such exceptions are geomagnetic-based systems and Wi-Fi™-based systems[1]. Geomagnetic applications do not require any infrastructure to be added to the building. In some cases, the number and locations of existing Wi-Fi access points are already sufficient to support IPS functionality; in other cases, improving the access point density serves to make the Wi-Fi network more robust, in addition to enabling IPS.

Multi-Technology IPS

Most IPS systems use a combination of technologies, because each technology has its own strengths and weaknesses. Thus, there will be some cases where a small amount of a second IPS technology will be needed to utilize existing infrastructure for an IPS. Regarding infrastructure reuse, in most cases the benefits of adding security capabilities into a larger IPS project justify the incremental cost for the security applications.

Smartphones and IPS

Smartphones have become a central part of everyday living, and making phone calls per se is now the smallest part of their functional use — about 5 percent. Phone and tablet manufacturers continue to add capabilities to expand the functionality and value of mobile devices. As used in this paper, the term *mobile device* primarily refers to either a smartphone or a smart tablet. Sometimes the term is used to reference an indoor mobile robotic device.

1. Wi-Fi is a trademark of the Wi-Fi Alliance www.wi-fi.org.

Typically, mobile robot applications utilize IPS technologies built into the robot, and are only partly dependent or not dependent at all upon facility IPS infrastructure.

Many analysts have identified *precision indoor location sensing* as one of the top mobile technology trends and capabilities.[2] Knowing an individual's location to within a few feet is a key enabler of the delivery of highly relevant contextual information and services, such as the common example of sending in-store promotional messages to smartphone apps, which is known as *proximity marketing*.

Location-based services advanced by leaps and bounds in 2016, and that level of growth and innovation is set to reach new heights in 2017, according to the Smarter Insights analysis of the top eight mobile technology trends.[3] Apps exploiting precise indoor location currently use technologies such as Wi-Fi, Li-Fi, photo and video imaging, ultrasonic beacons and geo-magnetics — alone or in combination.

Intelligent building systems now commonly incorporate IPS technologies for purposes of improving the indoor building experience of occupants. One convenience and cost-saving application is providing personal control of lighting and HVAC in a building occupant's work area. This is a location-based function. The use of mobile phones as both physical and logical access credentials is also a growing trend.

Most indoor positioning systems have potential value for facility security and life-safety operations, including in high-risk scenarios such as active shooter, terror attack, fire evacuation, active stalker and slip-and-fall situations. Many less dramatic insider threat scenarios can benefit from location data, such as visitor management, including providing wayfinding assistance for visitors to help locate their parked vehicles upon building departure.

Some IPS technologies can also be used outdoors, but that is not discussed in this paper.

Two Positioning Perspectives

The top two IPS uses for location-based smartphone apps are *proximity marketing* and *indoor wayfinding*[4]. These use cases typify the two basic perspectives involved in IPS technology, which are most easily expressed as questions:

- **Proximity:** What are you near?
- **Position:** Where are you exactly?

Proximity Marketing Example. Proximity detection works to identify *what specific location you are near*, to the degree of accuracy needed. Thus, beacon technology is commonly used for proximity marketing. Very small battery-powered radio beacons, such those based on Apple's

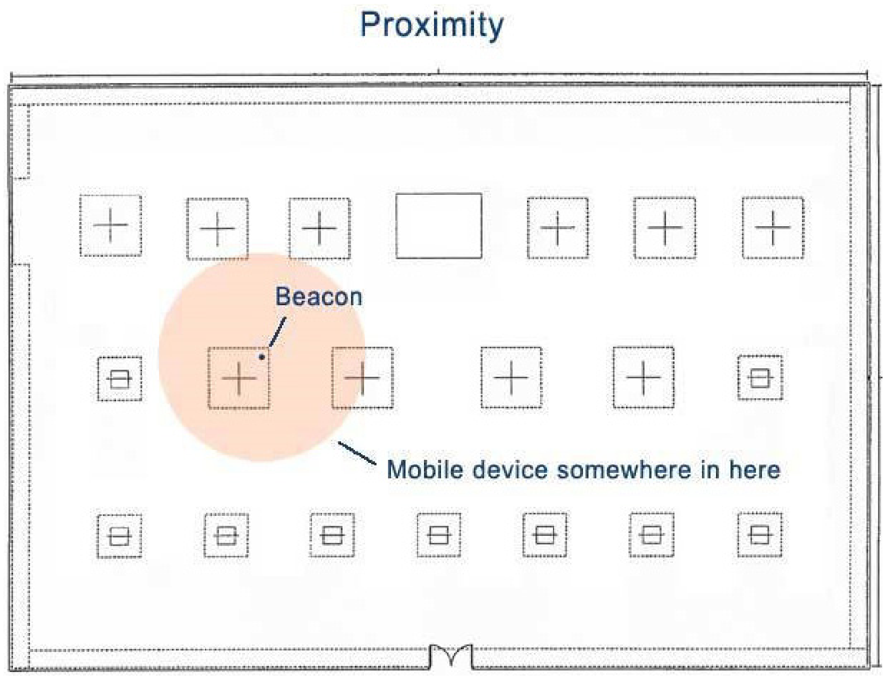
2. "Gartner Identifies the Top 10 Strategic Technology Trends for 2017", "Gartner Identifies Top 10 Mobile Technologies and Capabilities."

3. "The top 8 mobile technology trends for 2017", smartinsights.com.

4. "The Rise of Indoor Positioning", IndoorAtlas/VansonBourne, 21 Sep. 2016, p. 6.

iBeacon™ protocol[5], are placed in various locations throughout a store. For example, locating one beacon at each merchandise display. When your mobile smartphone gets near a specific merchandise display, the store's marketing app on your phone receives the beacon's ID number via Bluetooth transmission, and sends that ID number to the store's marketing server. The marketing server sends your phone a relevant message, such as a discount coupon. You could be in any of the aisles in the children's shoe section. The beacon's transmission zone may be a 25-foot circle. Exactly where you are within that circle, or any other display beacon's transmission circle, doesn't matter — you will always get the right marketing message.

Figure 1. Proximity-based location finding.



Source: AirPatrol

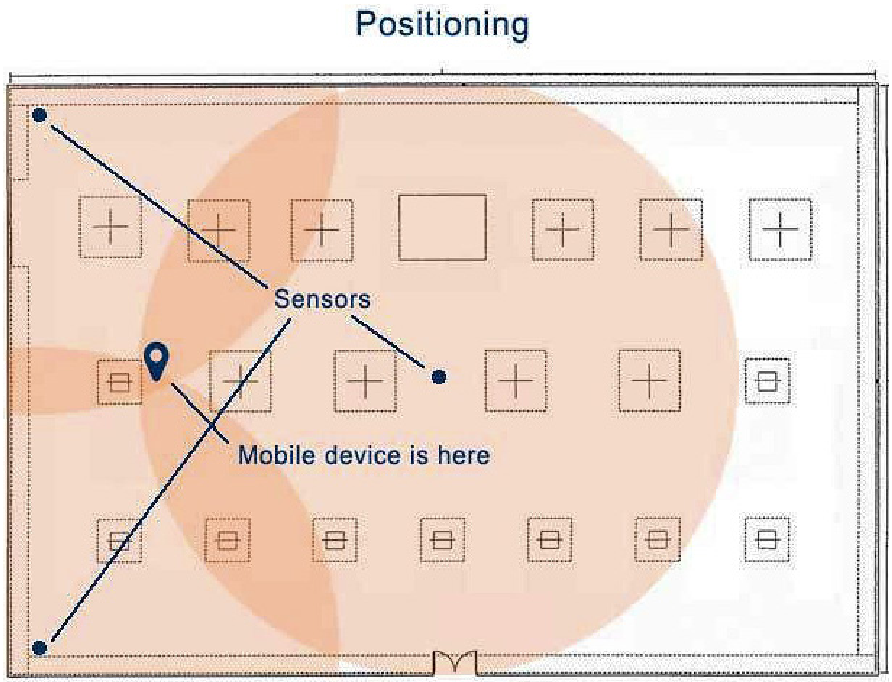
Proximity Loss Prevention/Asset Management Example. Wheelchair tracking is an example of the usefulness of proximity locating. Because wheelchairs are highly visible items, the accuracy of proximity detection is sufficient, as opposed to high-precision locating.

Wayfinding Example. Position detection works by finding exactly where you are in a building, to the degree of accuracy needed. Let's consider wayfinding in a hospital. You enter the main lobby, and start the hospital's app on your smartphone. You type in the room number where your friend is, and the phone app reminds you what the visiting hours are, and then shows you a map of the lobby area, with a blue dot indicating your location. A position accuracy of about two feet is sufficient. The app shows you the path to follow on the map, and you begin walking. The app asks if you would like to stop in the gift shop. At first you reply "No", because you brought your own gift, but then you change your answer to "Yes", because you just saw the very nice flower arrangements the app was showing. When you are done with your purchase and step back into the hallway, the app resumes guiding you to your friend's room.

5. There is a common misconception to be found in many media articles, manufacturer marketing materials and online discussions, and unintentionally perpetuated by some of Apple's own documentation. where the term "iBeacon" is used as if it were a product name, which it is not. iBeacon is a communications protocol and an open standard, developed by Apple and released in 2013, for using the Bluetooth Smart technology that is built into modern smart mobile devices.

As you follow the path, the app tells you that you will pass a large orange art display produced by the 3rd graders of a nearby school, after which you will turn right into the elevator lobby. The system calls an elevator for you, and instructs you to enter elevator car #4, which is highlighted on the map. You are instructed to exit the elevator on the third floor, turn left, and proceed down the hall to your friend's room, which is now highlighted on the map. The system texted your friend to keep her updated on your progress, and she excitedly welcomes you. Near the end of your visit, the app gives you ten minute notice that visiting time is about over, and when you leave, the app maps your way back to the main lobby.

Figure 2. Position-based location finding.



Source: AirPatrol

Several different technologies could have been used in this scenario, one for the lobby and hallways (positioning), another for the store (wide proximity) and a third inside the elevator (narrow proximity).

Precision positioning and proximity applications are not mutually exclusive, as was the case with the hospital example. What's more, multiple organizations can participate in a facility-wide IPS system. For example, an airport's wayfinding IPS can provide the parking vendor with traveler location information within the parking structure. Wayfinding can guide travelers to the appropriate check-in counter, providing the airline with notice of your arrival. Airline staff can be directed to walk up to travelers whose departure times are imminent, and expedite their processing. Wayfinding will direct passengers to the correct security checkpoint lane, and then to their specific passenger gate. Along the way, for travelers early enough to allow for it, the airport app can provide proximity-based messages as they pass by gift stores, food outlets, art exhibits or other airport features. An airport app could also provide travelers who are dining or shopping with appropriate reminders about their departure times, based on the time it takes to get from each traveler's current location to the flight's departure gate.

Indoor Positioning

An IPS is about location. *A position is a location in context.* Something is where it is, and in an absolute sense, that's its location. We give meaning to its location by understanding that location relative to other things. Those “other things” are what we use to define and express the location both in space and in time. They can be coordinates within a measurable system (such as Earth geographical positioning), or positions relative to observable things, such as landmarks, objects or people. *Position data is information about location at a specific place and time, within a specific context.* How accurate the position information needs to be depends upon the how the position information is to be used. Is the task at hand arriving at the right meeting room, or the right parking lot?

Furthermore, in defining a position as “a location in context”, it is important to understand that the value of the position information relates to the much broader context of how the position information may be used. The broader context may involve a limited set of data, such as what product display the customer is standing in front of, or it may involve a complex set of data, such as the position of an active shooter relative to police responders and people at risk nearby. The context can be even broader, and can include large data sets, such as all customers who came into a store during a promotional campaign, and what product displays they stopped at and for how long. Or it could be a security context, such as how many times someone entered the store and went directly to a specific display, only to leave immediately when store staff began to walk over to them.

The Broader Context and Security

From an organizational perspective, the “right” indoor positioning system will be the one that provides the most value to the organization. That includes considering the potential security applications of the indoor positioning system or systems under consideration. Often it will be the case that the *broader value context* is what justifies funding an IPS initiative or determines technology selection.

A situation can arise where an organization has two IPS technologies to choose from, and both are of equal value from core business perspectives. However, will the security value be the same for both? If one has greater security value than the other, then, all other things being equal, the “right” IPS for the organization (i.e. the one with the greatest value overall) will be the one with the greatest security value, even if there is an incrementally higher difference in overall cost.

Other considerations can also enter the picture, such as supplementing a basic IPS technology with a small amount of a different IPS technology, to increase the security effectiveness of the total solution.

Factors such as these are reasons why it is important to understand (a) how IPS technologies work, (b) what types of facilities they are suited for, (c) what the full range of their applications is relative to an organization’s purpose and operations and (d) what IPS applications would increase the security-effectiveness or cost-effectiveness of security operations.

Indoor Positioning Systems

Indoor positioning’s growth is being fueled by its value to within a wide spectrum of industries, including retail, healthcare, transportation, government, museum, historical sites, tourism and construction. Analysts use such industry perspectives to identify target markets for IPS technology, by determining how various business sectors could benefit from IPS capabilities.

However, considering IPS from a physical security perspective involves a much simpler analysis, because any organization that owns or occupies a building is a likely candidate for the security and safety benefits of indoor positioning.

An ideal situation from a security funding perspective, is one where an organization has adopted or will adopt an IPS technology for business reasons, and the selected IPS technology has security-related benefits that can be obtained by little to no additional investment added to the existing or planned IPS investment.

Wheelchair Tracking Examples

Hospitals benefit tremendously from IPS systems used to track and locate wheelchairs. It's a way to help eliminate wheelchair hoarding, a phenomenon that can cause patients to miss scheduled tests and treatments due to low wheelchair availability. This is not just an administrative scheduling problem, as a missed test can result in the needless postponement of a critical operation.

In addition to its patient service benefits, a wheelchair locating and tracking system has security loss prevention benefits. A decade ago most hospitals reported losing about 10 percent of their wheelchair fleet each year, with some annual losses topping 25 percent[6]. Orderlies and other staff can spend up to 30 percent of their working time trying to find wheelchairs. At one hospital, the resulting cost for the time spent searching for wheelchairs was estimated to be $28,000 per month.[7] With the cost of replacing a single wheelchair estimated at $500 to $1000, in most cases the combined benefits of loss prevention, recovered staff time and timely patient care more than justify the cost of a wheelchair locating and tracking system.

Hospitals aren't the only facilities with wheelchair tracking concerns. In December 2016, Los Angeles International Airport (LAX) announced its initial deployment of a beacon-based wheelchair tracking system in the Tom Bradley International Terminal, with continuing rollout airport-wide to follow. In 2015, LAX had received over 970,000 requests for wheelchairs across all terminals, and expects that number to exceed 1 million in 2017.

Positioning Applications

This paper will consider two aspects of IPS design and deployment: applications, and the underlying technologies used to implement them. They are separate areas of consideration, as nearly all IPS applications can be achieved by more than one technology approach. Which technology to choose can sometimes be determined more by the building structure and the nature of the activities within it, than by the applications themselves.

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6. Snowbeck, Christopher. "Hospitals seek to stop wheelchair theft", *Pittsburgh Post-Gazette*, 27 Jul. 2003, retrieved from http://old.post-gazette.com/healthscience/20030727hotwheelshealth2p2.asp, 2 Jul. 2017.

7. Raider, Rhonda. "Next Wave for Wireless", *Packet*, Fourth Quarter 2005, p. 37.

Indoor Positioning Applications

The following paragraphs describe more than a dozen of the most common applications of IPS technologies, presented in alphabetical order. Potential security or safety uses for the applications are noted.

The technologies themselves are discussed separately in a following section, as many IPS applications can be performed by more than one type of IPS technology, and some applications involve multiple technologies.

All IPS applications involve analytics of some kind, whether for low-level analysis of radio waves for position calculation, or for high level evaluation of the risk situation that a tracked object or individual may be in. Position computation and related analytics can run on the mobile device, an IPS server or both.

Accessibility Aid – for the Visually Impaired. Accessibility aids are a specialized application of wayfinding. Their purpose is to audibly or otherwise provide directions or location clues to those who are fully or partially blind. BlindSquare, an iOS phone app, is an outdoor positioning GPS-based application that works to provide its users with the distance and orientation of destinations and possible points of interest, using open source databases for points of interest and street map information. Similarly, indoor positioning for the visually impaired relies on precision location technologies that can provide the user's current location relative to indoor features and visual frames of reference (such as areas, pathways, building floor names and descriptions, as well as signs and building features like columns or art displays). This location information can help the visually impaired utilize in-person or telephone assistance from sighted individuals (such as business receptionists) who are familiar with the indoor spaces and typically describe them using indoor landmarks and building-structure frames of reference.

In April 2017, after excellent results from initial testing, San Francisco International Airport approved a two-year pilot program with the FAA's Hughes Technical Center *Airport Technology Research & Development Branch* to research, evaluate and implement technologies intended to enhance and improve wayfinding assistive technology at U.S. airports for blind and visually impaired passengers. The application's map contains more than 500 points of interest throughout the terminal, adding a level of fidelity to navigation that a blind passenger might never have had otherwise.

The airport's app audibly highlights key points as users walk by, bringing attention to anything from gates and restaurants to power outlets, ATMs and restrooms. It aims to help visually impaired travelers get from the curb-side drop off area all the way to their departure gates.

Security Usage: A registered user of the IPS application can be provided with emergency incident instructions, specific to the type of incident and to the user's exact location. These could be instructions to shelter in place, move to a safe location or to wait for sighted assistance that is on its way, with a continuing update on the estimated arrival time for in-person assistance.

Accessibility Aid – for Foreign-Language Visitors. Verbal wayfinding instructions in the user's native language can help when verbal directions by building occupants and signage are not understandable, not detailed enough or don't reference landmarks appropriately. Not only is this application of high interest to hospitality venues like hotels and convention centers from a customer-service perspective, it also eases a staffing challenge for venues with a high percentage of international visitors.

Security Usage: *A registered user of a security application integrated with an IPS, can be provided with emergency incident instructions specific to the user's language, with turn-by-turn wayfinding assistance, or even the ability to request same-language telephone or in-person assistance, as appropriate for the situation. For international hospitality venues, language-specific safe areas can be created to allow mutual support and comfort by same-language guests, residents and staff.*

Activity Detection. The fusion of location sensor data, combined with object mapping and tracking analytics, can be used to detect and assess the activities of objects, vehicles and people, and evaluate the significance of their co-location. It helps marketers understand both the effectiveness of their promotional campaigns and the resulting impacts that can occur in store traffic paths, waiting areas and parking areas.

Security Usage: *Detecting prohibited activity such as multiple vehicles congregating, parking lot racing, group loitering, or individual or group stalking, such as might occur after hours in a parking structure area or indoors in building areas that should not be occupied. From a "location in context" perspective, multiple large flames appearing above the heads of a group of protestors would indicate a different kind of emergency than large flames appearing above a hot dog vendor's cart.*

Augmented Reality (AR). Reality augmentation refers to overlaying visual or audio information onto a direct or indirect real-world picture, such as a photo or live camera image (direct) or a map or diagram (indirect). For example, an AR construction worker's helmet could display elements of a building's infrastructure that have yet to be put into place, as the worker looks around at various parts of the building site. It could also color-code the visual information to indicate a time frame such as this month, next month and so on. The helmet's display could include safety warnings about temporary conditions in a specific part of the site, for the safety of the helmet wearer.

A user's mobile device app could, for example, overlay information about stores and restaurants being viewed by the device's camera, or information about the user's friends and associates within a restaurant or an event venue. It could also display detailed information about a product that the device's camera points at. AR is an area of emerging and rapidly evolving consumer technology, which has the potential to offer future security and safety applications.

Security Usage: *A security system platform would support integration with an HR system and a visitor management system, and support patrolling officers with a security mobile app. For example, an officer patrolling a parking structure (or even parking service staff) could simply point a smartphone at a vehicle that had been left unlocked, and a license plate recognition function would retrieve the name, mobile number and email address of the driver (and whether employee or visitor), giving the officer the option of texting and/or emailing a message to inform the driver that the vehicle is not locked. A company's personnel security mobile app could allow an employee to send a photo and message about an unlocked car to the security department, which would follow up as just described.*

For a case where there appears to be very recent damage to the vehicle (such as a broken headlight or window with debris on the ground, a photograph could be captured and included with the message to the driver.

An AR-enabled app would enable any personnel with the security mobile app, who also see the vehicle damage, to point their smartphones at the vehicle and be informed that the situation had already been reported. Additionally, the app could inform an officer or parking staff that the driver had been notified and was en route to the vehicle, optionally showing a video image or photograph of the individual. This would allow the individual to be greeted and informed of options for having the vehicle serviced on site if desired. Such AR applications may seem futuristic now, but two years from now they will be commonplace, as will be expectations of this level of personal service.

Backtracking. Backtracking is useful to users who realize they have dropped or left an object behind and need to backtrack to find it, or who find themselves separated from a group and need to backtrack to a missed turn or room entrance.

Security Usage: Backtracking a criminal suspect allows identification of accomplices and the suspect's vehicle if parked. Backtracking from an object left behind or the scene of theft or damage, supports swift and effective incident response, especially for high-risk critical infrastructure facilities and public venues.

Check-in/Checkout. Check-in and checkout functionality can be provided for people and articles, where transitioning from one space or location to another indicates the beginning or end of specific activity or conformance to a physical presence requirement, such as inspection activities. This functionality is by geo-fencing applications or by third-party products interfacing with them.

Security/Safety Usage: Tracking arrivals in a safe area or restricted zone, or people exiting from an occupancy-monitored area, has value for security and safety incident response.

Fall/Injury/Sleep Detection. Several IPS technologies can detect anomalous motion, sudden stopped motion or motionless periods of time.

Security/Safety Usage: Sudden cessation of motion can indicate injury, illness or other incapacitation, as can anomalous motion without a resumption to normal motion. Detection of motion or anomalous non-motion can be an important application, for example, in mining and manufacturing environments that involve hazardous conditions or chemicals. Security and safety monitoring duties may prohibit sleeping or other forms of non-observation.

Geo-Fencing. Geo-fencing is the creation of a virtual (imaginary) line or spacial boundary, for tracking entry into, exit from, or dwelling in or near a designated part of an open area. A boundary crossing function can be used to trigger alerting or other actions. Geo-fencing has a long list of uses that include: retail shopper behavior tracking, employee activity tracking, child monitoring, check-in/checkout activity tracking, inventory management, vehicle and equipment monitoring, trespass detection, warehouse management, beginning and ending of group activities, anti-graffiti monitoring, sports venue monitoring, and area occupancy monitoring.

<u>Security Usage:</u> Geo-fencing is useful for detecting unauthorized loitering or congregating, entry into restricted vehicle and equipment parking and storage areas. Geo-fencing with occupancy counting can trigger crowd control activities. Many museums use velvet ropes, floor markings or other indications of restricted space around exhibits. Geo-fencing can provide audio warnings and visual alert signals as a deterrent to prohibited activity, and initiate alarms when prohibited activity persists.

<u>Safety Usage:</u> For long-term medical or assisted-living facilities where visitors or residents have use of gardens and other grounds areas, geo-fencing can be used for detection of wandering, disorientation of individuals or outsider trespassing.

Indoor Robotics. Indoor positioning is used in indoor robot navigation, which typically will utilize a combination of IPS technologies. Automated control rules based on location can be applied to robot activity, such photographing or video surveying of locations, or triggering alerting or reporting upon arrival and departure in an area or zone. Robots can be used for facility maintenance surveys, to check doors, stairwells, and areas that routinely require maintenance attention, to identify conditions that need attention, and for quality assurance for maintenance and facility upkeep.

Indoor robotics applications typically use a combination of IPS technologies for several reasons. An indoor robot is a purpose-built device that does not suffer from the same form factor constraints as do personal mobile computing devices; more technologies can be incorporated into a robot. Robots must perform a variety of tasks including indoor travel, that involve complex real-time multi-object positioning using the robot's own moving location as the central frame of reference for locating other fixed and moving objects. A robot must deal with multiple types of indoor environments and multiple indoor locations. It must be able to adapt to changes in those environments and cannot rely solely on fixed mapping or fingerprinting of the indoor environments. Extensive machine learning capabilities are integral to indoor robots. Thus, indoor robotics will typically utilize several or all the IPS technologies provided in this paper.

<u>Security and Safety Usage:</u> Robotic patrols can replace certain aspects of staff-based security patrols. Robots can enter areas where environmental conditions are not safe for human entry. Robots can be used in active human threat situations where there is danger of injury or death for human responders.

Life Safety Monitoring. This is a dedicated security/safety application. When an individual in an isolated area of a facility feels apprehensive or has their personal safety at risk, such as in an actual or potential stalking or harassment situation, a security officer or monitoring center can use location-tracking via the individual's smartphone app to stay apprised of the individual's location and status, and if requested remain verbally in touch via an ongoing telephone call. Such applications include a "Help Me" function where the individual can summon active assistance, with or without a phone call in progress. Usually such applications allow the monitored individual to send photos or use the phone's video camera to transmit video of a threat situation or environmental conditions of concern. An advanced version of such an application would integrate with a facility's video system and automatically display camera views of the individual's location and nearby areas to monitoring personnel.

Lost Person/Customer Assistance. Anomalous behavior can be used in many types of venues for identification and tracking of individuals needing assistance. For example, at a transportation venue, continued wandering, circular walking and extended examination of venue map displays can all indicate that a traveler or someone meeting a traveler needs assistance.

Security/Safety Usage: *Self-concealment and other behavior can indicate stalking or lying in-wait, and can be used to trigger automated responses (such as lighting activation or announcements), or in-person responses by trained staff or security personnel.*

Proximity Assurance. When two or more people are traveling together at a venue or activity where crowded conditions or distraction can result in separation, geo-fencing or proximity tracking can be used to ensure that the intended level of proximity is maintained.

Safety Usage: *When for medical, personal safety or other reasons close supervision of a group or individual is required, proximity assurance provides a safeguard against accidental or intentional separation that can occur in any number of activities or conditions.*

Suspect/Offender Directional Tracking. When an incident occurs, or is expected to occur, such as at a transportation facility, entertainment venue or other type of facility where people congregate in expected patterns, anomalous behavior such as wrong-direction detection can indicate a need for assistance or response.

Security/Safety Usage: *Such behavior can highlight suspects or actual offenders, who, once identified, can be tracked by location technology.*

Tour Guiding. There are many forms of automated tour guiding. Museum venues have benefited for decades from many forms of location-specific audio/visual guidance. However, the introduction of personal mobile devices adds a new dimension that enables tailoring the information provided based upon factors beyond presence, such as group membership or repeat attendance. It enables the promotion of exhibit- or display-related museum store items. It can provide guidance information in the user's native language. For group tours, a geo-fencing area can move as the group progresses through the tour, even providing alerts or instructions to an individual who has strayed from the group, as well as to live tour guides. For animal park tours, tour guiding can be paired with proximity tracking and progressive geo-fencing for group control. *Also see the Accessibility Aid descriptions on page 8, and the Geo-fencing description on page 10.*

Security Usage: *Object position tracking can detect if any items were moved or removed during the presence of a group in any specific exhibit or location, and could identify stragglers or wanders who were close to the object's original position. Location technology can continue tracking an offending individual's mobile device, or the related tour guide, to support swift item recovery or offender apprehension.*

Safety Usage: *For workers and visitors at large construction sites, audio and written safety instructions can be provided via mobile device, which can help address location-specific conditions — such as temporary safety risk situations — which may be unplanned and not covered by the usual site safety instructions.*

Wayfinding. Indoor wayfinding is a general-purpose location function that has many applications, including:

- Finding a room or office in a hospital, school or other building that is unfamiliar
- Locating a store or other business in a shopping mall
- Finding a department, a product display or a specific product in a store
- Locating a designated seat, restroom, or snack counter in a large performance venue
- Meeting someone in a crowded venue
- Finding a vehicle in a parking lot

In a wayfinding application, a user selects a destination, and the IPS system provides map-based turn-by-turn instructions, and may also include landmark information such as statues, paintings, or building architectural features as a means of keeping the user visually oriented within the travel path. In an intelligent building, an advanced wayfinding system would be integrated with the building's elevator system, and would specify which elevator to enter. The system would automatically activate the destination floor button. As part of an intelligent building's visitor management system, the app would also let the user know, for example, that the individual the visitor is meeting is now on the way to greet them at the reception desk or in the elevator lobby.

Typically, in a wayfinding application, a map would be used with a blue dot or other conventional location marker, to indicate the current location of the user. Other location information would be displayed, such as the building floor or building wing name, and the names of the nearby offices suites, stores or other building areas. When the destination is within visual sight, it is highlighted on the app's map.

For example, in an intelligent building IPS application, the location system would be integrated with the building's security camera system, and would display a video-based forward path view of the user progressing through the parking structure. The user's vehicle would be outlined when it came into view. An advanced app would allow the user to send a "meet me at my car" invitation to a fellow worker or shopper, who would use the wayfinding information to be routed to the vehicle. In a shopping mall, the user could request via the wayfinding app that store staff, or the store or shopping mall's robot delivery service, bring the purchased merchandise out to the vehicle. The IPS, video system and robotic technologies already exist to support such functions, only the high-level software applications need to be written.

<u>Security Usage:</u> *Wayfinding can be used to vary security officer patrols, and to provide patrol guidance to new, substitute or supplementary security personnel. Wayfinding can be used to automatically generate the most direct route to an individual requiring emergency assistance, for in-house security personnel and outside fire, police or medical emergency responders.*

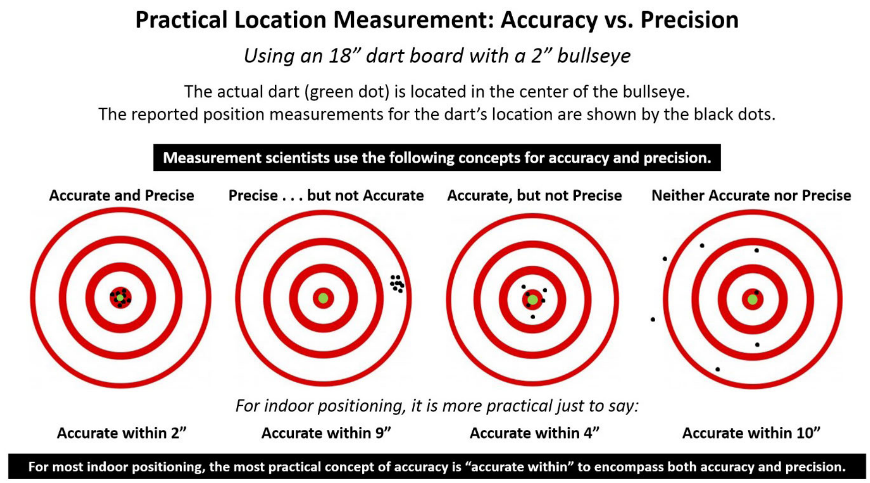
Accuracy

As used in this paper, a positioning system's *accuracy* refers to the difference between the *actual position* of the object being located and the *measured position* reported by the IPS. *The statement "accurate to within one foot" means that whatever position is reported, it will always be within 12 inches of the actual position.*

Precision and Accuracy

In technical literature about measuring systems, a distinction is made between accuracy and precision, as shown in the visual chart of Figure 3, which utilizes a dart board to illustrate the two concepts. However, the indoor positioning applications that are the subject of this paper do not require the precision of a dart game to be successful. That is why Figure 3 shows how to derive a single accuracy statement from the two technical concepts of precision and accuracy. This makes for a simpler discussion that is fully sufficient for the needs of indoor positioning design.

Figure 3. A practical way to express Indoor Position System accuracy.



Source: Author, bullseye chart illustration concept by Carly Barry, courtesy of The Minitab Blog.

Accuracy Range

For many positioning technologies, accuracy is to some degree determined by design and/or implementation factors. For example, the locations of fixed beacons, the spacing of survey grid points of measurement when fingerprinting a facility (see the Fingerprinting section on page 17), and the number and location of LED lighting fixtures. Thus, accuracy is sometimes listed as a range of minimum to maximum values generally found in deployments.

Computational Error Correction

Most positioning devices and systems are subject to various types of sensing errors due to the nature of the technologies involved and their sensitivity to external influences, including mechanical shock, vibration, electronic interference, radio or light wave distortion, and so on. Nearly all positioning devices and systems include various means of mechanical and computational error correction, which is an aspect of positioning technologies that continues to improve over time.

Accuracy as a Design Consideration

How important the degree of accuracy is for an IPS depends upon its intended use. From a product selection perspective, this means that potential future uses must be considered as well as the immediate use case at hand. From a security practitioner’s perspective, this means that immediate and potential future security and safety applications must be considered because they may have differing accuracy requirements than the business IPS applications. An accuracy level of plus or minus 3 feet may be fine for many marketing IPS applications but not for security applications. For example, an IPS report to a security system that a person is in the middle of an at-risk hallway, when they are actually against a wall inside a shelter-in-place room next to the hallway, would not be acceptable. Thus, the development of security IPS requirements must be scenario-based to ensure that accuracy requirements are appropriately specified. Such requirements can vary across different building areas and pedestrian paths. Continuing with the example, a system based on visual light communications could not report a person's position as being on the wrong side of a wall, because light waves do not penetrate a wall, whereas Wi-Fi radio waved do penetrate walls. This example also shows that the concept of "location within context", in this case the security context, is an important consideration.

Fortunately, in most cases, the accuracy requirements of business-related IPS applications will meet or exceed those of the potential security applications. Due to ongoing research, and the accelerating rate of adoption of IPS technologies, accuracy will continue to improve over time.

When accuracy is a cost factor, sometimes budgetary restraints restrict the level of accuracy or increase the number and size of blind spots to what is minimally acceptable but less than optimal. In such cases, a two-phase deployment can be planned to upgrade the installed capabilities to the desired level of system performance. The full cost picture should be considered to as to optimize the total cost of deployment over time, given initial budgetary restrictions.

Extent of IPS Coverage

Extent of accurate coverage is another issue that can be more important for security applications than for other applications. For example, if the primary purpose of an IPS is to track and map shopper activity in a retail store, then it won't matter if the IPS doesn't "see" people who may be hiding behind furniture or racks of clothing, as that will be a very rare situation and statistically unimportant. However, in a security threat situation, it may be critically important to identify the locations of individuals who are hiding, whether they are threat actors or at-risk individuals seeking safety. This is another example of the importance of "location within context."

Real-Time Analysis vs. Data Collection

Proximity marketing, wayfinding and life-safety monitoring are examples of real-time positioning applications. In contrast, tracking shopper movements for analysis of shopper behaviors, and monitoring warehouse vehicle movements for analysis of warehouse operations efficiency, are examples of data collection applications that involve future analysis rather than real-time analysis.

When the IPS application is performing tracking or any other type of information for storage and future analysis, it is important to take information security and privacy into account. Even real-time analysis data may involve privacy issues, especially where video or identity information is displayed, even if briefly.

Real-Time Locating vs. Indoor Positioning

The Real-Time Locating Label

There are two generations of terminology that have developed relating to indoor positioning systems. IPS systems used for real-time applications are also called Real-Time Locating Systems (RTLS). At the time that the term *Real-Time Locating System* was coined[8], technologies from the 1990s or earlier were in use.

The 1990 and earlier era technologies included RFID, infrared light and barcode scan technologies, which were effective for object tracking applications in manufacturing and logistics facilities. Most of these technologies utilized mobile transmitters on objects and fixed receivers, enabling moving objects to be scanned at meaningful location points such as packages on a conveyor belt or automobiles moving down an assembly line.

Due to the proliferation of proprietary RTLS technologies, ISO guidelines and standards were developed to foster interoperability between brands and enable wider adoption of RTLS technologies. The terms "Locating" and "Real-Time Locating" were adopted in the standards and in the documentation and promotional materials from industries that manufactured and utilized RTLS products.

The Indoor Positioning Label

The following technologies came into widespread use after the RTLS label was born:

- Wi-Fi networking
- Smart mobile devices
- Mobile device GPS navigation apps
- Cloud computing
- LED-based Visual Light Communications

As these technologies listed above emerged, mobile-device-based use of personal GPS navigation became widespread. However, GPS microwave transmissions don't penetrate sufficiently into parking structures and buildings. As location-based retail applications began emerging for GPS locating, the revenue potentials for mobile app-based indoor positioning systems became obvious and began to drive the development of indoor locating technologies.

To leverage the phrase "Positioning System" from "Global Positioning System", the terms "Indoor Positioning" and "Indoor Positioning System" were adopted by mobile-device-based manufacturers and technology providers, and "IPS" thus became the complementary term to "GPS".

This is why the Internet contains two information categories: IPS and RTLS, with IPS referring to mobile-phone based indoor positioning applications at first, but later also starting to be used for any type of indoor locating/positioning system. In manufacturing and logistics operations,

8. The term RTLS was created (circa 1998) at the ID EXPO trade show by Tim Harrington (WhereNet), Jay Werb, (PinPoint), and Bert Moore (Automatic Identification Manufacturers, Inc.), Source: Wikipedia "Real-time locating system", retrieved 12 Jul 2017.

the term RTLS dominates as GPS is a form of real-time locating, and thus both indoor and outdoor tracking of shipped items can be labelled as RTLS applications. Terminology usage is mixed across various industries. For example, in healthcare, the term RTLS dominates and IPS is less common but growing. In retail, IPS dominates, and RTLS is sometimes used in tandem with IPS by technology providers who install a wide spectrum of locating/positioning products. And cloud-based indoor positioning systems are almost always referred to as IPS technology.

Due to this paper's focus on mobile-device-based IPS technologies, and for simplicity's sake, the terms *IPS* and *Indoor Positioning* are used from this point forward, and no other mention of RTLS is made regardless of which label is commonly applied in specific business sectors.

Indoor Positioning Techniques

The five most common indoor positioning techniques, which are methods not technologies, are:

- Proximity
- Fingerprinting
- Triangulation
- Vision analysis
- Dead reckoning

The first three — proximity, fingerprinting and triangulation — are commonly used by geomagnetic, light-based, radio and sonic IPS technologies. Vision analysis is used in image-based technologies, and dead reckoning is used by inertial technologies. These techniques are briefly explained below, just ahead of the section about indoor positioning technologies

Proximity

The simplest location sensing technique is proximity, where the mobile device's approximate location is identified by a signal received from a single transmission source, which contains the ID of the transmitting device. The ID received is then used to look up the transmitting device's record (in a list or database) and retrieve the location information of the transmitting device, which is then reported as the location of the mobile device.

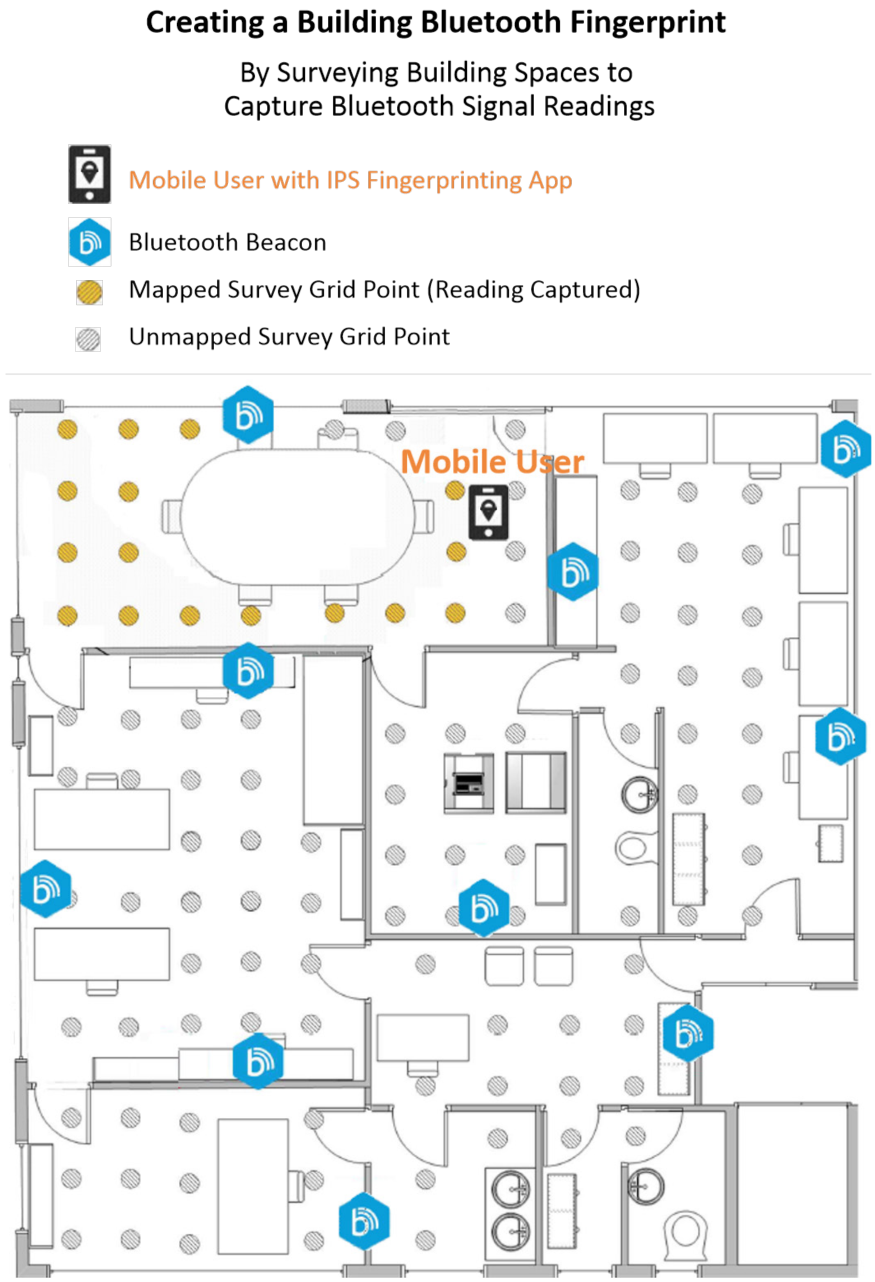
Fingerprinting

Fingerprinting is a technique used by many implementations of Bluetooth, Geomagnetic, Visual Light Communications and Wi-Fi positioning systems to achieve high accuracy and resolution in positioning. Fingerprinting, sometimes called mapping, takes place after the fixed transmitting elements are in place, such as Wi-Fi access points, Bluetooth Low Energy beacons, or LED lighting fixtures. (The Earth magnetism used by geomagnetic systems is always in place.)

Fingerprinting is the performance of a facility survey in which a surveyor walks to pre-designated positions within the facility and records readings of signal characteristics, such as received signal strength. Often a grid system is used where the gridline spacing is 5 or 6 feet and readings are taken at each grid line intersection point. Based upon the type of technology, the manufacturer will provide direction as to the details of taking the readings. For example, it may be having the surveyor always facing in the same direction, such as North. See Figure 4.

Preferably, the surveyor will use a personal mobile device of a type that will be used by positioning system users to take the readings using a mobile app made for this purpose. The app used to perform the surveying records the Wi-Fi, Bluetooth, or LED light signal strength (or Earth magnetism properties) or other characteristics at the chosen locations. This information is stored in the fingerprint database. Each entry in the database is a mapping between a location and a position fingerprint. In the case of a large facility, multiple surveyors can simultaneously survey different parts of the facility.

Figure 4. Grid-based approach to creating an IPS Bluetooth building fingerprint.



Source: Author, adapted from Sensors journal illustration. Loizos Kanaris, Akis Kokkinis, Antonio Liotta, Stavros Stavrou, "Fusing Bluetooth Beacon Data with WiFi Radiomaps for Improved Indoor Localization," Sensors*, 10 Apr. 2017, Figure 2.*

Once the fingerprint database has been established, when users run the indoor positioning app, the readings taken by the user's app are compared to the readings in the fingerprint database, and compared using the positioning systems algorithms to determine the user's position.

In most facilities, it is not feasible to utilize pure signal triangulation only, due to the various types of interference that can occur with each technology, such as signal reflection, and attenuation of signals by structural elements of the facility.

Because facilities change and evolve over time, it is important to determine the intervals at which facility fingerprinting will have to be repeated. This will depend upon both the nature of the facility and the type of IPS technologies selected.

Triangulation

Triangulation determines an absolute position by using the geometric properties of triangles in complicated computer algorithms based upon the speed of received radio signals (for Wi-Fi and Bluetooth) or the speed of light (for LED lighting), or the strength of received radio signals (RSS) or the light intensity of received light beams. Triangulation techniques have been and continue to be actively researched in an overall effort to improve the accuracy of positioning systems.

Vision Analysis

Vision analysis involves the geometric relations between the 3D positions of objects in the real world and their 2D positions in their projections on a camera image sensor. Vision analysis requires reference information that establishes a correspondence between objects whose 3D world locations are known (i.e. in a list or database) and the object positions in the 2D camera image.

Vision analysis is primarily used in robot positioning systems, however, one company filed a patent in 2014 that uses a smartphone's camera and the light fixture location information transmitted by intelligent LED lighting fixtures, to determine the relative location of the smartphone based upon the locations of the LED lighting fixtures in the camera image.

Dead Reckoning

In navigation, dead reckoning is the process of calculating one's current position by using a previously determined position, or fix, and advancing that position based upon known or estimated speeds over elapsed time and course[9]. It is used when the stars and other visual navigation aids are not available.

In indoor positioning, dead reckoning is used when positioning signals (Wi-Fi, Bluetooth, etc.) are not available. It works by using the accelerometer, gyroscope and compass sensors within a smartphone to advance the position of the user from the last known position. This technique is subject to cumulative errors, and so it is used only to compensate for the absence of positioning signals, for example during wayfinding, so that a "close enough" position can be provided to the user until positioning signals are available again. This is typically necessary for only small portions of a path to be walked. It is important to know If dead reckoning will be required due to the nature of a facility or its IPS infrastructure, as that may affect which mobile devices "work best" for certain IPS applications within the facility.

Indoor Positioning Technique Conclusion

The technical details of the indoor positioning techniques and the formulas and computer algorithms they use (such as *Received Signal Strength* calculations) are not important to know.

9. Source: Wikipedia, "Dead Reckoning", retrieved 10 Jun. 2017.

Regarding system design and product selection, knowing a little bit about these techniques is important primarily for two reasons, both of which are cost factors:

- They impact the number and locations of installed devices, such as Wi-Fi access points or Bluetooth beacons. Their number and location will determine the accuracy that the system will be capable of.
- They determine the type of on-site work that is involved in performing system setup, including fingerprinting surveys, which can take days or weeks depending upon the size and nature of the facility. For example, fingerprinting is very easy in a warehouse and very challenging in a hospital.

The manufacturers of IPS products will be able to provide design guidance specific to their own technologies, so that these determinations can be made during the technology evaluation and selection process.

Indoor Positioning Technologies

Currently there are six main categories of indoor positioning technology utilized in IPS systems:

- **Geomagnetic:** sensing a building's distortions of the Earth's magnetic field
- **Inertial**: sensor estimation of position changes in a mobile device's inertia
- **Image-Based**: analyzing video camera scene motion
- **Light-Based**: sensing distances from visible and infrared light beam sources; decoding locations of LED light sources; and receiving location data via data transmissions from LED lights, including LiFi transmissions[10].
- **Radio**: analyzing signals from Wi-Fi access points, Bluetooth beacons, and/or other radio wave sources to determine the location of the receiving device
- **Sonic**: measurement of sound and ultrasound transmissions and reflections

Definitions and Abbreviations

The following abbreviations and definitions are used in this charts that follow. Other terms and abbreviations are defined or described where they are first used.

Line of Sight (LOS): For most light-based indoor positioning systems, a clear line of sight is required between a light transmission point and the light receiving point. For some light-based applications, the data contained in reflected light signals maintains its integrity.

Radio Frequency (RF): The initials RF for radio frequency are used to refer to any type of radio-based signal or to considerations relating to radio signals, such as RF interference, which is a situation in which a radio signal from one source interferes with a radio signal from another source.

Received Signal Strength (RSS): Received Signal Strength is the name of the most common method of calculating the relative distance from a single signal receiver (like a smartphone)

10. Light Fidelity (LiFi) is the use of intelligent LED lighting for data transmission, by switching the LED lighting on and off at frequencies well beyond what the human eye can detect, but which light sensors can detect.

to several signal transmitters. Usually, the strongest signal is the closest, but not always. For example, if the signal originates from behind a smartphone user, the user's body will block some of the signal. Thus, the closest signal may not be the strongest, and various technical approaches are used to account for environmentally caused variations of signal strength.

Multipath Effects: Multipath effects are the signals that result from a single broadcast signal being reflected from several locations, as happens when GPS satellite signals bounce off buildings in downtown locations. Some IPS technologies are more subject to multipath effects than others.

Density: In IPS technology, density refers to how many IPS transmitters and/or receivers there are within a given building space. For example, when Wi-Fi access points are used for positioning, accuracy is high when there is a high number of access points on a building floor, and low when there are fewer access points. Wi-Fi access point density is a key factor in the accuracy of a Wi-Fi based positioning system.

Visible Light Communications (VLC): Visible light communication is a wireless method that uses light emitted by LEDs to deliver networked, mobile, high-speed communication similar to Wi-Fi, leading to the term Li-Fi, which stands for Light Fidelity.

Technology Comparisons

Two tables, presented on the following pages, provide IPS technology comparisons. Table 1 is a comparison chart of relative advantages and disadvantages of individual IPS technologies. Table 2 is a high-level comparison of the basic aspects of IPS technologies.

Note that these tables become most useful when they are updated based on building-specific designs for candidate technologies. The nature of a building, and the target levels of accuracy desired, are key cost and complexity factors for an IPS initiative.

Table 1. Comparison chart of Indoor Positioning System technology advantages and disadvantages

IPS Technology	Advantages	Disadvantages
Geomagnetic	Fully cloud based; very low cost because it requires no additional infrastructure to be added to a building; utilizes personal smart mobile devices.	Requires fingerprinting of the building, which will likely require updating on bi-annual basis, when parts of the building are remodeled, or when the contents and furniture of an area are significantly changed.
Inertial	Little to no cost through utilizing existing sensors (such as in smartphones or robots) and does not require additional building infrastructure; usually can be used in combination with other technologies as a low-cost means to compensate for dead zones.	Calculates only an approximate position; errors accumulate, continuing to decrease accuracy the longer the inertial-based positioning session lasts.
Image-Based – Photo, Visual Code	They are relatively cheap compared with other technologies such as Ultrasound and Ultra Wide Band.	Photo data can be utilized for additional purposes, such as automated inspection.
Image-Based – Video	Has business applications in addition to security applications; security systems usually in place to receive video data.	LOS requirements can be challenging; coverage may be limited depending upon contents of building areas and rooms.
Radio – Bluetooth Low Energy	Does not require LOS between communicating devices; is a lighter standard and highly ubiquitous; is also built into most smartphones, personal digital assistants, etc.; standards provide interoperability and have fostered a wide product base; relatively low cost compared to other IPS technologies.	The greater the number of beacons, the better the accuracy, but more beacons increase the cost; requires some relatively expensive receiving cells; requires a host computer to hold the fingerprint database and perform location calculations; because the 2.4 GHz spectrum Bluetooth uses is unlicensed, new applications for it are to be expected, and as the spectrum becomes more widely used, radio interference is more likely to occur.
Radio – RFID, Active Radio – RFID, Passive	Does not require LOS; has a 2- to 6-year button battery life; standards-based; has a wide product base.	The antenna affects the RF signal, the positioning coverage is small, in the role of proximity lacks communications capabilities, cannot be integrated easily with other systems; RF communication is not inherently secure and consumes more power than IR devices.
Radio – Wi-Fi	Uses existing communication networks that may cover more than one building; the majority of devices available nowadays are equipped with WLAN connectivity; WLANs exist in the majority of buildings; LOS is not required.	Requires fingerprinting of the building, which will likely require updating on bi-annual basis, when parts of the building are remodeled, or when the contents and furniture of an area are significantly changed. In-room accuracy can be affected by open/closed doors; subject to multipath effects and interference.
Radio – Ultra Wide Band (UWB)	High accuracy positioning, even in the presence of severe multipath effects, effectively passes through walls, equipment, and any other obstacles; UWB will not interfere with existing RF systems if properly designed.	Although UWB is less susceptible to interference relative to other technologies, it is still subject to interference caused by metallic materials. In the U.S. it is regulated by the FCC for indoor applications only.
Radio – Zigbee	Its sensors are very low energy and low cost; standards define secure communications; in some buildings Zigbee technology will already be in place for control system applications.	Operates in unlicensed IS bands; seems vulnerable to interference caused by a wide range of signal types (using the same frequency); Wi-Fi and Zigbee may interfere with each other; is suitable for networks in which conversations between two devices takes only a few milliseconds, allowing the transceiver to switch into sleep mode quickly.
Lighting-Based – Infrared LED	Since IR signals cannot penetrate through walls, it is suitable for sensitive communication because it will not be accessible outside a room or a building; useful as return data path in Li-Fi, because it does not require a high density of receivers, which can be located in visible LED lighting fixtures or in dedicated IR fixtures.	Does not penetrate walls, therefore it is typically used in small spaces such as one room for proximity positioning; IR communication is blocked by obstacles that block light which includes almost everything solid; requires LOS between sender and receiver when using direct IR; Fluorescent lighting has low-level infrared emissions that may interfere with the positioning IR signals.
Lighting-Based – Visible LED	ID code and VLC network data integrity is maintained even in reflected light; LED lighting reduces lighting energy costs and provides ongoing cost savings when traditional lighting is replaced	Requires a significant design effort that encompasses both standard building lighting requirements and indoor positioning requirements.
Sonic – Audible	Usually low cost; acoustic sensors can be used for off-hours intrusion detection and alarm verification.	Subject to audio interference depending upon internal building environment, operations and activities within the building, as well as external audio sources.
Sonic – Ultrasound	Does not require LOS; does not interfere with electromagnetic waves.	Requires precise alignment of ceiling grid receivers.

Table *2*. Summary comparison of Indoor Positioning System (IPS) base technologies

IPS Technology	Accuracy	Complexity	Robustness	Cost	Infrastructure Requirements, Impacts and Notes	Transmitter to Receiver Range
Geomagnetic	< 3 ft.	Low	Performance depends on density of fingerprinting.	Very Low	None (smartphone capability); Requires fingerprinting; rechargeable battery life of smart mobile device is hours.	N/A
Inertial	N/A	Low	Performance depends upon the accuracy of phone sensors and the length of time inertial activation lasts.	N/A	None (smartphone capability) – is a supplementary technology; battery life of smart mobile device is hours.	N/A
Image-Based – Photo	Per design	High	Performance depends upon proprietary implementation factors.	High	Primarily used in robotics systems.	N/A
Image-Based – Video	Per design	High	Performance depends upon camera locations and effectiveness of video analytics technology.	High	Requires video cameras and video analytics applications.	N/A
Radio – Bluetooth Low Energy	3 ft. to 10 ft.	Medium	Performance is affected by obstacles.	Medium	Accuracy is a factor of beacon density; rechargeable battery life is hours to days.	90 ft.
Radio – RFID, Active	1 ft. to 3000 ft.	Medium	Performance achieved by matching technology to application requirements.	Medium	More effective with reference RFID tag grid.	60 ft. to 300 ft.
Radio – RFID, Passive	1 in. to 30 ft.	Medium	Performance achieved by matching technology to application requirements.	Medium	For room location or proximity.	15 ft. to 60 ft.
Radio – Wi-Fi	15 ft. to 45 ft.	Medium	Performance depends on the positioning algorithm and fingerprinting database.	Low	Can use existing Wi-Fi; rechargeable battery life of smart mobile device is hours.	450 ft.
Radio – Ultra Wide Band (UWB)	6 inches to 2-1/2 ft.	Medium	Susceptible to multipath and interference from reflected UWB signals.	Medium to Low	Requires UWB wave generator and receivers; rechargeable battery life is hours.	60 ft.
Radio – Zigbee	10 ft. to 16 ft.	Low	Susceptible to interference.	Low	Requires Zigbee Module; device battery life is 2 to 6 years.	30 ft. to 900 ft.
Lighting-Based – Infrared LED	4 inches to 10 ft.	Low	Positioning (vs. Proximity) requires overlapping light zones.	Low	Requires clear line of sight from smartphone to lights; rechargeable battery life of smart mobile device is hours.	24 ft.
Lighting-Based – Visible LED	1 ft. to 10 ft.	Low	Positioning (vs. Proximity) requires overlapping light zones.	Low	Can use facility LED lighting; smart mobile device must detect three lighting zones for precision positioning, one for proximity; rechargeable battery life of smart mobile device is hours.	24 ft.
Sonic – Audible	1.5 ft.	Low	Influenced by sound waves in the surroundings, location of sensors.	Low	Requires acoustic sensors.	150 ft.
Sonic – Ultrasound	2 inches to 3 ft.	Medium	Performance can be affected by other reflected waves, location and alignment of receivers	Low to Medium	Typically uses mobile ultrasound emitters and a ceiling-based grid of fixed receivers.	150 ft.

Geomagnetic Indoor Positioning

Modern buildings have a unique magnetic landscape produced by the interaction between the Earth's magnetic field and the steel and other materials found in the structures of buildings. Geomagnetic IPS technology utilizes the built-in magnetic sensor (compass) in smart mobile devices to measure the indoor magnetic field throughout a building. These measurements define a magnetic profile for the building, referred to as the building's geomagnetic fingerprint or map. This magnetic profile varies very little over time.

The map is created using a mobile device (smartphone or tablet) with an IPS mapping app installed. An individual builds the map by walking the building spaces and taking magnetic readings at intervals specified by the IPS manufacturer. Usually a grid system is used, as illustrated in Figure 4 on page 18, to specify the measurement points in the facility.

Once the map is established, mobile device users can use an IPS mobile app that takes geomagnetic readings and sends them to an IPS server, which compares them to the measurements in the building's geomagnetic map, to calculate where the mobile device is. The server then updates the mobile app's location display and provides other information based upon the purpose of the app.

Inertial Device-Based Positioning

An inertial measurement unit (IMU) is an electronic device that measures and reports on an object's specific force, angular rate, and sometimes the magnetic field surrounding the object, using a combination of *accelerometers* (to measure acceleration rate), *gyroscopes* (to measure rotational rate), and *magnetometers* (to determine a compass direction). Small lightweight inertial systems are classified as *micro-machined electro-mechanical systems* (MEMS).

Most personal mobile devices contain an IMU. Typical uses for IMUs include maneuvering aircraft, such as unmanned aerial vehicles (UAVs), and spacecraft, including satellites and landers.

An IMU allows a GPS application to work when GPS-signals are unavailable, such as in tunnels, inside buildings or when electronic interference is present. In such cases an IMU works to provide location estimates based on speed and direction until GPS signals are available again.

Ruggedized versions are commonly installed in indoor vehicles such as those used in warehouses and loading docks, and are utilized to monitor compliance with safety rules regarding speed, acceleration, braking, and driving within defined lanes and areas of operation.

Loss prevention systems use ruggedized inertial devices placed on equipment and other outdoor articles at construction sites, such as spools of copper cable and storage bins for expensive material. Such systems report on item or equipment motion or vibration, and can trigger actions such as alarm alerting, lighting and siren activation, and activation of video recording.

Image-Based

There are two categories of image-based positioning technology: still-image-based and video-based.

Still-Image-Based Positioning

The primary opportunity for still-image-based positioning is with robotics, as the use of positioning in robotic applications has different and broader scopes than for most other uses of positioning, and because the computing and data storage capabilities of robot devices exceed those of mobile computing devices.

One method of still-image-based positioning involves comparing photos taken by a moving device with photos taken from known locations in an area, and calculating the position of the moving device by computer-based comparison.

Another method of still-image-based positioning involves the decoding of a barcode, QR code or signs located on fixed architectural features such as doors, walls and columns. The decoded data may contain location information, or simply contain an ID number used for data lookup. A method of light-based distance calculation, using visible or infrared light, is employed to determine the distance between the object to be located and each coded image. Triangulation or other means can be used to calculate the moving object's location.

Still-image based analytics can provide other benefits. For example, a facility maintenance robot can use still image analysis not only for positioning purposes, but also to identify potential changes of interest to facility maintenance, such as deteriorating conditions of doors and architectural features, down to small details such as dislocated door stops, chips in wallboard, signs of attempted forced entry at door locks, peeling paint, water damage, and substituted furniture (replacing expensive furniture with cheap lookalikes).

Video-Based Positioning

Video analytics technology, including object recognition and location functions, has been in use in the retail sector use for over 10 years, and continues to be popular because of the breadth of intelligence going far beyond positioning that can be extracted from video information. Today, the new generation of object-based video analytics extracts much more intelligence from what the cameras see[11]. When such systems are in use, indoor positioning is often a subset of the total range of system capabilities.

Positioning-related data from a video-based IPS includes object path, object pause or dwell time (which we call loitering, for a person), and other people behavior-related activity recognition such as group loitering, climbing, and fighting, plus identification based on facial recognition, gait recognition and so on. Video-stream positioning is usually system-initiated, whether for security surveillance purposes or business data-gathering purposes. This contrasts with mobile-device-initiated positioning, which is user-initiated.

Video-based positioning typically requires that cameras be placed in ceiling locations facing directly downwards at right angles to the floor, so that visual positioning can be easily accomplished in the two-dimensional picture provided by the camera images.

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11. Bernard, Ray. "The State of Security Video Analytics", 22 Jul. 2016, retrieved from https://www.securityindustry.org/Pages/Technology/State-Video-Analytics.aspx, 2 Jul. 2017.

Light-Based

There are two categories of light-based positioning systems, those that use facility lighting fixtures that provide building illumination, and those that require lighting fixtures dedicated solely to the IPS function.

Dedicated Lighting

Dedicated light-based optical positioning technologies are based on direct visible and infrared light transmission from fixed light sources throughout a facility. There is a variety of techniques for calculating mobile device distances to the light sources, which use multiple data points such as triangulation to calculate a position. Direct line-of-sight is required from multiple light sources to the mobile device, which means that facilities whose area designs provide a low number of light mounting options may not be suited for the direct lighting approach, or may require additional technologies to be used such as Wi-Fi or BLE. Dedicated lighting approaches typically have 3- to 6-foot accuracy.

Intelligent Facility Lighting

Light-based positioning is currently a wide and very active field of research and development, due in large part to LED lighting technology's ability to serve two roles: facility lighting and facility wireless communications via Visual Light Communications (VLC), which includes LiFi technology. LiFi can out-perform Wi-Fi from many perspectives, due to limitations inherent in radio-frequency (RF) transmission and distinct advantages inherent in light transmission. One-foot accuracy can be achieved with VLC-based positioning.

LED lighting use electronic bulbs, which can be switched on/off at a high frequency that is not detectable by the human eye, but is detectable by light sensors like those used in digital cameras. This high frequency switching capability allows the light beams to be used to send electronic data. Two approaches have been developed:

- **One-way data communications.** This is a non-networked beacon-style approach for broadcasting a light's ID message (shown in Figure 5 on page 27).
- **Two-way data communications.** This is a networked approach, whereby the lighting fixtures are connected in a local area network and provide two-way data communications, using visible light for outgoing data from the light fixture, and infrared light for incoming data to the light fixture. Using two distinct light technologies provides a high bandwidth two-way data communications capability (not illustrated).

VLC is an area of very active research and development as well as standards development.

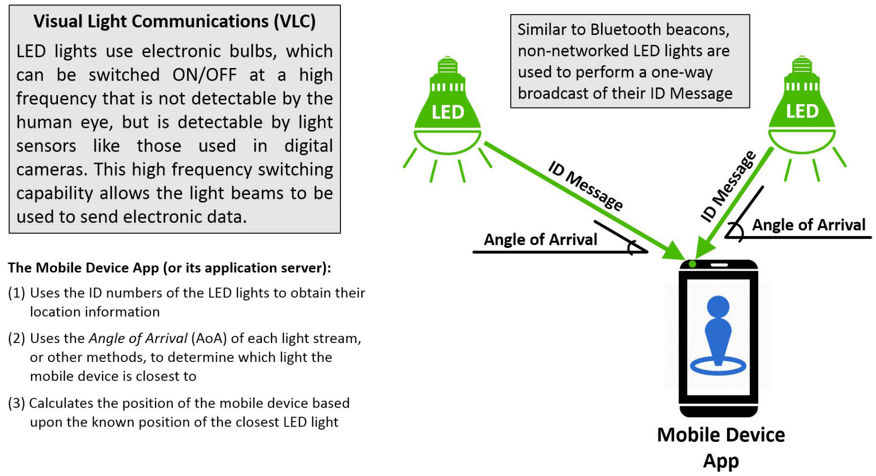
Intelligent LED Lighting Systems

A change from traditional lighting sources to intelligent PoE-powered LED lighting fixtures brings the following benefits:

- 50 percent to 80 percent reduction in lighting energy costs
- 85 percent or greater reduction in generated heat — lowering air conditioning costs
- 25 percent reduction in controllable lighting system installation costs
- 10-year LED life span eliminating three full traditional light replacement cycles

These benefits plus the comparatively low cost of VLC vs. Wi-Fi are reasons why most new buildings are strong candidates for intelligent light-based indoor positioning. For some specific types of buildings, there are even more compelling reasons. For example, VLC-based positioning can be deployed in hospitals without causing any interference to MRI scanners or other equipment. It can also be used in other RF-inappropriate environments where location can be extremely important, such as under water and in underground mines. Another major advantage of VLC-based positioning is that compared to RF, the visible light is much less subject to multipath effects (see the section on Wi-Fi-Based Positioning). Thus, light reflecting off walls and other surfaces maintains its data integrity, and so direct line-of sight is not required for VLC data transmission.

Figure 5. Visual Light Communications positioning approach using LED facility lighting.



Source: Author

Radio-Based Positioning

Bluetooth Low Energy (BLE)

Bluetooth Smart is the marketing name for Bluetooth Low Energy, commonly identified as BLE and categorized as beacon technology. Dictionary.com defines "beacon" as "a guiding or warning signal, such as a light or a fire, especially one in an elevated position." Thus, when devices that contained Bluetooth transmitters were used for object tracking purposes, the transmitting devices were called "beacons".

There are two basic beacon-based positioning approaches:

- Stationary beacons and mobile device receivers (typically for user positioning)
- Stationary receivers and mobile beacons (typically for indoor object or vehicle tracking)

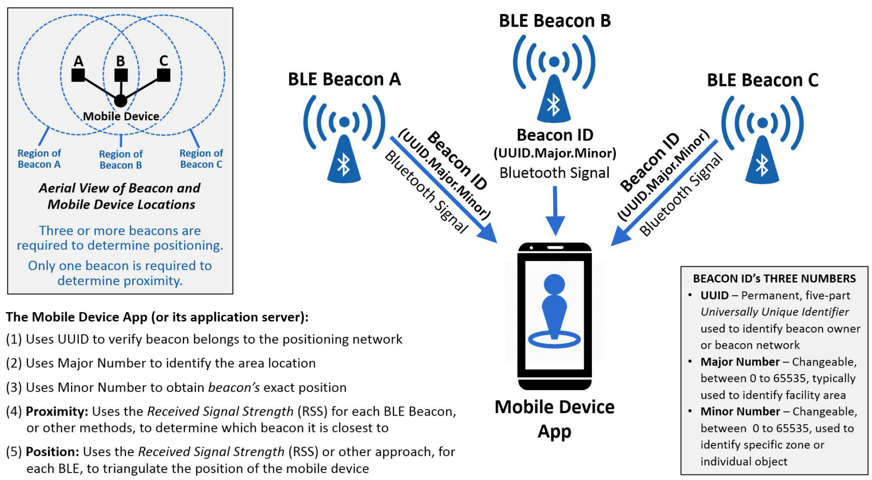
Stationary Transmitters and Mobile Device Receivers

Indoor positioning using stationary beacons is a popular design for proximity marketing applications. Proximity applications require a mobile receiver to receive only a single transmitter's signal, as the act of receiving the signal indicates that the receiver is in proximity to the transmitter.

Positioning applications require that a mobile receiver receives signals from at least three transmitters.

See Figure 6, which depicts a Bluetooth-based indoor positioning system with fixed beacons and mobile devices as receivers.

Figure 6. Bluetooth Positioning approach using fixed beacons and mobile receivers (mobile devices).



Source: Author

Stationary Receivers and Mobile Transmitters

A cargo tracking system is a good example of a mobile beacon application. Attaching beacons to cargo container trucks and placing receivers at the docking sites enables tracking the time and place each cargo item is unloaded. A more complex version of this example would be attaching beacons to shopping carts in large grocery stores. By installing receivers on every aisle, each shopper's movement path can be tracked and the aggregated data used to analyze customers' shopping behaviors.

Ultra-Wide Band (UWB)

Ultra-wideband is a radio technology that spreads high-bandwidth communications out over a large portion of the radio spectrum. This allows UWB transmitters to send large amounts of data while consuming little transmit energy. UWB can use a very low energy level for short-range communications. UWB achieves high-accuracy precision positioning to within 6 inches. The low frequency of UWB pulses effectively pass through walls, equipment, and any other obstacles. Properly designed, UWB will not interfere with existing RF systems. The very short transmissions pulses of UWB enable it to easily distinguish between direct signals and reflection, because reflected signals do not overlap the directly received signals. Thus, UWB is not susceptible to multipath interference. This makes it ideal for manufacturing plants and other environments that challenge most radio-based IPS technologies.

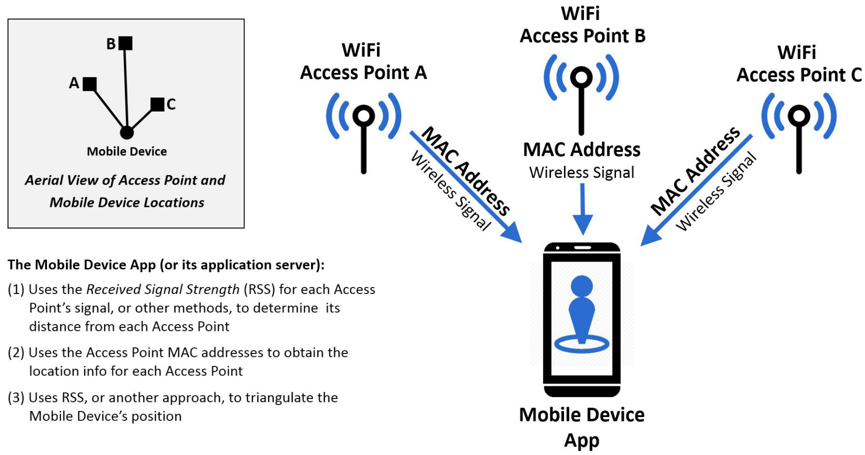
UWB uses fixed-location sensors (receivers) and tags. Various manufacturers provide a variety of commercial and industrial grade tags for assembly line products and indoor vehicle tracking, including, for example, locating transit authority buses within multi-level parking structures. Another example use case is the tracking of cows in large dairy farm facilities.

Most UWB indoor positioning systems are server-based systems, with an architecture like that shown for Zigbee positioning systems in Figure 8 on page 29.

Wi-Fi Positioning

When considering Wi-Fi based IPS technologies, a significant part of the required IPS infrastructure may already be in place. Plus, adding wireless access points for IPS purposes has the added value of increasing the capacity and reliability of the base Wi-Fi system.

Figure 7. Wi-Fi Positioning

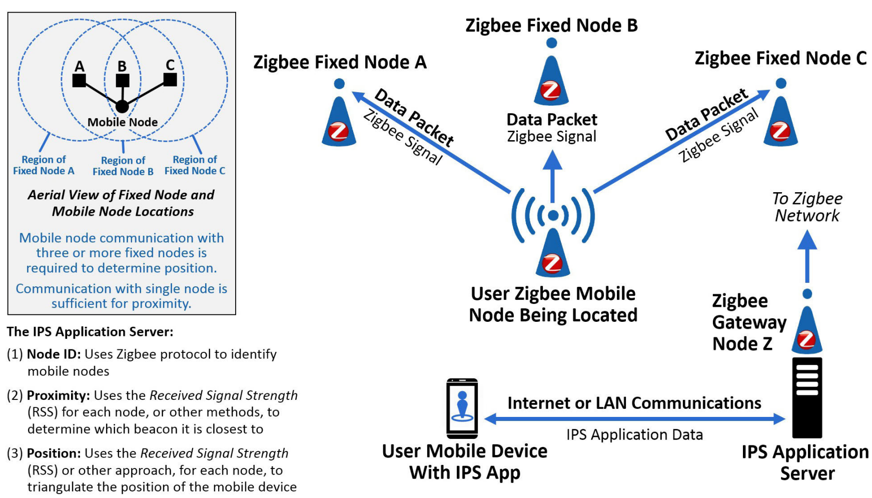


Source: Author

Wi-Fi positioning takes advantage of the planned or existing Wi-Fi wireless networking capability in a building. It uses the Wi-Fi receiver in a smartphone to calculate the distances to three or more Wi-Fi access points. Greater accuracy is provided by having more than three access points reachable from any location where positioning will be used. Mobile devices do not have to be connected to the Wi-Fi system, they simply need Wi-Fi enabled.

Zigbee

Figure 8. Zigbee Positioning



Source: Author

The Zigbee standard defines a short distance and low rate wireless personal area network. A basic Zigbee node is small and has low complexity and cost. It consists of a microcontroller and a multichannel two-way radio on a single circuit board. Zigbee is designed for applications that require low power consumption and low data throughput, and requires a button battery life of 2 years or longer for a product to be certified as Zigbee compliant, and products exist with a 6-year battery life. Zigbee nodes can be slightly larger than 1/2 in. square and 1/10 in. thick, small enough for a pendant or wrist-worn device.

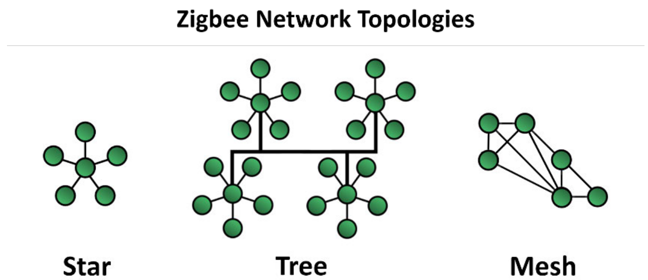
Zigbee supports star, tree and mesh networks, depicted in Figure 9 on page 30. Mesh networks are typically used for indoor positioning, because they are self-healing, meaning that if one node goes offline, nodes communicating through it will begin relaying data through a different node.

Zigbee technology achieves positioning by coordination and communication with nearby nodes, estimating the distance between the nodes. Zigbee-based positioning systems are server-based systems, as personal mobile devices do not currently support Zigbee. Zigbee wayfinding

IPS deployments require a wearable or hand-held Zigbee node.

Although the received signal strength approach can be used, calculating the fixed node distances from the mobile node in real time, more accurate readings can be obtained through the fingerprinting approach.

Figure 9. Zigbee Network Topologies



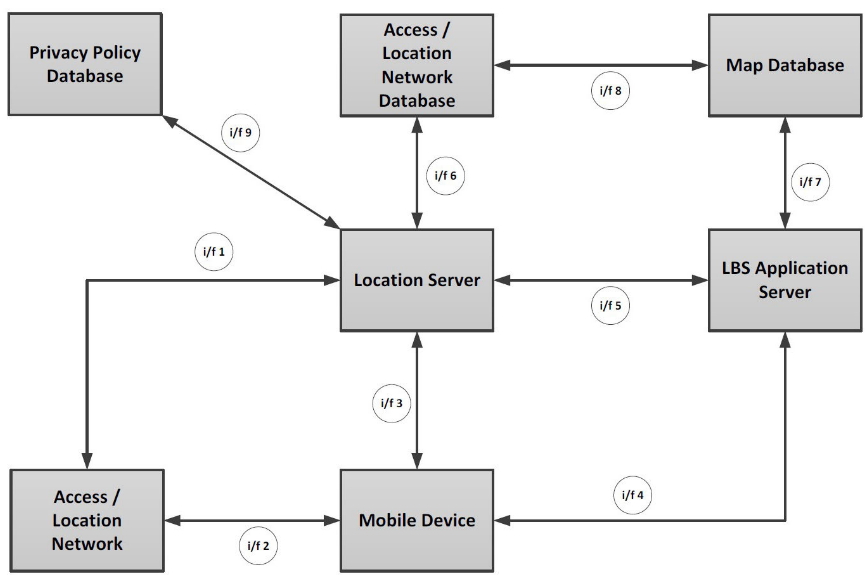
Source: based upon Wikipedia Star, Tree and Mesh diagrams

Dual/Multiple Technology Systems

Every IPS technology has advantages and disadvantages relative to other technologies. It is common for current-day IPS products to use more than one technology in a system. As already mentioned, smartphone inertial technologies are used to help transition through building dead spots in Wi-Fi or other radio-based positioning technologies. The following list presents the technology combinations that are currently used in modern IPS systems:

- Barcode + RFID
- Bluetooth + RFID
- GPS + Magnetic
- Inertial + Bluetooth
- Inertial + Wi-Fi
- Infrared + RFID
- VLC + BLE + Inertial
- Ultrasound + RFID
- Ultrasound + Wi-Fi

Figure 10. Indoor Positioning System Architecture



Source: InLocation Alliance

IPS System Architecture

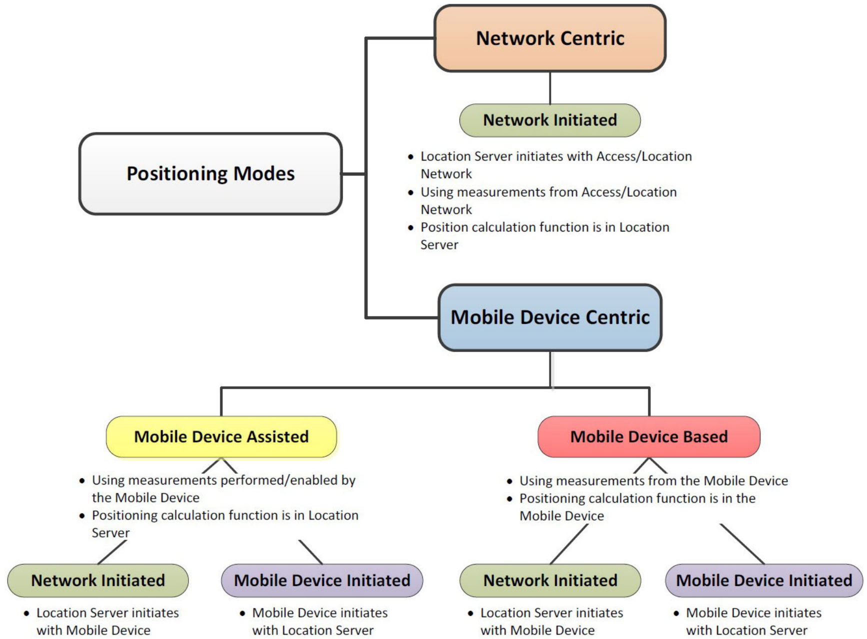
According to its website (www.inlocationalliance.org), the *InLocation Alliance* (ILA) was founded in 2012 by the mobile industry to accelerate the adoption of indoor position solutions that will enhance the mobile experience by opening new opportunities for consumers and venue owners. In 2014 the ILA created an open, technology-independent architecture in support of accurate location of mobile devices within different types of indoor venues (see Figure 10), which presents seven key system elements and nine interfaces.

The architecture supports a wide variety of use cases and provides an excellent frame of reference for the evaluation of specific product offerings. The architectural elements provided in the architecture may be delivered as subsystems within a single product or delivered as separate products. One intent for the architecture is to promote interoperability amongst various IPS offerings and device technologies, and to support multi-vendor deployments. The architecture document can be downloaded from the ILA website[12].

The 47-page architecture document contains a well-defined and very useful vocabulary for referencing important system elements and their functionality in discussions and documents.

Figure 11 from the architecture document provides a graphical representation of the different positioning modes (Network Centric, Mobile Device Centric), the mode of operation (Mobile Device Assisted, Mobile Device Based) and the originator of the location session (Network Initiated, Mobile Device Initiated).

Figure 11. Positioning Modes



Source: InLocation Alliance

The document contains eleven additional system diagrams, with detailed explanations, depicting the steps of a variety of system functions, communications interface and protocol requirements, plus example high-level end-to-end message flows for specific scenarios and use case steps.

The architecture document also addresses high-level privacy and security considerations.

Documenting Architecture

At the appropriate times, take the following steps with prospective system providers:

- Provide the two architecture diagrams (Figures 10 and 11) to prospective vendors, and ask them to document the architecture and positioning mode(s) of the IPS being considered, relative to these diagrams.
- Plan and document any data import or export functions.
- Review the existing system's reporting capabilities against what reporting requirements apply for business uses and security uses of the system.
- Review what applications reside where, such as an on-premises server or a cloud server.

12. Architecture document available at http://inlocationalliance.org/2014/09/inlocation-alliance-delivers-system-architecture-white-paper/

- If any integrations are needed, document what elements are to be integrated and what functionality will be provided, and how that will be supported.

Key Considerations Regarding Technology Selection

- Venue Suitability
- Complexity
- Compliance
- Carried/Wearable vs. Fixed Elements
- Mobile Device Dependencies
    - App required
    - Dedicated vs. shared resources

Data Privacy

Data privacy regarding indoor positioning systems is a complex subject. Achieving system data privacy requires the implementation of system data security controls, which include people, process and technology elements. Securing server-based, highly networked systems requires both information technology and cyber security expertise.

The security of the data communication technologies used in IPS products is continually improving. The ease or difficulty of achieving data privacy, which includes data in transit and data at rest, in large part is dependent upon the design of the positioning system and the nature of data security protections built into a manufacturer's IPS products.

The wide variety of technologies involved, and the product-specific nature of some system data security vulnerabilities, put a complete examination of data privacy outside of this paper's scope. However, it is important to understand the key privacy considerations for IPS applications. The SIA technical paper titled, "Big Data and Privacy for Physical Security," addresses privacy concerns for physical security systems, and is highly applicable to IPS systems that store data involving the activities of people and vehicles. The high-level guidance in that paper can be applied by organizations deploying IPS products, in addition to applying the data privacy principles described in the following paragraphs.

Key IPS Privacy Considerations

Mobile device IPS applications should treat history records of people and vehicle location information as personal and private data, and provide appropriate information security controls.

IPS Applications That Share Data

Special consideration should be given to applications that share data, such as family or group geo-fencing or proximity monitoring. IPS application features that include family or group messaging, sharing of location data with friends, or interaction between parent and child mobile devices must provide full disclosure of the data-sharing aspects of mobile apps that interact with mobile apps on other devices, especially the mobile devices of children.

Social media features, which may be found in retail store, restaurant, and entertainment venue IPS applications, must provide disclosure of data sharing, and control over data sharing to app users, with parental control being given to applications being used by minor children.

IPS Search Capabilities and Privacy

Mobile devices and social media have introduced a level of personal and business data sharing that is many orders of magnitude beyond what would have been acceptable in earlier times. IPS application search capabilities can answer the following common workplace questions:

- Did Frank leave the building for lunch yet?
- Is Bob still in the project meeting?
- Is Karen back in her office yet?
- Is the second-floor break room empty?

There are valid personal and business reasons for questions like these, which IPS systems can answer. However, there are also valid reasons for an individual not to want his or her current location known. Thus, IPS users must be able to opt-out of location reporting at any point in time. In contrast, there are also valid reasons for security and safety personnel to override personal location preferences for life safety reasons. These and other considerations lead to several requirements for IPS privacy policies and disclosure:

- **Opting out option:** Users must be informed that at any time a user can opt-out and opt-in for location reporting. Opting out of *location finding* should not be allowed for security and safety reasons. The opt-out must be for *location reporting* only, with security and safety being able to override an opt-out preference.
- **Opting-out convenience:** Opting in and out of location reporting must be convenient, which means that the opt-out period should be timer-based, with the user having reasonable control over the duration of the opt-out interval, so that the user isn't burdened with having to remember to opt back in again.
- **Security protection location** lockdown: There are executive protection and at-risk-personnel protection scenarios for which authorized security must have the capability to turn off location finding except for security personnel.
- **Disclosure:** The above location privacy considerations should be included in the IPS privacy policy, and be clearly disclosed to users.

Conclusion

Indoor positioning is a valuable category of technologies that is experiencing an accelerating adoption rate in many business sectors, including business and residential security applications. Due to the wide variety of IPS applications, and the broad array of IPS technologies, this paper only scratches the surface of this large subject. The information that is not included in this paper can be easily found online, and is readily provided by IPS technology manufacturers.

When security personnel understand the basics of indoor positioning applications, both for ordinary business and for safety and security incidents and emergencies, it is possible for security and safety personnel to ensure that their organizations appropriately consider the benefits of security IPS features, which in most cases can be obtained through a reasonable incremental addition to the IPS initiative's planning and budget resource allocations.

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References

1. Alarifi, Abdulrahman, et al. "Ultra wideband indoor positioning technologies: Analysis and recent advances." *Sensors* 16.5 (2016): 707.

2. Zhuang, Yuan, et al. "Smartphone-Based Indoor Localization with Bluetooth Low Energy Beacons." *Sensors* 16.4 (2016): 596.

3. Kanaris, Loizos, et. al. "Fusing Bluetooth Beacon Data with Wi-Fi Radiomaps for Improved Indoor Localization". *Sensors* 17.4 (2017): 812.

4. Ni, Yepeng, et al. "An Indoor Pedestrian Positioning Method Using HMM with a Fuzzy Pattern Recognition Algorithm in a WLAN Fingerprint System." *Sensors* 16.9 (2016): 1447.

5. Huynh, Phat, et al. "VLC-Based Positioning System for an Indoor Environment Using an Image Sensor and an Accelerometer Sensor." *Sensors* 16.5, (2016): 783.

6. Do, Trong-Hop, et al. "An In-Depth Survey of Visible Light Communication Based Positioning Systems." *Sensors* 16.5, (2016): 678.

7. Jachimczyk, Bartosz, et. al. "Using the Fingerprinting Method to Customize RTLS Based on the AoA Ranging Technique." *Sensors* 16.6, (2016): 876.

8. Liu, Junjie. "Survey of Wireless Based Indoor Localization." PDF. Washington University in St. Louis, 30 Apr. 2014. Web. 6 July 2017.

9. Luo, Yan, et al. "Enhancing Wi-Fi fingerprinting for indoor positioning using human-centric collaborative feedback." *Human-centric Computing and Information Sciences* 2013 3:2.

Product Information

Product and case study information reviewed for this paper was provided by the following companies:

Acuity Brands Lighting, Inc., www.acuitybrands.com

AeroScout, LLC., www.aeroscout.com

Aisle411, http://aisle411.com

Apple Inc., www.apple.com

Aruba Networks, www.arubanetworks.com

Cisco Systems, Inc. www.cisco.com

Ekahau, Inc., www.ekahau.com

Estimote, Inc., https://estimote.com

General Electric Company, GE Lighting, www.gelighting.com

Google, Inc., www.google.com/about/

IndoorAtlas Ltd., www.indooratlas.com

Maxxess Systems, Inc., www.maxxess-systems.com

Philips Lighting Holding B.V, www.usa.lighting.philips.com/home

pureLiFi, http://purelifi.com

Ubisense, https://ubisense.net

ZIH Corp, www.zebra.com