The Technologies behind a Context-Aware Mobility Solution

Introduction

The concept of using radio frequency techniques to detect or track entities on land, in space, or in the air has existed for many decades. Since the experimentation on radio waves in 1887 by Heinrich Hertz, the existence of electromagnetic waves and how they could be embraced to detect entities has been a continuous area of research and development. As early as 1915, Robert Watson-Watt used radio signals to track thunderstorms. World War II saw radar introduced to track enemy aircraft.

Today's context-aware mobility solutions have evolved and adapted to the requirements of complex business processes, integrating information beyond the location of assets such as telemetry and motion. This white paper will discuss the location-tracking aspect of context-aware mobility solutions. Once the location of an asset has been recorded, the telemetry information from sensors can be correlated to the location information.

In this paper, you will learn about the main location-tracking technologies and the different techniques that are used to calculate the location of business assets as part of a context-aware mobility solution. The technologies described should be thought of as complementary rather than competing. Indeed, most of the time, a business process encompasses multiple use cases at once and thus benefits from a mix of these technologies. For instance, a factory may have to track finished goods in the plant and outside on the parking lot. These are two different environments and thus call for different location technologies.

What Is a Context-Aware Mobility Solution?

Today, context-aware mobility solutions provide the ability to dynamically capture and use contextual information about mobile assets to optimize, change, or create communications flow and business processes. Contextual information can be collected for any mobile asset involved in a business process, and this includes not just devices and products but also people. For instance, a mobile asset can be a worker, a customer, or a patient, or it can be a pallet of finished goods.

Typically, several wireless networks have to be used during execution of the same business process. The most widely adopted wireless technology is the wireless LAN (WLAN), but Wi-Fi mesh, WiMAX, cellular, or GPS networks can also be used when devices, tags, and sensors with the proper radios are available. A variety of context-aware technical solutions using Wi-Fi or other wireless networks can be deployed running standalone or simultaneously. Context-aware mobility solutions are most often Wi-Fi based, since the majority of enterprises today have a WLAN deployed, which they use for corporate communications. Also, the majority of mobile devices include Wi-Fi radios.

In a context-aware mobility solution, wireless devices, tags, or sensors send the contextual information they collect via the WLAN. The network, in turn, uses these signals to calculate the location of the assets and correlate it to additional sensor information, if available. The algorithms used to determine the location vary depending on the RF environment and the accuracy needed for a specific application. For some business applications, it is important to track an asset continuously throughout an entire facility. On the other hand, some business processes only require information that captures whether an asset is in or out of a zone (room, parking place, and so on).

Sensor capabilities can be directly embedded into tags in order to link the data captured (for instance, motion or temperature data) with the location of the mobile asset. Many industries are already using context-aware technologies to manage the mobility of their assets. Healthcare, manufacturing, retail, and education are integrating context-aware information into their business practices and processes for innovation. For a context-aware mobility solution to tightly integrate with vertical application and business processes, it is crucial that the solution provides an open API and an ecosystem of best-in-class partners.

Typically, in a context-aware mobility solution there are two kinds of location-tracking systems used: active and passive tracking. In an active tracking system, the locatable device has a battery and uses it to send messages to the readers continuously. In a passive system, the locatable device has no battery and sends messages only after it receives energy coming from a chokepoint.

Active Location Tracking

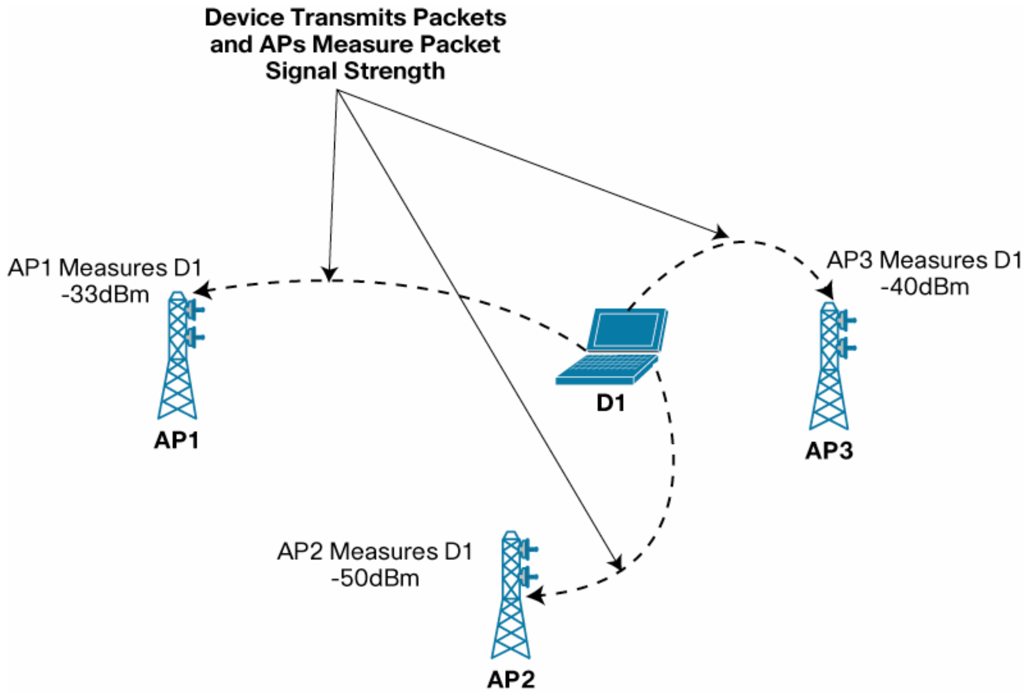
Active location tracking uses two different technologies: received signal strength indication (RSSI) and time difference of arrival (TDoA).

Received Signal Strength Indication (RSSI)

Active location tracking can be performed on wireless assets or assets such as wheelchairs, which carry active RFID tags. It provides a versatile option for enterprises that like to take advantage of context-aware mobility solutions to increase the productivity of their business. Active tracking using RSSI is a technique in which a measuring device detects the signal strength of a transmitter’s packets and determines its own location or the location of the transmitter based on those measurements. Figure 1 illustrates active tracking that uses wireless network infrastructure.

Network infrastructure devices, such as 802.11 access points, are deployed to track devices—for example, a dual-mode phone (cellular and 802.11). The access points use the received signal strength of packets transmitted by the phone to determine the phone’s location.

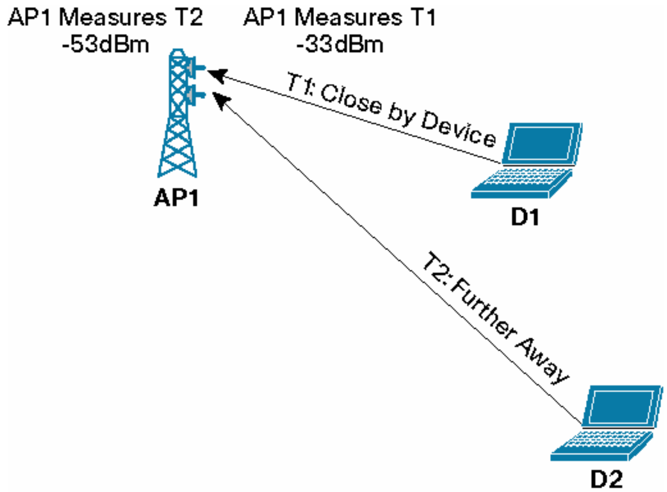
Figure 1. Active Tracking Using Access Points



To be able to determine the location of a mobile device in the environment illustrated in Figure 1, the device that performs the location calculation (typically a location server) must know the location of all measurement devices (in this example, the access points). When the mobile device transmits a packet, that packet may be detected by one or more access points listening on the same RF channel that the packet was transmitted on. When the access point listens to the packet, it measures the signal strength of the packet and forwards that measurement to the location calculation engine. The location server then correlates the various measurements and calculates the location of the transmitter using triangulation or other advanced techniques.

If there is a direct line of sight between the transmitter and the measurement point, a simplifying assumption is that the lower the received signal strength of the packet at any particular measurement point, the further away the transmitting device is from that measurement point. Figure 2 shows an example in which two devices are transmitting to the measurement device, one close to the measurement device and a second further away. The measurement device receives the transmissions of both devices, but at different signal strengths. The signal strength of the object that is further away from the measurement device is lower. Based on this information, the distance between the devices and the measurement point can be calculated.

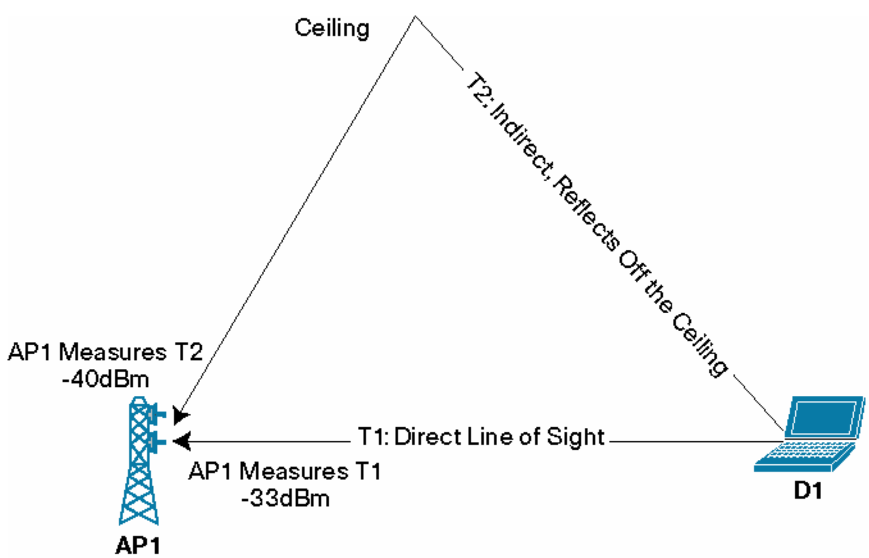
Figure 2. Measuring Signal Strength Based on Distance



In certain physical environments, the line of sight between the transmitter and measurement device can be impacted. Many environments, including offices, hospitals, and warehouses, are difficult RF environments with RF obstructing structures and reflective surfaces. In these cases, the signal sent from the device does not go directly toward the measuring device, but is reflected off a surface such as a room ceiling. This causes the signal of the device to take a longer path, and thus it arrives with a lower signal strength at the measurement point. The actual distance between the device and the measurement point might appear larger than it actually is, because of the reflection.

Figure 3 shows this scenario and how multipath interference can affect the accuracy of location determination. Context-aware mobility systems are designed to minimize the impact of obstructions by using real-time measurements and predictions sometimes called “RF pattern recognition” or “RF fingerprinting.”

Figure 3. RF Line of Sight and Multipath Interference



Benefits and Limitations of RSSI

One advantage of active tracking is that it typically uses a wireless network infrastructure that is already in place and at the same time functions as a network for data, voice, and video communications. All wireless devices that are working on the network can be directly tracked. For devices that have no radio interface, such as infusion pumps or wheelchairs, active RFID tags, which can actively transmit signals to the wireless network, can be physically attached to an asset so that it can be tracked.

Since 802.11 is the most commonly deployed wireless technology today, most context-aware mobility solutions are based on Wi-Fi networks for a lower total cost of ownership. Indeed, the network serves multiple purposes, including connectivity and the collection of contextual information, and all these network services can be centrally managed.

When the network infrastructure provides tracking data, the location information can be easily integrated with other relevant network data, such as security credentials, statistical information, and user information, to enable a complete collection of contextual information on the mobile device (users or physical assets) in the network.

In an active tracking technology, the device being tracked sends signals to the wireless network so its location can be calculated. In a network where wireless devices such as laptops are primarily sending data packets that are usually bursty, location determination can become inconsistent over time.

To overcome this problem and achieve accurate and consistent tracking, the network can instruct the tracked device to transmit one or more packets at regular intervals on a set of specified RF channels. The network can also instruct the tracked device to include certain information in the transmitted packets—for instance, the transmit power used for the transmitted packet. This extra information makes it easier to determine the location of an asset accurately. Wireless clients that have been certified under the Cisco Compatible Extensions program specifications are designed for high compatibility with Wi-Fi networks and mobility solutions and eliminate the issues of bursty client signals.

For environments where the RF space has many obstacles and obstructions, such as in the outdoors or in warehouses, active location tracking based on RSSI performs better than other techniques described later in this paper. RSSI is most suitable to collect context-aware information of high value or high utility items indoors. Indoor offices, hospitals, banks, smaller warehouses, are suitable for active tracking with RSSI, particularly when coupled with RF fingerprinting. In these environments, it is particularly useful and outperforms other location determination techniques.

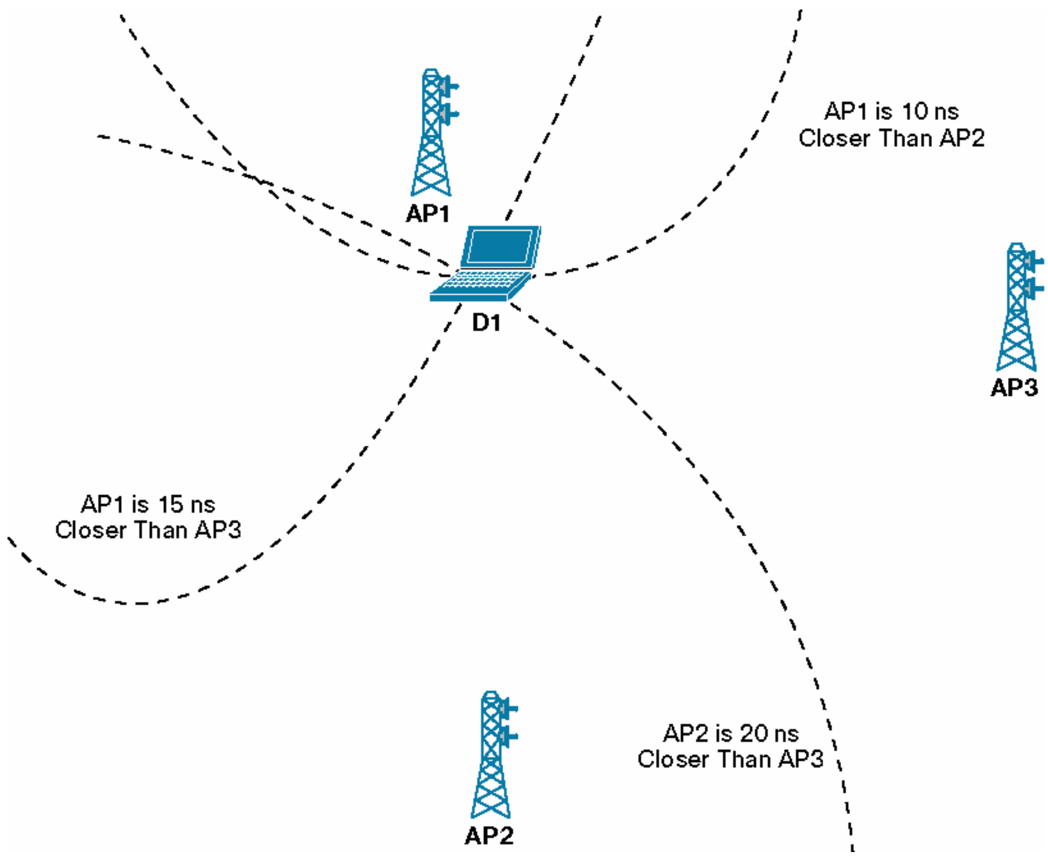
As an example, consider the following scenario: An alert is sent to the IT team when the wireless sensor on laptop L, running in building A, registers abnormal temperatures. When the member of the IT team arrives in building A, her mobile device automatically opens a map of building A and helps locate L. Once the IT staff member is close enough to L, the associated case report appears on the screen, accelerating the process and reducing the chance for error. Meanwhile, if another IT case opens and is located in building A, the same IT staff member is notified. Thus the contextual information is used to optimize the team’s resources and speed up resolution of the problem.

Time Difference of Arrival (TDoA)

Time-difference-of-arrival (TDoA) or network-infrastructure-based systems avoid requirements on the client. This is important because of the hundreds of millions of Wi-Fi devices sold and being sold that do not have the hardware to support systems based on time-of-arrival.

Here's how TDoA works. First, all receivers are synchronized, using either over-the-air signaling or a common clock distributed via separate cabling to each receiver. Second, when a client transmits, all receivers record the time of arrival (ToA) of the packet and send it to the device that performs the location calculation (typically a location server). Even though the location calculation engine doesn't know when the packet was transmitted, it can compute TDoAs. For instance, if one receiver hears the transmitted data frame 10 nanoseconds before a second receiver, then the first receiver is 10 feet closer to the transmitter. With multiple pairs of receivers, there can be multiple TDoAs from which location can be calculated, as shown in Figure 4.

Figure 4. A Time-Distance-of-Arrival System: Determining Device Location by Reconciling the Hyperbola Defined by Access Points



Benefits and Limitations of TDoA

For the TDoA system, the location calculation becomes more accurate with higher bandwidth and greater transmit power. In line-of-sight environments, TDoA systems can achieve greater accuracy than RSSI systems, especially when the clients are at greater distances from the receivers or the receivers are mounted at great heights.

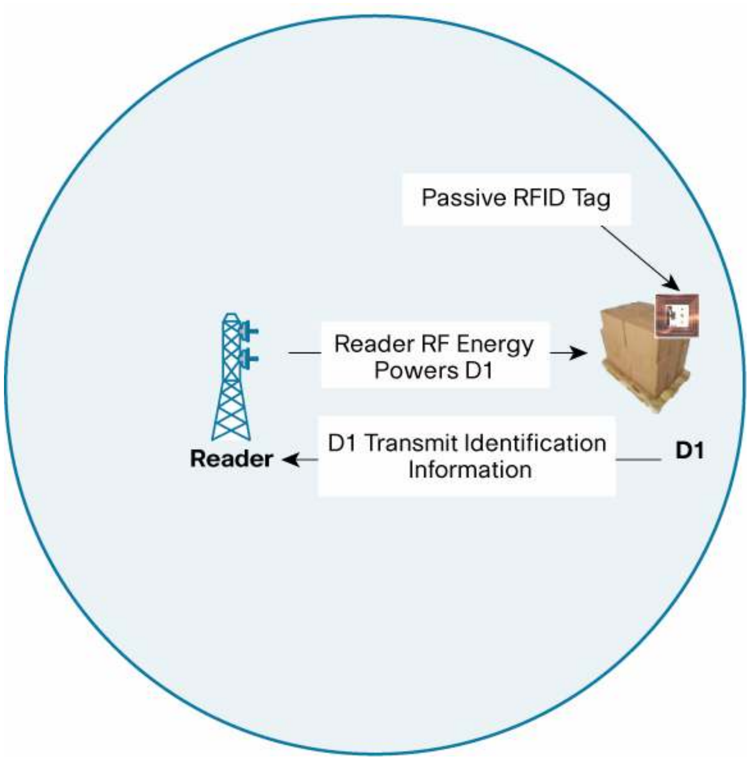
Network infrastructure TDoA systems can be used to track assets in large physical open spaces such as university campuses, car lots, ports, or in RF-challenging environments, such as large, open warehouses and factories.

In schools that have a pervasive WLAN, attendance can be tracked using the students' Wi-Fi laptops as locatable devices. If a laptop is lost, it can also be located throughout the campus using the WLAN. An example in manufacturing is that goods that are ready to be shipped can be tracked outside of the warehouse while they are moved to different locations and then loaded onto a truck.

Passive Location Tracking

Passive tracking is a technique where wireless network infrastructure devices, such as passive radio frequency ID (RFID) readers, or chokepoints are deployed to track devices that have no battery. These locatable devices can send messages only after they receive energy coming from a chokepoint or RFID reader (Figure 5).

Figure 5. Passive Reader and Tag Communication



The communication between the RF reader and the device allows the passive RF reader to identify the passive RFID tag and transmit the tag's identification information and location to an asset tracking application. When a passive RFID tag is not within range of the passive RFID reader, the tag's location cannot be determined.

Benefits and Limitations of Passive Tracking

Passive tracking can be deployed for specific applications such as tracking items that are being moved in and out of a specific limited zone or for error checking (for example, when associating two objects such as patient and medication, or a pallet and objects being loaded on the pallet for delivery). This is usually accomplished by protecting entrances and exits in a facility with readers or chokepoints, which capture the movement of assets in and out of the facility.

The limitations of passive tracking include the fact that the location of a device tracked by passive technology cannot be determined when it is not within range of a measurement device. Furthermore, in passive tracking, additional information such as telemetry data cannot be captured.

In general, passive RFID tags are smaller and lower in cost than active tags, thus they are useful for tracking low-cost items in retail, distribution, or for keeping track of paperwork in hospitals.

Combining Multiple Technologies for Best Results

The choice of location-tracking technologies in a context-aware mobility solution depends on the RF environment of a facility or outdoor area, the accuracy needed for a specific application, and the type of information that should be recorded. For indoor applications, location tracking is often based on received signal strength indication (RSSI). For outdoor or high-ceiling environments such as warehouses, time difference of arrival (TDoA) is most appropriate. Passive location tracking is best used when it is important to note the close proximity to a specific point that has a reader attached. Complex business processes commonly require the use of multiple location-tracking techniques based on the existing network, the accuracy, or range needed by the applications, the type of locatable devices, and the continuous tracking of assets indoor and outdoor. The following use cases highlight the need for deploying multiple location-tracking technologies to support a complete business process.

In a manufacturing environment, for example, the passive RFID systems can be deployed on the assembly line to monitor production and in-process goods. Mobile RFID readers that are Wi-Fi-enabled can be tracked within the facility by combining active and passive location tracking. Suppliers can be automatically notified so that raw materials can be replenished when they are running short. At the same time, finished goods can have an active Wi-Fi tag to monitor their location in a continuous manner anywhere throughout the facility, as well as to update inventory management applications when they leave the building for shipping. A chokepoint attached to the exit door of the facility will record when an item leaves the building to be processed and shipped outdoors. For the highest accuracy inside a typical storage room, RSSI can be used for location tracking. With the goods moving into a large warehouse with high ceilings, the context-aware solution needs to start deploying TDoA tracking technology, since RSSI will not be as effective. As the business process continues and the finished goods are moved to the outdoors for shipping, the most appropriate technology for this environment again is TDoA.

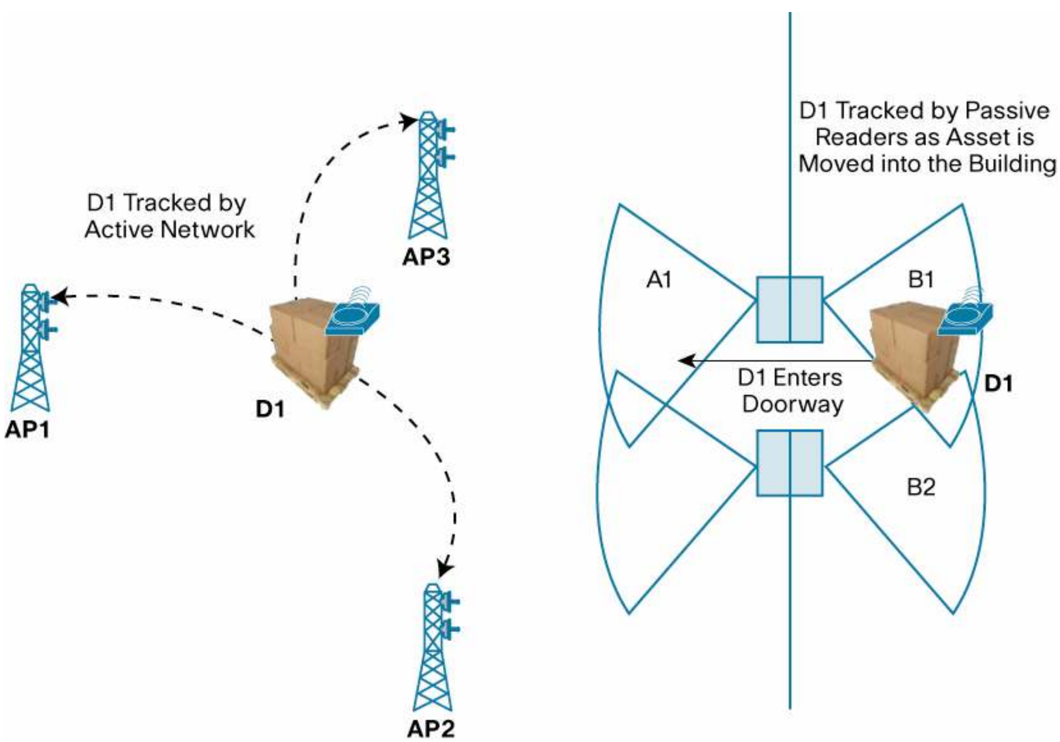
In healthcare, several hospitals have used their context-aware solution based on a WLAN (already used for voice, data, and video applications) to continuously track physicians and make sure they are present in the emergency room when needed. A chokepoint can be attached to the doorway of the emergency room so that personnel entering and exiting can be tracked and the system can record whether there is a physician present in the emergency room at any certain time. When a medical specialists needs to be called in, the closest medical specialist can be located using RSSI technology.

In schools that have a pervasive WLAN with a context-aware solution deployed, attendance in a classroom can be tracked using the students Wi-Fi laptops as locatable devices. If a laptop is lost or stolen, it can be located throughout the building with the technique of RSSI, and on the outdoor campus using TDoA.

Some business processes profit most when a combination of active and passive tracking technologies is combined into a single context-aware solution. A network device that has both active and passive capability can be tracked almost continuously using the network. If the device is not within range of a passive network infrastructure, the device is tracked by the active network infrastructure. When it is in range of the passive network infrastructure, the device location is determined by the passive components of the network tracking solution. Typically, both elements of the network tracking solution can provide their data to a central location server, where aggregation of the data can provide the optimal location determination.

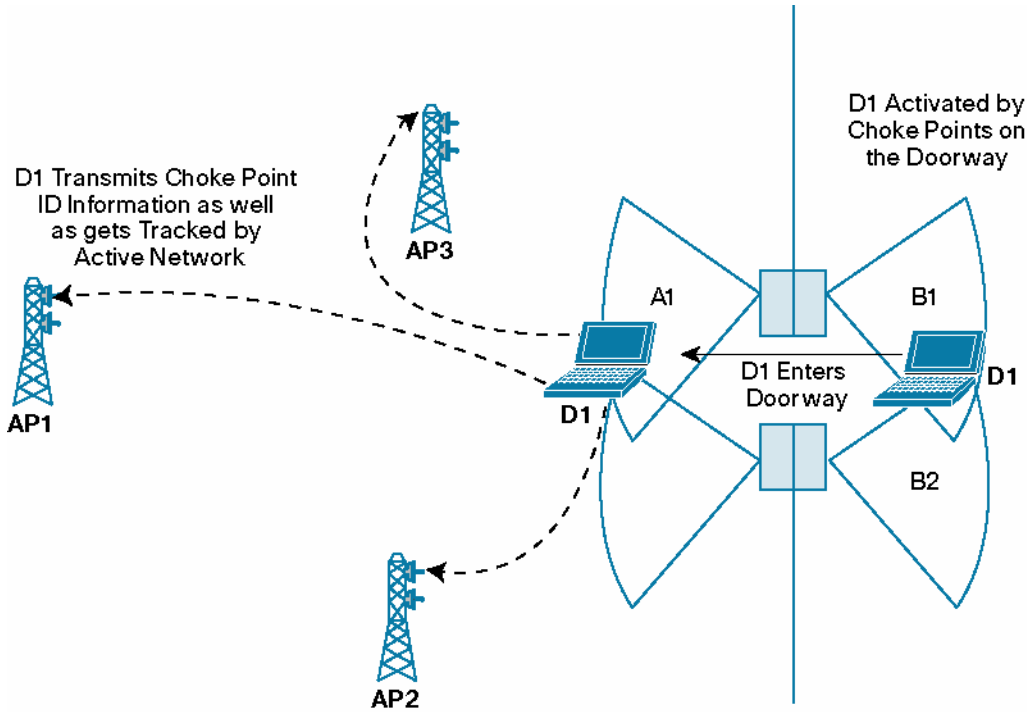
One example of how active and passive tracking can be combined is where the tracked asset has both a passive RFID tag and an active network interface (for example, an 802.11 interface). As Figure 6 shows, this allows the device to be tracked with a combination of active and passive tracking and the use of chokepoints.

Figure 6. Combined Active and Passive Tracking Example



Another example, illustrated in Figure 7, is where a chokepoint is used in place of a passive RFID reader. In this case, the chokepoint does not read any data back from the tagged asset; instead, the chokepoint transmits an RF energy field similar to a passive RFID reader. When a tag comes in range of the chokepoint's RF energy field, the tag reads the information transmitted by the chokepoint and then the tag transmits this information to an alternative data network, such as the 802.11 data network, that allows the device to be tracked actively. A business application for this is the tracking of patients that enter and leave their room with a chokepoint that activates a patient's RFID tag. Once the patients are moving around the hospital they can be located at any time through active tracking via the Wi-Fi network.

Figure 7. Active Tracking Example Using Chokepoint Activation



The use cases just described show that when considering the implementation of a context-aware solution, it is crucial to choose a solution that integrates a variety of different location-tracking techniques. Only a versatile and expandable industry solution can answer the full range of business needs today and evolve as you integrate contextual information more and more into your business processes.

Future Directions in Location Tracking

Just as location techniques for use with Wi-Fi networks are being developed, non-Wi-Fi technologies are under development as well. Although non-Wi-Fi technologies have the disadvantage of not tracking the existing base of Wi-Fi devices and of requiring an additional network of receivers, these technologies do have different and often beneficial attributes. Context-aware mobility solutions that are designed with open APIs and that offer a ecosystem of partners are able to integrate new technologies easily.

The main attribute of ultra-wideband (UWB) systems is to transmit their energy over a significantly wider bandwidth than Wi-Fi: for instance, 500 MHz instead of the 20 MHz typical of Wi-Fi. As bandwidth and time resolution are inversely related, this greater bandwidth yields finer time resolution and hence the potential for markedly greater location accuracy.

UWB was first proposed as a low-cost communication scheme, using simple impulse waveform for modulation. This is inefficient in terms of communications theory, so alternative designs using the more spectrally efficient Orthogonal Frequency Division Multiplexing (OFDM) soon followed. Both systems have wide bandwidth and both are promising candidates for location services, with OFDM favored for high-rate communications. Standardization efforts were contentious, and today the landscape comprises:

- The WiMedia Alliance, which specified an OFDM system optimized for high-rate communication and therefore possessing too short a range for location.
- The ultra-wideband physical layer (UWB PHY) module within IEEE 802.15.3c, using an impulse waveform. This standard is optimized for low-cost devices principally performing medium-range location, plus some low-to-medium rate communications.

With 500 MHz of bandwidth, the base resolution of an UWB waveform is 2 nanoseconds or 2 feet. Using multiple UWB receivers, with each performing super-resolution signal processing, this can be improved by an order of magnitude or more. Thus UWB will become the accuracy leader—in relatively open spaces, subfoot accuracy is achievable.

Only a few proprietary systems, however, and no standards-based systems are available today, and a high density of receivers is required because regulatory constraints impose tight limitations on the achievable range. Accuracy depends upon the direct path from transmitter to receiver being discernible at the receiver, so intervening obstacles like metal reflectors can create strong, delayed echoes and are challenging. Accuracy that drops to 5 feet or less is typical.

UWB is suited to covering smaller areas for applications demanding very high accuracy, typically indoors. Examples include industrial manufacturing, warehouse distribution, and people-tracking—for example, soldier training, trade-show tracking, and player tracking during sports events. Ultrasound systems that may become available in the future might contribute to increasing the accuracy of context-aware mobility solutions for specific environments.

GPS is another technology that is highly mature and shows great promise for being integrated into context-aware mobility solutions. GPS tracking functions similar to the TDoA system already described, except that with GPS, satellites transmit signals to the client instead of vice versa. Satellite locations are embedded in the signaling, so that the client has all the information it needs to calculate its location autonomously. GPS is very accurate in the outdoors where line-of-sight links to the satellites are possible, but does not penetrate well into large buildings. Hybrid solutions like GPS with TDoA and Wi-Fi outdoor mesh networks with RSSI provide a combination that can avoid this problem.

Summary

In a context-aware mobility solution, wireless devices, tags, or sensors send the contextual information they collected via a Wi-Fi, cellular, or other wireless network, which in turn uses these signals to calculate the location of locatable assets. The location-tracking technologies used vary depending on the RF environment and the accuracy needed for a specific application. For typical indoor facilities such as business offices, a combination of active and passive location tracking provides the best context-aware mobility solution. RSSI works well as location-tracking technique in these environments. For outdoor areas, such as university campuses and challenging RF environments such as buildings with high ceilings or warehouses, TDoA is more appropriate.

When the mobile asset does not have a radio capability, RFID tags can be attached to it to collect the parameters needed.

Businesses might consider implementing context-aware solutions into their business practices to empower workers to meet and exceed business mobility goals. To implement a durable and customized location solution, companies should clearly define the requirements the location solution has to satisfy. Do they need continuous or event triggered tracking? How accurate does the solution have to be? What are the locatable devices?

Companies should then look at the network already in place and estimate how much additional equipment is required, how the management of the network and the location solution will integrate, how long the installation will take, and how likely it is that the location solution will match their needs. Weighing all these considerations, a staged approach may be appropriate. Especially if a pervasive WLAN is already in place, a Wi-Fi RFID system should be deployed first because it is most economical and simple to deploy.

When selecting a context-aware mobility solution, it is crucial to consider several primary requirements:

- **Supports a broad range of enterprise environments:** For a context-aware mobility solution to support complex business processes, it has to integrate different location technologies and techniques. Active and passive location-tracking technologies combined with RFID tags and chokepoint technology provide the best solution for diverse environments and application requirements.
- **Helps innovate business processes and operations:** A context-aware mobility solution should directly support your current business processes and lead to innovations throughout the entire business operation. To optimize business processes, it is necessary to track more information about assets than just their location. It is crucial to be able to collect and process additional information about an asset, such as motion and telemetry information (temperature, humidity, pressure, and so on). To enable an enterprise to expand the solution seamlessly according to its growing needs, choose a context-aware mobility solution that supports the tracking of thousands of devices and clients.
- **Supports tight integration with business applications for vertical solutions:** Any context-aware mobility solution requires tightly integration with the specific business applications of an enterprise. Solutions that offer an open API support the integration of specific and vertical applications with best-in-class partners. Furthermore, the solution needs to be compatible with a broad range of clients and RFID tags, which can be accomplished through the Cisco Compatible Extensions program specifications. Cisco Compatible Extensions also helps ensure that RFID tags and applications from different partners can be integrated into the overall solution.
- **Offers investment protection:** You get the best investment protection from a context-aware mobility solution based on a Wi-Fi network that is already in use for business communications and applications and is easily expandable and extendable to future technologies. Easy deployment and central management of all network services reduces total cost of ownership.

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