Note from the Authors: This article is an excerpt from Chapter 3, Section 3.4 of *Wireless Internet & Mobile Business How to Program*. Wireless communications is growing at a rapid rate and people are using wireless technologies to enhance all aspects of personal and business communications. This article explores how businesses and consumers are taking advantage of new location-identification technologies for commerce and the various technologies used to determine the location of wireless-devices, including Cell of Origin (COO), Angle of Arrival (AOA), Time Difference of Arrival (TDOA), Global Positioning Systems (GPS) and more.

3.4 Location-Identification Technologies

In this section, we explore the various technologies used to determine the location of wireless devices (Fig. 3.2). These technologies enable businesses to provide location-based services to users. For example, when a user asks for directions to the nearest coffee shop, the wireless carrier (such as AT&T, Verizon or Cingular) can determine the location of the user's wireless device. This information is presented to the content provider (the business offering the location-based service) in the form of a *geocode* (the latitude and longitude of the user's location). The geocode is then translated into a map or step-by-step navigational instructions with the help of a mapping service. As we discussed in Section 3.2, Enhanced 911 Act (E911), Phase II of the E911 Act mandates that network providers locate wireless devices within 125 meters 67 percent of the time.

Triangulation is a popular technique used by many location-identification technologies. A device's location is determined by using the angles from (at least) two fixed points a known distance apart. Location-identification technologies are either *satellite based* (a "constellation" of satellites determine location) or *network based* (a series of cellular towers determine location). Satellite-based methods, such as GPS, have been used longer than network-based methods, such as Time Difference of Arrival (TDOA), Angle of Arrival (AOA) and Location Pattern Matching.[1] Location-identification technologies are *network centric* (the network manages location identification, and no device enhancements are necessary), *handset centric* (an upgrade to the device is necessary to determine a user's location) or a combination of both. In some cases, a location-based service must have users enter location information manually. For example, users can submit their zip-code. However, this does not enable location-based services to provide highly accurate location information because zip codes generally cover large areas.

Technology	Requires Upgrade to Device or Network	Degree of Accuracy
Cell of origin (COO)	No	Least accurate of technologies discussed. User could be anywhere in tower's range. Meets only the requirements of Phase I of E911 Act.
Angle of Arrival (AOA)	No	Fairly accurate. User is within the overlap of two towers' cell sites. Used primarily in rural areas where there are fewer towers. Complies with Phase II of E911.
Time Difference of Arrival (TDOA)	No	Accurate. User's location is determined by triangulating from three locations. Complies with Phase II of E911. Most effective when towers are close together.
Enhanced Observed Time Difference (E-OTD)	Yes	Accurate. User's location is determined by triangulating from three locations. Complies with Phase II of E911.

Fig. 3.2 Location-identification technologies. (part 1 of 2)

Technology	Requires Upgrade to Device or Network	Degree of Accuracy
Location Pattern Matching	No upgrade to device or network, but database must be maintained.	Accurate. User's location is determined by analyzing multipath interference in a given area, making the technology more effective for locating a device in an urban area.
Global Positioning Systems (GPS)	Yes	Highly accurate. A user's location can be determined anywhere on earth. However, GPS is not as effective when the user is indoors.

Fig. 3.2 Location-identification technologies. (part 2 of 2)

There are many obstacles in developing location-identification technologies. Cost is one issue. Satellite-based services, such as those supported by GPS technology, are expensive because handsets must be enhanced. Standardization presents another challenge. In accordance with the E911 Act, each wireless carrier must be able to identify users' locations. However, the carriers may choose from a variety of technologies to provide this information. No one standard exists, thus locating users becomes a proprietary effort, challenging the seamlessness of location identification, as users move from an area covered by one network provider to another.

m-Fact 3.1

The total cost of building, staffing, maintaining and monitoring a satellite used for location-identification purposes is estimated to be $12 billion. The satellites currently being used have lifespans of 7–15 years, making periodic replacement inevitable.[2]

3.4.1 Cell of Origin (COO)

Cell of origin (COO), the most primitive method of locating a wireless user, does not require individual handset or network infrastructure enhancements. However, COO is the least accurate of all location-identification technologies and does not meet the requirements of Phase II of the E911 Act.

Each call made from a cell phone is transmitted to a nearby tower. From this tower, the call is sent to the intended recipient. The tower transmitting the call covers the COO—a specific area, usually a circumference of several kilometers (Fig. 3.3). When the call is made, the caller is located within the transmitting tower's range. There is no way to determine whether the user is north, east, south or west of the tower. In areas where towers are close together, users can be located more precisely, because the range of each tower is smaller. In rural areas, where there are fewer towers and the range between towers is greater, the degree of accuracy decreases.

3.4.2 Angle of Arrival (AOA)

Angle of Arrival (AOA) measures the angles from which a cell phone's signals are received by two or more towers, then uses this information to determine the user's location (Fig. 3.4). When a cell-phone user makes a call, the phone's signals are received by cell-tower antennas. The cell towers detect the compass direction of the phone's signal and relay this directional information to the AOA equipment. The AOA equipment then compares the angles between the caller and the various receiving cell towers and, using triangulation, determines the caller's longitude and latitude.

The accuracy of locations found using AOA is limited by signal interference. For example, city skyscrapers can cause the signal to bounce. If the signal bounces, it is less likely to reach the target, resulting in a weak signal or none at all. AOA works best in sparsely populated areas, where there is a lower likelihood of interference.[3] To deliver the most accurate service, many companies combine AOA with Time Difference of Arrival (TDOA).

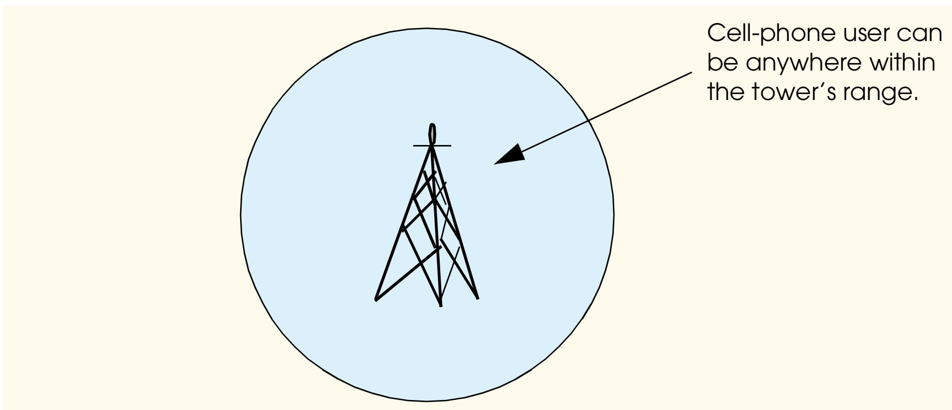

Fig. 3.3 Example of a cell of origin (COO).

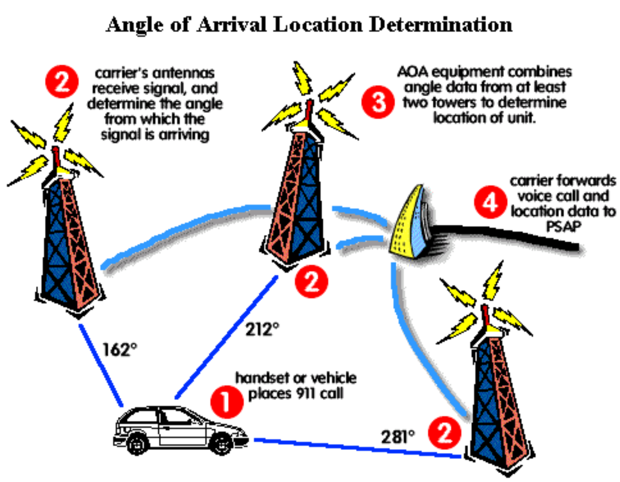

Fig. 3.4 Angle of Arrival (AOA). (Courtesy of Dispatch Monthly Magazine.)

3.4.3 Time Difference of Arrival (TDOA)

Time Difference of Arrival (TDOA) also uses triangulation to determine the location of the user. Unlike AOA, TDOA measures the time it takes a cell-phone signal to reach the receiving tower and two additional towers.[4] From the signal's travel time, the network determines the user's distance from each tower. This information creates a set of arcs between the receiving tower and each of the two adjacent towers (used for positioning). The intersection of the arcs identifies the location of the cell-phone user (Fig. 3.5).[5]

TimesThree (a network-based solution provider), TruePosition and SigmaOne have committed to TDOA as their standard location-identification method (see Feature: Cell-Loc, Times Three and TDOA). Each company uses TDOA to offer a wide range of location-based services to its customers.

3.4.4 Enhanced Observed Time Difference (E-OTD)

Like TDOA, *Enhanced Observed Time Difference (E-OTD)* measures travel times between the handset and multiple towers to determine the user's location. However, using this method, cell towers initiate transmission to the handset and not vice versa. The handset calculates the user's location on the basis of the time it takes a message to travel from each tower (Fig. 3.6). Cambridge Positioning Systems (**`www.cursor-system.co.uk`**), a proponent of the E-ODT system, offers a product with positioning accuracy within 50 meters. However, unlike TDOA, this method requires users' handsets to be updated.[6]

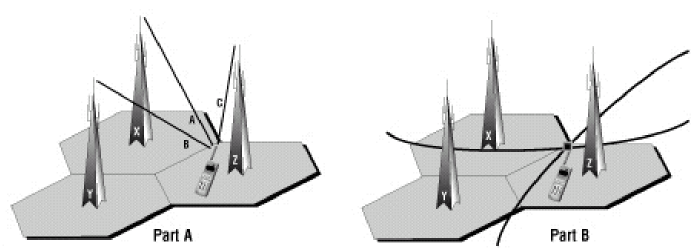

Fig. 3.5 Illustration demonstrating TDOA. (Courtesy of National Communications System.)

Cell-Loc, TimesThree and TDOA

Cell-Loc, a Calgary-based wireless services provider, is developing location-based services for content providers and wireless information portals. Cell-Loc has spun off an infrastructure development company called TimesThree to build a network that makes location-based services widely available.

TimesThree, which is testing its infrastructure in Canada, plans to begin offering services in the United States. The network will cost an estimated $200–$500 million and will offer a variety of consumer-oriented services.[7] In addition to its ability to locate callers, TimesThree technology can be used to manage transportation and shipping fleets. Fleet management includes redistributing and rerouting shipments to maximize efficiency. TimesThree's *Geofencing*™ technology establishes boundaries that indicate to managers when their employees have entered or exited a geographic area. Individuals can manage their commutes by using TimesThree. Users can request traffic reports based on their locations and alter their routes as necessary. Another service is L411, which helps consumers find restaurants, stores and directions.

Cell-Loc has created its own proprietary communications method based on XML. XML (eXtensible Markup Language) is a specification developed by the World Wide Web Consortium (W3C) to allow for the customization of Web documents. Location XML allows carriers and devices using disparate systems to communicate accurately and efficiently. Independent developers who wish to create location-based applications can use the Cell-Loc XML standard to build their products. The company has set up a service bureau called the *Location Exchange*™ that allows developers to access location information in real time.[8]

Cell-Loc is lobbying for TDOA to become the standard location-identification technology. U.S. Wireless (**`www.uswcorp.com`**) and Focusystems (**`www.focusystems.com`**) have begun offering location-based services using TDOA. All three companies are preparing their systems for E911 compliance and are developing other commercial location-based applications.

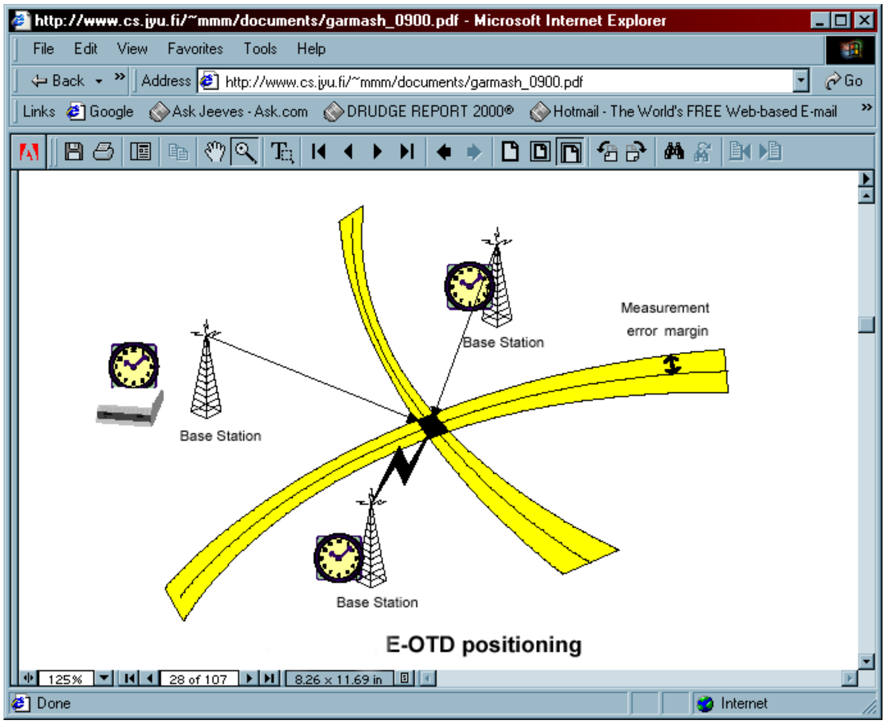

Fig. 3.6 E-OTD in operation. (© ETSI 2001. Further use, modification, redistribution is strictly prohibited. ETSI standards are available from **publication@etsi.fr <mailto:publication@etsi.fr>**, and **<http://www.etsi.org/eds/eds/htm>**.)

One barrier to the E-ODT method is its dependence on the GSM wireless standard. Although GSM is a leading standard in many parts of the world, it is not widely used in the United States.[9]

m-Fact 3.2

Location-based services are expected to be valued at $6.5 billion in the United States and $9 billion in Europe by 2005, according to Strategy Analytics.[10]

3.4.5 Location Pattern Matching

A cell phone emits energy, or *radio frequency (RF)*, that is received at a tower.[11] After leaving a cell phone and before reaching a tower, a single beam of energy may be scattered into *multipath*.[12] In wireless communications, multipath refers to mobile transmissions bouncing and reflecting off obstacles to reach the receiving tower via multiple paths. In urban settings, multipath is common because transmissions must bypass buildings, cars and stationary objects. Satellite-based location services like GPS and network-based systems that rely on triangulation are seriously hindered by errors resulting from multipath.

U.S. Wireless has created a location-identification technology called *Location Pattern Matching*, that actually uses multipath to locate wireless users (Fig. 3.7). The company has built a database of location profiles that define locations by their unique multipath characteristics. When radio frequencies reach receiving towers, the frequencies' multipath is compared to these profiles, and the location of the cell phone used to make the transmission is identified. For example, transmissions from a mobile device used by a person standing in Times Square will almost always produce the same location pattern; therefore device can be located with a relatively high degree of accuracy. A slight modification in an environment can cause an area's multipath characteristics to change, but U.S. Wireless' technology combats this problem by differentiating between "major" and "minor" multipath. This enables the company to update its databases only twice a year while still providing accurate location-identification services. Although rural areas contain fewer objects with which signals can collide to create multipath, testing has indicated that Location Pattern Matching is effective in a wide variety of environments.

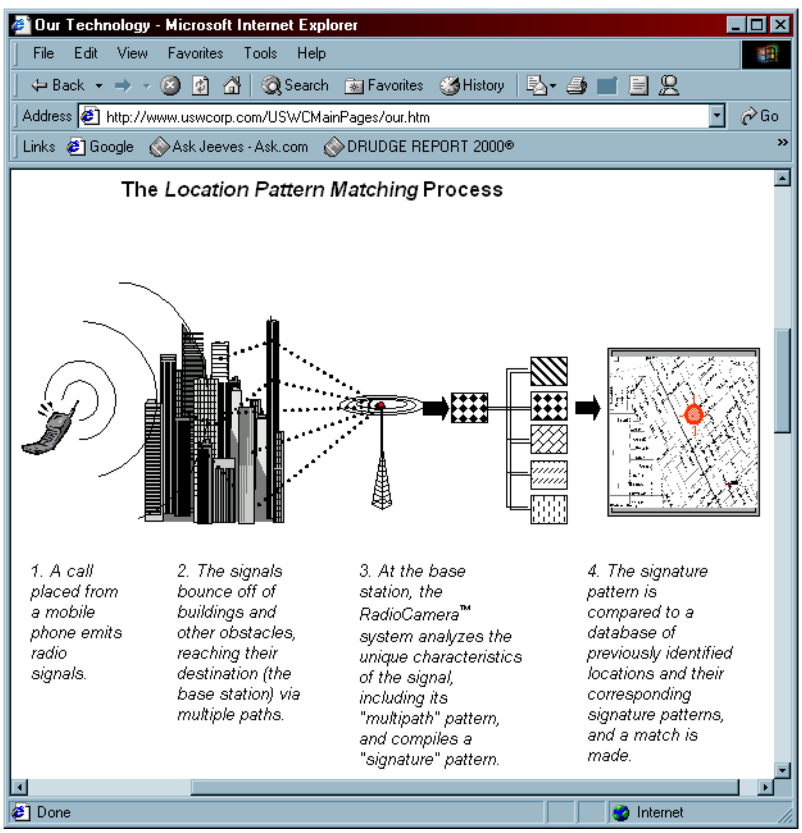

Fig. 3.7 Location Pattern Matching. (Courtesy of U.S. Wireless Corporation. All rights reserved.)

3.4.6 Global Positioning System (GPS)

The *Global Positioning System* (*GPS*) was developed by the United States Department of Defense in the late 1970s to coordinate military operations. It is now used in commercial devices. GPS uses satellites to track a user's latitude, longitude and altitude. The system can be used virtually anywhere in the world, including on airplanes and ships.

Originally, the government had two levels of GPS service. The *Standard Positioning Service* (*SPS*) was available for public use. SPS was accurate to approximately 100 meters horizontally (along the ground) and 156 meters vertically. The *Precise Positioning Service* (*PPS*), originally designed for the military but now commercially available, is precise to 10 meters 90 percent of the time.[13] The enhancement in accuracy between SPS and PPS has a positive impact on industry: ships and trucks use GPS to avoid traffic, poor weather conditions and other delays.[14]

Before making GPS technology available to the public, the U.S. Department of Defense controlled the technology for reasons of national security. A *random-error signal* (a scrambling mechanism) was used to alter tracking information, making it impossible to determine a device's location within 300–500 meters.[15] This was done to protect national security.

GPS uses 24 satellites to locate wireless devices. The satellites follow fixed orbits 12,500 miles above the earth.[16] To determine a user's location, each satellite sends a signal containing a *pseudorandom code* to the user's device. This code identifies the time the signal left the satellite. The time is measured by highly accurate atomic clocks built into each satellite. The user's device, which contains a GPS receiver, determines the signal's travel time by comparing the time the signal left the satellite with the time the signal was received. The travel time is multiplied by the speed of light to determine the distance between the device and each of the satellites.[17]

After the distance has been determined, the next step is to identify the location of each satellite. As previously mentioned, this information is readily available, because each satellite follows a fixed orbit. The location of the satellite and the distance from the satellite to the user's device create an imaginary sphere around the satellite. The user could be located on any point along the surface of this sphere. The point where the three spheres intersect indicates the user's location.

While GPS is extremely accurate, it is also expensive. Building the satellites and maintaining them in space costs billions of dollars. In addition, GPS chips make handsets heavier and more expensive.[18] Aside from cost, GPS has other disadvantages. For example, the signals emitted from the satellites lose strength as they travel through space. Therefore, GPS is not an effective solution for indoor use.

3.4.7 Java and Location-Identification Technologies

Location-based services are developed with a number of programming languages. *Java* offers improved interoperability and a greater number of options for developing location-based services than do many other wireless programming languages.

The Java Location Services Web site (**`www.jlocationservices.com`**) offers news and information describing Java-based initiatives in location-based services. In the future, a convergence of technologies is expected to change the way location-based services are offered to consumers. It is likely that a single handheld device will serve as a phone, computer, television, radio and PDA. Java will facilitate this convergence and enable the proliferation of location-based services for each of these devices. *Jini*™, an enabling technology that integrates with the Java language, is designed to improve portability across disparate systems, such as home appliances, industrial machinery and various other computer systems. The combination of Jini and other Java specifications makes Java a valuable development tool for the many wireless devices available today. Java offers a great deal of flexibility to support the many changes that location-based services and technology will undergo before a standard is reached.[19]

Location-based services rely on databases to store personal data and mapping information. This information must be retrieved and analyzed before the user receives location information. Retrieval is conducted by intelligent agents—software programmed to seek out specific information in large databases. JavaBean technology is an ideal development option for designing intelligent agents.

ObjectFX (**www.objectfx.com**) is one of many companies that has chosen to use Java in its efforts to develop location-identification services. *C-it Locate*, version 3.0, is ObjectFX's latest location-based product. Users can locate their employees, map the current locations of employees and track inventories.

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