MOBILE AND WIRELESS POSITIONING TECHNOLOGIES

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Contents

Summary

Wireless positioning determination has received increased attention during the past few years. Several wireless applications have been envisaged when mobile terminal location can be determined with sufficient accuracy at any time. In this chapter, we attempt to identify the various indoor and outdoor mobile and wireless positioning techniques that can be used for the provision of location based services. In order to maximize the benefits of this research in the area of positioning technologies, we propose a classification with detailed analysis and evaluation of these techniques based on the accuracy that is needed for various mobile location-based services.

1. Introduction

The continuous proliferation of new services and the processes of commodization, industrialization and reorganization of services on a global scale, suggest that services are the core of current structural changes in modern economies (Sirilli et al., 1998). In this context, the sector of telecommunications -especially the domain of mobile and wireless technologies- is expected to play a pivotal role in revolutionizing the way most traditional services and applications are produced, traded, and delivered.

Apart from the attributes of ubiquity, personalization, and dissemination, the common underlying characteristics of wireless systems are mobility and location identification. In particular, wireless systems promise to enable the development of advanced mobile location services (MLS) in both business-to-consumer (B2C) and business-to-business (B2B) markets. In fact, mobile and wireless positioning techniques have attracted much interest and research recently, since they represent a core enabling technology for a continuously increasing number of mobile business applications (Mennecke & Strader, 2002). Examples of these applications range from fleet management to fraud detection and from location-sensitive billing to network management (Zeimpekis et al., 2002).

However, a key factor that has been identified towards this perspective is the need for accurate knowledge of mobile terminal position, since the latter facilitates the provision of mobile value-adding services. Location awareness, which refers to the ability of mobile hosts to determine the current physical location of wireless access devices (Tseng et al., 2001) is thus the prerequisite for the visualization of an alluring mobile business operation.

Although a number of different enabling positioning technologies exist, there is still no clear classification of the types of indoor and outdoor positioning techniques according to the accuracy requirements needed by each mobile location service. The research presented in this chapter aims to identify the most promising current and emerging positioning techniques and to match their characteristics and attributes to the needs and requirements of various mobile location services.

The structure of the chapter is as follows. Section 2 identifies the need for positioning determination and shows the accuracy level requirements for the most popular location based services. Section 3 presents the architecture of radio positioning systems that are used for position identification. Section 4 presents an overview of the most pertinent outdoor and indoor positioning techniques that are used by radio positioning systems and have enabled the emergence of mobile location services. In section 5, emerging services in the business and consumer segment are synthesized into a taxonomy that is based on the accuracy needed for each case. The chapter concludes by discussing limitations as well as future research challenges that need to be overcome in order to fully exploit the business opportunities provided by mobile positioning techniques in indoor and outdoor environments.

2. The Need for Positioning Determination

Position is always relative, which means that it does not exist independently. Indeed, position can only be given as a displacement from another object or point whose position is itself already known and that position in turn is only relative to yet something else. It is a matter of definition where to stop in this chain, but whenever it is, is then called the reference "origin".

The simplest way of defining position is to give it as a distance (range) and bearing from some known object. A simpler statement (i.e. information concerning only distance) does not define position, but only that a person is somewhere on a circle of certain miles radius. So, it is important to note that at least two lines of position are always needed to give position but also that it is assumed in all this, that vertical position (altitude) does not matter. We are thinking of a flat map –a flat Earth- where the transmitters and users are lying on its surface (Blanchard, 1995).

Positioning determination through mobile and wireless technologies has received increased attention during the past few years. Several applications have been envisaged if mobile terminal (MT) location can be determined with sufficient accuracy at any time. Current mobile and wireless communications systems offer positioning services but future mobile and wireless networks intend to provide high-quality location services regardless of the physical location of customers. In order to achieve a truly global coverage a satellite-based interface is always a key component within such infrastructure (Pateli et al., 2002).

The accuracy for location services can be expressed in terms of a range of values that reflect the general accuracy level needed for each application. Different services require different levels of positioning accuracy. The range may vary from tens of meters (navigation services) to perhaps kilometers (network management). The majority of attractive value added location services are enabled when location accuracies of between 25m and 1Km can be provided. Based on decreasing accuracy requirement, examples of location services are provided in Table 1.

Positioning accuracy	Location based services

Location-independent	Most existing cellular services, Stock prices, sports reports
PLMN or country	Services that are restricted to one country or one PLMN
Regional (up to 200km)	Weather reports, localized weather warnings, traffic information (pre-trip)
District (up to 20km)	Local news, traffic reports
Up to 1 km	Vehicle asset management, targeted congestion avoidance advice
500m to 1km	Rural and suburban emergency services, information services, wireless system design, mobility management
100m - 300m	U.S. FCC mandate (99-245) for wireless emergency calls using network based positioning methods
75m - 125m	Urban SOS, localized advertising, home zone pricing, network demand monitoring, asset tracking, information services
50m - 150m	U.S. FCC mandate (99-245) for wireless emergency calls using handset based positioning methods
10m - 50m	Asset location, route guidance, navigation, fleet management

Table 1: Accuracy requirement of location services (3GPP, 2000)

3. Radio Positioning Systems

Location based services (LBS) are provided by location systems whose main function is to gather information about the position of a mobile terminal (MT), operating in a geographical area, and to process that information to form a location estimate.
A popular approach is the *radio positioning system* which is one of the three basic methods used in Automatic Vehicle Location (AVL) techniques. Basically, an AVL system comprises the acquisition and further processing of information to estimate the position of mobile terminal (MT) within a pre-established area (Riter & McCoy, 1977). The other two methods, which are used in AVL, are *dead reckoning* and *proximity systems*.

- *Dead reckoning systems* obtain the position of the MT by computing distances and direction of travel from a known fixed starting point (French, 1987). Since the current location depends on previous location estimates, errors tend to accumulate and can lead rapidly to large positioning errors. To compensate for this, the system must be updated frequently with the correct information. If the MT operates on a fixed route, this process might not be difficult to implement, but in random route MTs (i.e., no predefined mobility pattern exists) rather sophisticated techniques would be needed to accomplish this.

- *Proximity systems* determine the location of the MT by its nearness to fixed active or passive devices strategically placed throughout the intended coverage area (Braun & Walker, 1970). As in the case of dead reckoning, this technique is suitable for fixed route MTs and has the additional drawback of needing an excessive number of fixed devices for extended areas service.

In contrast to the two previous systems, radio positioning can be used to locate any type of users (both fixed route and random route MTs). That is why many existing wireless location systems such as Global Positioning System (GPS), GLONASS and so on, make use of that method.

The basic idea in radio position determination is that there should be enough information available at any place or time to provide a point of intersection between the lines of position (LoP) generated by the measurements. Due to the fact that the best fix accuracy is achieved when two lines of position intersect at right angles, it is common that even though the received signal has an adequate level, the fix cannot be accurately estimated. To obtain the right geometry, the intended coverage area must be defined carefully and the location of the reference transmitter/receiver points must be designed accordingly. This is one of the major problems when implementing a radio positioning system in an established wireless communication network as communications systems are usually designed to ensure a high signal-to-interference-and-noise link between mobile terminals and base stations. On the other hand, an adequate accuracy in positioning mobile terminals in a 3-D system requires several reference points with known position within the mobile range (Alvarez, 2000).

Radio-positioning systems locate the mobile terminals (MTs) by measuring some physical characteristics of the radio waves transmitted between the network and the MT. The user location is then derived from known geometric relationships. In general these systems are composed of three main parts:

- *Location method*: Corresponds to the physical parameters of the RF wave used to obtain the MT location.
- *Estimation technique*: It is used for deriving the positioning information from the RF wave.
- *Processing algorithms*: They are used for obtaining the fix from various noisy measurements.

A simplified structure of a radio positioning system based on the above division is depicted in Figure 1.

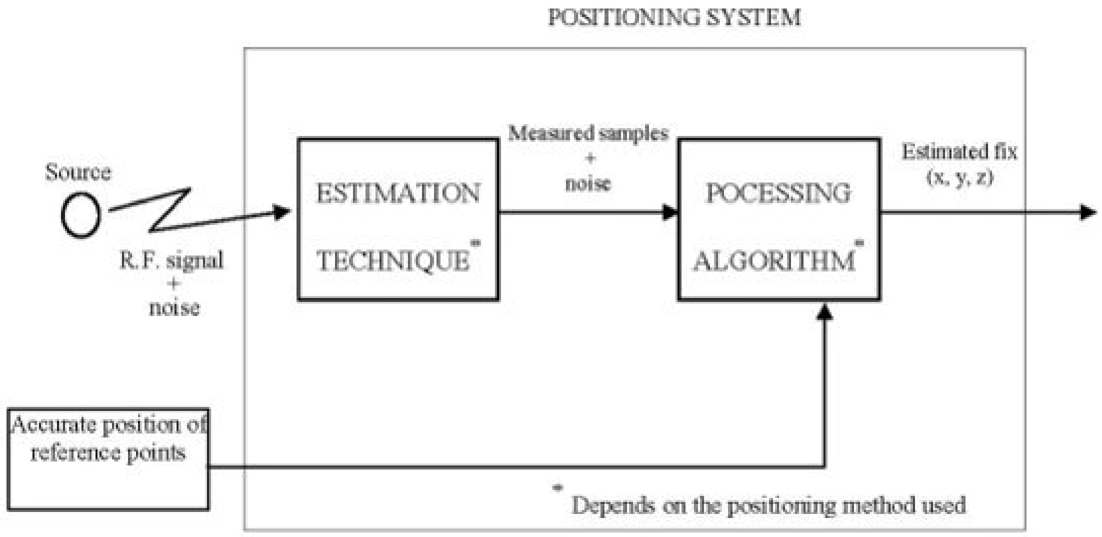

Figure 1: General structure of a Radio Positioning System

In the following sections the location techniques (outdoor and indoor positioning technologies) that comprise the first part of a radio positioning system are going to be further analyzed.

4. Outdoor Positioning Technologies

Outdoor positioning technologies can be implemented in two ways: Self-positioning and remote positioning. In the first approach (self-positioning), the mobile terminal uses signals, transmitted by the gateways/antennas (which can be either terrestrial or satellite) to calculate its own position. More specifically, the positioning receiver makes the appropriate signal measurements from geographically distributed transmitters and uses these measurements to determine its position. A self-positioning receiver, therefore, "knows" where it is and applications collocated with the receiver can use this information to make positioned-based decisions such as those required for vehicle navigation.

The second technique is called remote positioning. In this case the mobile terminal can be located by measuring the signals traveling to and from a set of receivers. More specifically, the receivers which can be installed at one or more locations measure a signal originating from, or reflecting off, the object to be positioned. These signal measurements are used to determine the length and/or direction of the individual radio paths, and then the mobile terminal position is computed from geometric relationships.

4.1. Self Positioning Techniques

4.1.1. Global Positioning System (GPS)

Global Positioning System (GPS) is the worldwide satellite-based radio navigation system, and consists of three main segments namely: a) space segment, b) the control segment and c) the user segment (Kaplan, 1996; Leick 1995).

- *Space Segment:* The Space Segment of the system consists of the GPS satellites. These satellites send radio signals from space. The GPS constellation of 24 satellites equally spaced in six orbital planes 20,200 kilometers above the Earth. There are often more than 24 operational satellites as new ones are launched to replace older satellites. The satellite orbits repeat almost the same ground track (as the earth turns beneath them) once each day. This constellation provides the user with between five and eight satellites visible from any point on the earth.
- *Control Segment:* The Control Segment consists of a system of tracking stations located around the world. The Master Control facility is located at Schriever Air Force Base. These monitor stations measure signals from the satellites which are incorporated into orbital models for each satellite.
- *User Segment:* The GPS User Segment consists of the GPS receivers and the user community. GPS receivers convert satellite signals into position, velocity, and time estimates. Four satellites are required to compute the four dimensions of X, Y, Z (position) and time. GPS receivers are used for navigation, positioning, and other services.

The GPS system was offering an accuracy of 100 meters for civilian services due to the use of Selective Availability (SA). The latter was an artificial error introduced into the satellite data by the US Department of Defense to reduce the possible accuracy of a position. SA was turned off "permanently" in May of 2000. Without SA typical commercial GPS position accuracy are about 20 meters.

The main advantage of this technique is that the GPS system is already in use for many years. However in order to operate properly, GPS receivers need a clear view of the skies and signals from at least three or four (depending on the type of information needed) satellites, requirements that exclude operation in indoor environments.

4.1.2. Assisted-GPS (A-GPS)

Assisted-GPS (A-GPS) technology overcomes the downsides of the conventional GPS solution, and achieves high location accuracy at reasonable cost (Djuknic & Richton, 2001). The assistance to the mobile phone trying to determine its own location comes from the network over the air-interface, and this distributed approach leads to performance level that exceed those of conventional GPS. What makes this technology work so well is that the mobile network, using its own GPS receivers, as well as an estimate of the mobile's location down to cell/sector, can predict with great accuracy the GPS signal the handset will receive and convey that information to the mobile. With this assistance the size of the search space is greatly reduced, and the time-to-first-fix (TTFF) shortened from minutes to a second or less. In addition, an A-GPS receiver in the handset can detect and demodulate signals that are order of magnitude weaker than those required by conventional GPS receivers. Only a partial GPS receiver is required in the handset to achieve this functionality, but legacy terminals cannot be used and new handsets are required for the technology to operate. The A-GPS method can be extremely accurate, ranging from 1 to 10 meters (Giaglis et al., 2002b).

4.1.3. Differential GPS (D-GPS)

Differential correction techniques are used to enhance the quality of location data gathered using global positioning system (GPS) receivers. Differential correction can be applied in real-time directly in the field or during post processing of data. Although both methods are based on the same underlying principles, each accesses different data sources and achieves different levels of accuracy (Alvarez, 2000). Combining both methods provides flexibility during data collection and improves data integrity. The underlying premise of differential GPS (D-GPS) is that any two receivers that are relatively close together will experience similar atmospheric errors. D-GPS requires that a GPS receiver be set up on a precisely known location. This GPS receiver is the base or reference station. The base station receiver calculates its position based on satellite signals and compares this location to the known location. The difference is applied to the GPS data recorded by the second GPS receiver, which is known as the roving receiver. The corrected information can be applied to data from the roving receiver in real time in the field using radio signals or through post processing after data capture using special processing software.

4.1.4. GLONASS

The GLONASS system is managed from the Russian Federation Government by the Russian Space Forces, system operator, providing significant benefits to the civil user community through a variety of applications. The GLONASS system has two types of navigation signal: standard precision navigation signal (SP) and high precision navigation signal (HP). SP positioning and timing services are available to all GLONASS civil users on a continuous, worldwide basis and provide the capability to obtain horizontal positioning accuracy within 57-70 meters. These characteristics may be significantly increased using differential mode of navigation and special methods of measurements (e.g. carrier phase etc.). To make 3D positioning, velocity measuring and timing user of the GLONASS use navigation radio signals, continuously transmitted by satellites. Each GLONASS satellite transmits two types of signal: standard precision (SP) and high precision (HP) on its own frequency which differ from the one of other satellites. However some satellites have the same frequencies but those satellites are placed in antipodal slots of orbit planes and they do not appear at the same time in user's view. GLONASS receiver automatically receives navigational signals from at least 4 satellites and measures their pseudo ranges and velocities. Simultaneously it selects and processes navigation message from satellites signals. Computer of GLONASS receiver process all the input data and calculate three coordinates, three components of velocity vector, and precise time. GLONASS system is used for the following activities: a) air and naval traffic management, b) geodesy and cartography, c) ground transport monitoring, d) ecological monitoring, and e) search and rescue operations. (Leick, 1998)

4.1.5. GALILEO

Galileo will be Europe's own global navigation satellite system, providing a highly accurate, guaranteed global positioning service under civilian control. It will be inter-operable with GPS and GLONASS, the two other global satellite navigation systems. Whilst deployment is imminent, an operable service is not expected before 2008.

GALILEO is based on a constellation of 30 satellites (27 operational and 3 active spares), positioned in three circular Medium Earth Orbit (MEO) planes in 23616 km altitude above the Earth, and at an inclination of the orbital planes of 56 degrees with reference to the equatorial plane. The large number of satellites together with the optimization of the constellation, and the availability of the three active spare satellites, will ensure that the loss of one satellite has no discernible effect on the user.

The GALILEO system will provide information concerning the positioning of users in many sectors such as transport (vehicle location, route searching, speed control, guidance systems, etc.), social services (e.g. aid for the disabled or elderly), the justice system and customs services (location of suspects, border controls), public works (geographical information systems), search and rescue systems, or leisure (direction-finding at sea or in the mountains, etc.). A user will be able to take a position with the same receiver from any of the satellites in any combination. By offering dual frequencies as standard, however, Galileo will deliver real-time positioning accuracy down to the metre range, which is unprecedented for a publicly available system. This will make it suitable for applications where safety is crucial, such as running trains, guiding cars and landing aircraft.

As a further feature, Galileo will provide a global Search and Rescue (SAR) function, based on the operational Cospas-Sarsat system. To do so, each satellite will be equipped with a transponder, which is able to transfer the distress signals from the user transmitters to the Rescue Co-ordination Centre, which will then initiate the rescue operation. At the same time, the system will provide a signal to the user, informing him that his situation has been detected and that help is under way. This latter feature is new and is considered a major upgrade compared to the existing system, which does not provide a feedback to the user (ESA, 2005).

4.2. Remote Positioning

4.2.1. Cell Identification (Cell-ID)

The Cell-ID (or *Cell of Origin, COO*) method is the basic technique to provide location services and applications. The method relies on the fact that mobile networks can identify the approximate position of a mobile handset by knowing which cell site the device is using at a given time. The main benefit of the technology is that it is already in use today and can be supported by all mobile handsets. However, the accuracy of the method is generally low (in the range of 200 meters), depending on cell size. Generally speaking, the accuracy is higher in densely covered areas (for example, urban places) and much lower in rural environments (Giaglis et al., 2002b).

4.2.2. Direction or Angle of Arrival (DOA-AOA)

The basic idea is to steer in space a directional antenna beam until the direction of maximum signal strength or coherent phase is detected. In terrestrial mobile systems the directivity required to achieve accurate measurements is obtained by means of antenna arrays (Sakagami et al., 1994). Basically, a single measurement produces a straight-line locus from the base station to the mobile phone. Another AOA measurement will yield a second straight line, the intersection of the two lines giving the position fix for this system. Since accuracy is dependent on distance from transmitter, in satellite mobile systems the antenna directivity necessary for achieving accurate positioning is quite impracticable with any sort of array that might be mounted on a satellite. In this case, an indirect estimate can be obtained by measuring the Doppler shift component in the direction of the mobile terminal produced by the satellite's motion.

4.2.3. Time Delay

Since electromagnetic waves travel at a constant speed (speed of light) in free space, the distance between two points can be easily estimated by measuring the time delay of a radio wave transmitted between them. This method is well suited for satellite systems and is used universally by them. There are two types of time delay methods that can be identified: Absolute Timing or Time of Arrival (TOA) and Differential Time of Arrival (TDOA) or Hyperbolic Technique.

- *Absolute Timing or Time of Arrival (TOA):* Positioning information is derived from the absolute time for a wave to travel between a transmitter and a receiver or vice versa. This implies that the receiver knows the exact time of transmission. Alternatively, this approach might involve the measurement of the round-trip time of a signal transmitted from a source to a destination and then echoed back to the source, giving a result twice that of the one-way measurement. This does not imply synchronization between the transmitter and the receiver and is the most common means of measuring propagation time (Zeimpekis et al., 2003).
- *Differential Time of Arrival (TDOA) or Hyperbolic Technique:* The problem of having precisely synchronized clocks at transmitter and receiver is solved by using several transmitters synchronized to a common time base, and measuring time difference of arrival at the receiver. If in a two dimensional system a line is drawn joining all points having the same time difference, a hyperbola will be plotted (hence the name hyperbolic technique). More specifically, each TDOA measurement defines a hyperbolic locus on which the mobile terminal must lie. The intersection of the hyperbolic loci will define the position of the mobile system (Zeimpekis et al., 2003).

4.2.4. Enhanced Observed Time Difference (E-OTD)

The Enhanced Observed Time Difference (E-OTD) method is employed for location finding of a mobile station (handset) and may be also used for location services. It is based on measurements in the mobile station (MS) of the Enhanced Observed Time Difference of arrival of bursts from nearby pairs of base stations (BS) (Alvarez, 2000). More specifically, the position of a mobile terminal is triangulated by: a) the coordinates of the base stations, b) the arrival rime of bursts from each base station and c) the timing differences between base stations. E-OTD is a handset based solution however the latter does not use any form of GPS neither is any need to change the existing antenna structure. The only requirement so as to enhance the existing measurement process modification is software modification of the mobile terminal.

4.2.5. Location Pattern Matching (LMP)

The Location Pattern Matching (LMP) is also an alternative method of locating a wireless caller. The process of location identification is as follows. A wireless subscriber uses any handset to make a call (e.g. to 911).The wireless phone's signal is received at various antenna sites equipped with special gear. The receivers send the caller's voice call to the mobile switch, where sophisticated equipment analyzes the acoustic radio signal, and then compares it to a database of standard signal characteristics. These characteristics include signal reflections (multipath), echoes and other signal "anomalies." The technique is effective in urban environments that include tall buildings and other obstructions, where other techniques might not succeed. The caller's voice call and the latitude and longitude are then sent for use by the dispatcher.

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