A Taxonomy of Indoor and Outdoor Positioning Techniques for Mobile Location Services

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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 paper, we attempt to identify the various indoor and outdoor positioning techniques that can be used for the provision of mobile and wireless applications and services. In order to maximize the benefits of this research in the area of positioning technologies, we propose a novel taxonomy with detailed analysis and evaluation of these techniques based on the accuracy that is needed for various mobile location-based services.

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1. INTRODUCTION

The continuous proliferation of new services and the processes of commodisation, 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 wireless and mobile technologies- is expected to play a pivotal role in revolutionizing the way most traditional services and applications are produced, traded, and delivered.

The common underlying characteristic of wireless systems (further to the attributes of ubiquity, personalization, and dissemination) is of course 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, wireless positioning techniques have

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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 paper 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 (MLS).

The structure of the paper is as follows. Section 2 will present an overview of the most pertinent technological developments that have enabled the emergence of MLS. This will be followed by an exploratory discussion of potential mobile applications and services where location-based techniques can be beneficial. In section 4, technological services and emerging services will be synthesized into a taxonomy of indoor and outdoor positioning techniques that is based on the accuracy needed for each mobile location service. The paper will conclude 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. CURRENT AND EMERGING POSITIONING TECHNIQUES

The last few years, positioning (also called location-aware) technologies, have emerged, enabling the design of applications with the capability to identify a user's location and modify their settings, interfaces and functionality accordingly (Pateli et al., 2002). However, in order to entirely exploit the new types of B2C and B2B applications and services, research must be carried out in order to match the capabilities of positioning techniques against the requirements of MLS provision.

This section discusses the most promising current and emerging positioning techniques. Section 3 will then review the characteristics of major mobile location services, which

will then be synthesized in a novel taxonomy outlining what the most suitable methods for each type of mobile location services are.

Positioning techniques 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 travelling 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.

2.1 Self positioning techniques

GPS and Assisted GPS (A-GPS): GPS is the worldwide satellite-based radio navigation system, consisting of 24 satellites, equally spaced in six orbital planes 20,200 kilometres above the Earth, that transmit two specially coded carrier signals, one for civilian use and one for military and government use (Djuknic & Richton, 2001). The system's satellites transmit navigation messages, which a GPS receiver uses to determine its position. GPS receivers process the signals to compute position in 3D – latitude, longitude, and altitude – with an accuracy of 10 meters or less. 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. As far as the Assisted-GPS (A-GPS) method is concerned, the mobile network or a third party service provider can assist the handset by directing it to look for specific satellites and also by collecting data from the handset to perform location identification calculations that the handset itself may be unable to perform due to limited processing power. The A-GPS method can be extremely accurate, ranging from 1 to 10 meters (Giaglis et al., 2002).

Indoor Global Positioning System (Indoor GPS): This system focuses on exploiting the advantages of GPS for developing a location-sensing system for indoor environments. It

should be noted that the GPS signal does not typically work indoors because the signal strength is too low to penetrate a building (Chen & Kotz, 2000). Nevertheless, indoor GPS solutions can be applicable to wide space areas where no significant barriers exist. Indoor GPS takes into account the low power consumption and small size requirements of wireless access devices, such as mobile phones and handheld computers. The navigation signal is generated by a number of pseudolites (pseudo-satellites). These are devices that generate a GPS-like navigation signal. The signal is designed to be similar to the GPS signal in order to allow pseudolite-compatible receivers to be built with minimal modifications to existing GPS receivers. As in the GPS system, at least four pseudolites have to be visible for navigation, unless additional means, such as altitude aiding are used (Pateli et al., 2002).

Mobile Terminal Positioning over Satellite UMTS (S-UMTS): In contrast with GPS and A-GPS, the technique that is suggested by Zeimpekis et al. (2002), uses only two satellites in order to provide positioning services, thus abolishing the need for specific satellite constellation (such as the GPS constellation) dedicated to positioning services. The proposed system makes use of a typical Satellite UMTS constellation, which will be able (through W-CDMA) to provide also other information such as cable TV, satellite telephony, data transfer, and so on. In order to achieve an acceptable accuracy, the latter combines three radiolocation methods: time delay, Doppler shift and Doppler rate. The only drawback of this system is that it can be used only for services that need medium accuracy (between 100-250m) such as fleet management, targeted congestion avoidance advice, mobility management, rural and suburban emergency services, as well as local information news, traffic and localized weather warnings.

2.2 Remote positioning techniques

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., 2002).

Direction or Angle of Arrival (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.

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.

a) 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.

b) 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.

3. A REVIEW OF FUTURE MOBILE LOCATION-BASED SERVICES

According to Durlacher (2001), the future mBusiness applications can be categorized into two main categories as illustrated in Table 1. The first one embraces all the business-to-consumer (B2C) applications whereas the second one concentrates onto business-to-business (B2B) services.

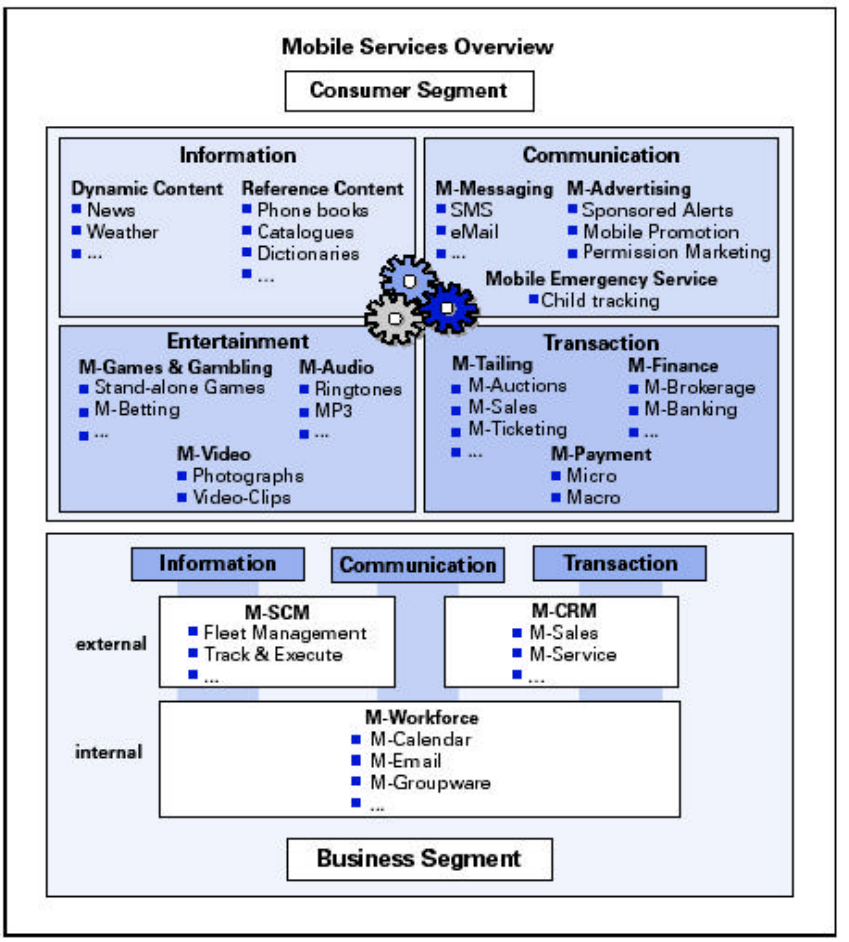

Table 1. A classification of mBusiness applications (Durlacher, 2001)

One of the clearest market applications of MLS can be identified in the consumer segment and especially in the area of mobile emergency services. The ability of a mobile user to call for assistance and at the same time automatically reveal their exact location to the emergency service called (for example, police, ambulance, automotive assistance, and so on) is considered one of the prime motivators for signing up subscribers to mobile location services (Hargrave, 2000). Navigation services are also playing a pivotal role in the development of mobile location-based services and can be based on mobile users' needs for directions within their current geographical location. Another type of applications embraces the location-sensitive information services, which mostly refer to the digital distribution of content to mobile terminal devices based on their location, time specificity and user behavior. One of the first trial applications of MLS is mobile advertising, due to its promising revenue potential as well as its direct links to mobile commerce activities. Furthermore, mobile advertising has gained significant attention because of its unique attributes, such as personalization (Kalakota & Robinson, 2001),

that offer new opportunities to advertisers to place effective and efficient promotions on mobile environments. Tracking services are also very promising as they can be equally applicable both to the consumer and the corporate markets. As far as consumers are concerned, tracking services can be utilized to monitor the exact whereabouts of, for example, children and elderly people. Similarly, tracking services can be effectively applied in corporate situations as well. One popular example refers to tracking vehicles so that companies know where their goods are at any time (mobile Supply Chain Management or mSCM). Finally, location-sensitive billing is also of significant importance as it refers to the ability of a mobile location service provider to dynamically charge users of a particular service depending on their location when using or accessing the service. For example, mobile network operators may price calls based on the knowledge of the location of the mobile phone when a call is made.

4. A TAXONOMY OF WIRELESS POSITIONING TECHNIQUES

Based on the various positioning techniques that currently exist and were presented in section 2, a novel taxonomy of these methods is proposed (Table 2) according to the accuracy needed by each mobile location-based service that was discussed in section 3.

The table embraces two main categories of future mobile location services: B2C and B2B. Each channel of services can generate various applications starting from mobile travel services, automotive assistance, people tracking and continuing with business applications such as vehicle/fleet management, mobile customer support, and mobile sales. According to the application environment (whether it is indoor or outdoor application) and the accuracy requirement (medium or high), we propose a list of the most appropriate positioning techniques. In addition, there is also technical information about the type of technology each technique uses to generate the position of the mobile terminal as well as how the position is calculated (i.e. by using terrestrial, satellite or device aid). Indoor applications need higher accuracy compared to the outdoor ones that is why the proposed techniques for indoor environment are based on time delay and indoor GPS methods that provide high accuracy (from 10 meters to few centimeters). On the other hand, techniques such as GPS, positioning over S-UMTS and Cell-ID are more suitable for outdoor environments, where high accuracy is not critical.

5. CONCLUSIONS

The taxonomy of positioning techniques against mobile location services presented in this paper is based on the accuracy needed for the provision of a series of mobile location services. More specifically, the main purpose of this classification is to assist stakeholders at placing themselves and their service offerings within a wider frame that will help them design better applications, match them with the most suitable underlying

technology, and direct them to the most receptive target market base. Furthermore, the framework focuses on assisting the process of understanding the dynamics of the emergent phenomenon of mobile location services, with a view to realizing its true added value. To this end, the framework is a valuable tool for theorists and practitioners alike, as it can be used both as an extensible analytical instrument and as a deductive actionable toolkit. However it must be mentioned that although the technology of mobile location services has been proven in a number of trials, it still remains unclear whether a market will be created and will take advantage of these technological capabilities. On the other hand, the MLS field is progressing at an extremely fast pace, therefore the static picture of the framework may be of limited value in a short time. Future work is continuously needed to place new technological and service developments within the framework dimensions so that its sustained usefulness and validity remains. It is also worth mentioning that the decision on using one technology or another is also based on other important issues apart from the technical side such as availability, the prevailing legal situation, and the associated implementation costs (for end-users, network operators, and device manufacturers alike). To this end, further research work will need to identify and explore these issues that lie beyond the scope of this paper.

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CATEGORY	EXAMPLE APPLICATIONS	APPLICATION ENVIRONMENT	ACCURACY REQUIREMENT	PROPOSED LOCATION METHOD	POSITION CALCULATION	TECHNOLOGY
Business -to- consumer (B2C)	Emergency calls	Outdoor	Medium to high	TDOA	Terrestrial Network or Device	Triangulation
	Automotive assistance	Outdoor	Medium	AOA/TOA	Terrestrial Network or Device	Triangulation
	Travel services	Outdoor	Medium to high	Cell-ID	Terrestrial network	Cell proximity
	m-yellow pages	Outdoor	Medium	Cell-ID	Terrestrial network	Cell proximity
	Banners, Alerts, Marketing	Outdoor	Medium to high	TOA	Terrestrial Network or Device	Triangulation
	People tracking	Indoor / Outdoor	High	GPS/Indoor GPS	Device from satellite data/ Pseudo Satellite	Triangulation
	Indoor routing	Indoor	High	Indoor GPS	Pseudo Satellite	Triangulation
Business -to- business (B2B)	Vehicle tracking	Outdoor	Medium	GPS/A-GPS/MT over S-UMTS	Device from satellite data	Triangulation
	Product tracking	Indoor / Outdoor	Medium to high	GPS/Indoor GPS	Pseudo- satellite /Device from satellite data	Triangulation
	Traffic management	Outdoor	Medium	GPS/A-GPS/MT over S-UMTS	Device from satellite data	Triangulation
	Product replenishment	Indoor	High	Indoor GPS	Pseudo- satellite	Triangulation
	Mobile sales	Outdoor	Medium to high	Cell-ID	Terrestrial network	Cell proximity
	m- customer support	Outdoor	Medium	GPS/TOA	Terrestrial/Satellite Network or Device	Triangulation
	Field personnel support	Outdoor / Indoor	Medium to high	Indoor GPS	Pseudo Satellite	Triangulation

Table 2. Appropriate positioning methods for mobile location services