CHAPTER TWO
The Technological Setting

The rise of the knowledge society and the informational economy has been documented and discussed in detail, *inter alia*, by Castells (1989, 1996). We have become a "network society" founded upon modern information and communication technologies (ICTs). In the 1990s we saw the introduction of the World Wide Web and the ubiquitous uptake for business and recreational use of networked PCs, the Internet and mobile communications. This period also saw widespread development and use of the Global Positioning System (GPS) for positioning and Geographic Information Systems (GIS) for the organisation and visualisation of spatial data. The number of mobile ICT device users increased rapidly. By 2001, more than 40% of the population in Europe and nearly 70% in the UK owned a mobile phone with 700 million subscribers worldwide. The number of worldwide subscribers has probably tripled by 2005 (though there is little way of confirming current mobile phone ownership, such is its ubiquity). The increasing mobility of individuals, the availability of broadband communications for mobile devices and the growing volumes of location specific information available in databases are inevitably leading to the demand for services that will deliver location related information to individuals on the move. Such services are generally known as Location Based Services (LBS). A range of applications will be described in §2.2 including navigation services which are aimed at providing information through mobile devices to assist people's wayfinding activities.

In this Chapter, a number of technological threads will be discussed. These form the background to LBS and this research. The purpose of the discussion here is to identify some of the areas of research that arise as a consequence of this changed technological setting. In §2.1 the individual threads are discussed; in §2.2 location-based services and their applications are introduced; and in §2.3 a research agenda is identified which frames the overarching aim of this thesis.

2.1 Technological threads

For the purpose of the research to be undertaken, a distinction will be made between what has now become standard information and communication technologies infrastructure and what are referred to in this research as new information and communication technologies (NICTs). NICTs are differentiable by the following characteristics:

- use of mobile telecommunication networks;

- high-level communication protocols, such as Compact HTML (I-Mode), Wireless Application Protocol (WAP) and Extensible Markup Language (XML);
- handheld, mobile and small size wireless communication devices;
- location awareness;
- wide usage in business and social life.

Some of the important aspects of these characteristics are discussed in the paragraphs that follow.

The mobile telecommunication networks have developed rapidly from second generation to third generation and towards future fourth generation. The second generation (2G) networks have a bandwidth of 9.6 Kbps, and include the Global System for Mobile Communication (GSM), Code Division Multiple Access (CDMA) and Time Division Multiple Access (TDMA). The 2.5 generation (2.5G) networks include General Packet Radio Service (GPRS) with their increased bandwidth of 115 Kbps and Enhanced Data Rates for Global Evolution (EDGE) with bandwidth of 400Kbps. The fully implemented third generation (3G) networks could support a bandwidth of 2 Mbps, and include the Universal Mobile Telecommunication System (UMTS) and Wideband Code Division Multiple Access (W-CDMA). The fourth generation (4G) is predicted to have a transmission rate of up to 100 Mbps (Peng and Tsou, 2003). Such bandwidth would be ample for delivering location aware services and applications. Wireless Application Protocol (WAP) was first implemented as a communication protocol in 1997 and has been developed to facilitate the mobile Internet. The development of mobile telecommunications provides a combination of speed, coverage and mobile devices, and has also transformed service status from focusing on transmission of voice to various applications of transmitting multimedia information.

Over the last decade, the number of mobile device users has rapidly increased as the costs of devices and services have fallen. Mobile devices are widely used in business and social life. In this thesis, the term 'mobile devices' is used to refer to handheld, mobile and small size wireless devices such as Personal Digital Assistants (PDA) and mobile phones, which can be connected to mobile communication networks. Successive developments in mobile devices have engendered faster processors, additional options, and improved graphics capabilities such as colour screens and greater display resolutions. There are also hybrid systems integrating the capabilities of PDA and mobile phones in a single device. Figure 2.1 illustrates some of these mobile devices. With the development of location awareness technologies (discussed below) and increasing numbers of mobile device users, services providing location related information are likely to become an application of rapidly growing importance.

Figure 2.1 Examples of mobile devices and their protocols (WAP=wireless application protocol, MMS = Multimedia messaging, J2ME = Java2 Micro Edition), (based on Li and Maguire, 2003).

With the widespread use of mobile telecommunication networks and mobile devices, location awareness has become another important aspect of NICTs. A number of techniques are available for determining the position of mobile communication devices when they are in use. One class of positioning technologies is mainly based on mobile telecommunication networks, and is referred to here as network-centric methods; while another is satellite-based positioning technologies (i.e. GPS) and is referred to here as device-centric methods. There are also combined positioning technologies which integrate both network- and device-centric methods. The following are key positioning techniques (Sage, 2001; Giaglis *et al*., 2002; Zeimpekis *et. al*., 2003; Grejner-Brzezinska, 2004):

- Network Cell Identification (NCI) or Cell ID – this network-centric method identifies the approximate position of a mobile device through locating which base station the device is using at the given time. The accuracy varies from about 250 metres in urban areas to over 10km in rural areas depending on the cell size. There is no specific hardware and software support required for the mobile device. There are also two types of enhanced Cell-ID methods. One of them uses timing advance method to improve the location accuracy while another improves accuracy by using measures of the signal strength to estimate the distance between a mobile device and a current base station.
- Time of Difference Of Arrival (TDOA) – this network-centric method calculates the time difference of the transmitted signal from a mobile device arriving at three separate base stations. In theory, the locational accuracy of the TDOA method can be between

50 to 200 metres. However there is the need for high synchronisation within the network of base stations to support TDOA in a GSM network. There is no specific hardware and software support required for the mobile devices.

- Angle of Arrival (AOA) – this network-centric method measures the angle of the same signal arriving at two or more base stations. An array of antennas, instead of just the one antenna per cell, is needed for base stations to measure the angles. The accuracy of the AOA method is usually within 300m, however, it can be degraded significantly in rural areas. There are hardware support requirements for both the network and mobile devices.
- Global Positioning System (GPS) – this device-centric method works by including a satellite navigation receiver in a mobile device. The accuracy can be within 20 metres. However, it needs a clear view of the sky and signals from three or four satellites. Moreover, mobile devices with built-in GPS receivers have higher power consumption and shorter battery life. Assisted-GPS is required for covering situations such as in-building areas and tunnels as a second supplement signal.
- Enhanced-Observed Time Difference (E-OTD) – a device-centric method which calculates the time taken for a signal to arrive from at least three base stations. The method requires installed software on the mobile device. The accuracy is about 50 metres. It can also be a network-centric solution as a modification of TDOA method explained above.
- One hybrid method is GPS in conjunction with TDOA/AOA - this solution works through GPS-enabled handheld mobile devices supplemented by Cell-ID, TDOA or AOA. The method, however, may create incompatibility as there is no standard for doing this amongst mobile network operators.

A wide range of applications is emerging based on such technologies, from delivering various information and services, tracking and managing fleets and mobile commerce to games and (in the future) digital TV delivered to the mobile phone. One such application for delivering location related information to individuals, LBS, has substantial relevance to this research and will be discussed in detail in the following Section.

2.2 Location-based services (LBS)

Location-based services (LBS) entail "the delivery of data and information services where the content of those services is tailored to the current or some projected location of the user" (Brimicombe and Li, 2006). Such information and services are provided to users by their mobile devices. LBS can be seen as the convergence of NICTs (discussed in §2.1), the Internet, GIS and spatial database as illustrated in Figure 2.2.

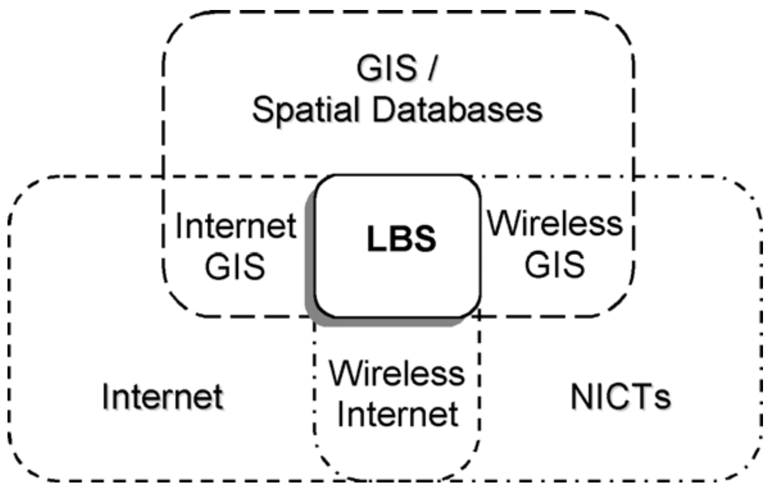

Figure 2.2 Convergence of technologies (from Brimicombe and Li, 2006).

The Internet can be regarded as a ubiquitous source of information and distributed services across networks, whereas the NICTs discussed in §2.1, provide capability for mobile access/delivery with location awareness. The other main area in Figure 2.2 is GIS which can be considered a mature technology for integrating, managing, analysing and visualising spatial data. Geographical information services have been offered over the Internet to provide data and processes on demand to distributed users through Web browser interfaces. Major GIS software providers also offer versions of their products for mobile handheld devices, giving rise to wireless GIS (Braun, 2003). These GIS applications provide the ability to deliver data, computing capability and integrated functionality to individuals at distributed locations. LBS have only been made possible by the development and convergence of these technologies.

One of the main drivers of LBS was the U.S. Federal Communications Commission's adoption of the enhanced 911 (E911) mandate. The E911 mandate aimed to improve the quality and reliability of the emergency services by being able to locate wireless 911 callers (Federal Communications Commission www.fcc.gov/e911/). The benefit of the E911 mandate is that it provides the basis for a wide range of additional, value-added location based services. In Europe, the concerns of locating wireless emergency calls only started to be tackled in 2000. Nevertheless, there has been fast development and deployment of both wireless and location-aware networks. The provision of location based services in Europe is driven by the motivation to provide differentiating and value-added services in a competitive marketplace. From the middle of 2003, European registration requires network operators "to determine and forward the most reliable caller location information available for all calls to the single European emergency call number 112" (The Commission of the European Communities, 2003).

With considerable growth potential in location-based services, a range of applications has been identified and are discussed here. All of these concern the delivery of information and services to users on the move via their mobile devices. User-solicited services provide location specific information for business and social purposes. For example, local public transport options, traffic information and availability of local services can be delivered to users on the move in real-time whenever required. Pushed services are the delivery of unsolicited information to users' mobile devices, such as proximity-related advertising and warnings. Another category of LBS applications emphasises services related to real-time tracking, such as managing vehicle fleets, or knowing when a friend or family member is nearby or at certain locations. This can include instant messaging services which can be used for communicating with people within the same or nearby localities. LBS can also be used for co-ordinating emergency services in responding to accidents and disasters. Future applications may well include commercial services directly related to a user's current location, such as location-based tariffs and pay-as-you-go car insurance.

One of the important services which LBS offer is providing information to people for exploring areas, planning routes and directing them to reach destinations. In-car navigation systems, as one example, can identify shortest route or fastest route given a start point and a destination point. Information is often given as route maps and/or sequential instructions. As another example, maps and/or instructions can be given through mobile devices to orientate and direct individuals to arrive at their required destinations. A range of input and output methods has been proposed and offered, and some applications seek to identify the desirable and more effective ways of delivering information. Voice has been suggested as a user-friendly method for inputting requests and giving instructions. Using speech via mobile phones to provide navigating instructions during driving is just one example. Three-dimensional or graphical images are being investigated for use in other applications.

Another aspect of LBS currently being researched focuses on adapting content to user needs. Here the emphasis is upon how to obtain and interpret the location and context information from the environment and from users. For example, user-adaptive content for LBS applications have been studied as a means of ascertaining users interest and preferences in areas such as map display for different countries, presentation of mapped zones with different levels of generalisation, and adaptation to user orientation (e.g. Zipf, 2002).

Brimicombe and Li (2006) outline a publisher and subscriber model to adapt information content based on location and context so as to maximise utility to the user. Furthermore, interactivity between a mobile computing device and its user has been studied with consideration of device ability to obtain and interpret contextual information for user benefit (Dey, 2001; Schmidt & Van Laerhoven, 2001).

2.3 Implications for research questions and challenges

2.3.1 LBS applications perspective

As discussed in the previous Section, LBS applications aim to provide locational information and services for people’s need. Although the information and services can vary, the main concerns are delivery of more relevant, timely information to people on the move. The emphases of current applications have been on the technical capability and the diversity of mobile devices to deliver and access locational information. The focus is also on the effectiveness and user friendliness of the mode of delivery of such information and services, such as “speak and listen”, maps, text and multi-media. For example, some applications for wayfinding assistance provide a number of different interfaces by which users can access locational information. Such systems can navigate people by the use of textual information or voice instruction. Information can also be delivered to mobile devices in combined formats, such as maps with calculated routes, or graphics with text. All along, an important consideration of these applications must be to provide pertinent and timely information to users. Therefore, the question arises as to what information is likely to be relevant in any given situation and how should it best be communicated to the users? The use of detailed personal profiling, precise user location and user movement history have been suggested and discussed as a means of ensuring greater relevance (Mountain & Raper, 2001; Fogli *et al.,* 2003).

Such emphases on improving information content have largely overlooked issues of individual spatial abilities. To date, little systematic research has been carried out regarding individual’s cognitive abilities, spatial awareness and other related skills in accessing and using LBS applications. Moreover, few studies on the design and implementation of applications for assisting wayfinding have been based on an understanding of wayfinding research.

2.3.2 Human-computer interaction for mobile devices perspective

With the availability and continuing development of mobile devices, there has been research interest into human computer interaction for mobile devices over recent years. This field of research is often referred to as mobile human computer interaction (mobile HCI). Human-computer interaction research has focused upon understanding the ways in which humans interact with computers, aiming to have a system to satisfy user needs and requirements in terms of system functionality and operation (Nielsen, 1993; Preece *et al.*, 1994). With an increasing number of applications using mobile devices (e.g. LBS), mobile HCI research gives more emphasis to human-device interaction in terms of developing mobile context-aware applications (Borntrager *et al.*, 2003). Kjeldskov and Graham (2003) have reviewed a number of mobile HCI research methods. They note a tendency of the research towards building systems and lack of emphasis on understanding design and usage which is limiting knowledge development in this area. Thus, the majority of the research tends not to address the question of what is useful from a user perspective. Approaches have tended to be laboratory-based, and whilst interaction between human and mobile devices can be studied in detail, the surrounding environment has not had a significant role.

In general, the interaction between users and mobile devices can be viewed as a new kind of human-computer interaction. In conventional desktop based human-computer interaction, the surrounding environment is under-represented in the research. For mobile human-computer interaction, the surrounding environment has started to be brought into consideration, for example by directly observing the phenomena and people (Oulasvirta *et al.*, 2003; Paay, 2003). However, the surrounding environment has not been regarded as a mutable information source with which people are interacting. Therefore, there has been no explicit focus upon the dynamic interactions between individuals, mobile devices and environments.

2.3.3 Wayfinding research perspective

There has been extensive research on wayfinding, which will be discussed in detail in Chapter 3. Research has been carried out aimed at understanding people's spatial behaviour and the differences amongst individuals (Lloyd, 1989; Gopal & Smith, 1990; Golledge & Stimson, 1997; Allen, 1999). Much of this work has focused on the nature of cognitive maps as internal spatial representations, as well as how they are developed and how information is acquired for performing spatial activities. When encountering a new environment, people are likely to need a range of information for completing spatial tasks such as wayfinding. People acquire and develop their spatial knowledge through various experiences and processes, which may include recognising and understanding characteristics of objects, localities and inter-relationship between elements in environments. Spatial knowledge can be acquired in different forms (Siegel & White, 1975; Kuipers, 1978; Thorndyke & Hayes-Roth 1982; Golledge & Stimson, 1997). Interaction between people and the environment has also been researched from cognitive perspectives over several decades. A range of conceptual models or schema has been established to understand how people structure and develop an inner representation through recording and processing of information based on their perceptions of the real world and inferences about it (Downs, 1970; Pocock, 1973; Gold, 1980; Golledge & Stimson, 1997).

With the wide usage of NICTs and the development of LBS applications for assisting wayfinding activities, a number of questions and challenges are being raised for wayfinding research. The means by which people acquire spatial information is inevitably changed when mediated by technologies - spatial information can be acquired in real-time, at any location. The information can also be provided in a range of forms such as different scale of maps, text and/or voice route instructions, graphics and other multi-media forms. Mobile devices can be used to access real-time dynamic locational information. All of these differ from traditional ways of accessing spatial information to assist wayfinding. Thus, the technologies and the availability of location-based information and services pose research challenges for our understanding of cognitive processes and spatial knowledge acquisition. How such information is provided and the way by which it is delivered is likely to have an influence on the acquisition and development of spatial knowledge. In addition, individual differences in spatial ability and behaviour should be considered in LBS applications. Importantly, how can these technologies assist our understanding of the process by which spatial knowledge is acquired, valued, communicated and applied for completing wayfinding activities? On the other hand, these technologies are also poised to impact the methods of spatial cognition research (Montello, 2001). Yet to date, the role of technology has not been included in wayfinding research. Moreover, mobile devices, as information sources, have not been considered in studies concerning interactions between people and the environment.

2.3.4 GIScience and spatial information perspective

The continuing development of NICTs and LBS provide the technological setting to enhance and change the ways people access and utilise spatial information. Geographical information services (GIServices) can be considered in both a traditional mapping sense (e.g. through the Internet and WWW) and at a conceptual level using NICTs. The applications of GIServices can be performed at a remote site, which allow the user to take advantage of remotely located data and services through their devices, and which provide ways of combining information gathered through the senses with information provided from digital sources (Longley *et al*., 2005). Applications of GIServices continue to grow steadily, but are to some extent restricted by current technical impedances arising from limited communication bandwidth and reliability (particularly in densely-built urban settings), and the constraints of battery technology. Still greater impediments arise out of user difficulties of interacting with devices in field settings. The convergence of technologies discussed above could lead to the ubiquitous GIS through mobile geographic services and a focus on individuals in mobile contexts (Li and Maguire, 2003).

From a GIScience perspective, a shift from generic to user-centred mapping is one of the important challenges (Longley *et al*., 2001). Given that the demand for real-time, fast-changing information is increasing, NICTs will mean that people will be able to receive more relevant, timely information in various forms. Personal needs are also being increasingly emphasized. But what information do people require, and consequently what kinds of data are needed? The dynamics and complexity of the urban arena present another consideration. This is in regard to mobile users accessing information whilst being located in real time within the environment to which the information pertains. In these situations then, what constitutes relevant and meaningful information? The conventional means of communication of spatial information has been the map and most GIS are conventionally designed to deliver map-based solutions. Within LBS the map is likely to be only one mode of information communication. How might the modes of communication evolve, particularly if they are to enhance people's ability to acquire spatial knowledge?

Another area requiring research is the semantics of communication between individuals and a database with or without the intermediary of a call operator. In navigation LBS applications, instructions are given to people by means of maps, spoken word and text. It is envisaged that various landmarks, points of interest (POIs) and key features of neighbourhood environments might be provided as spatial cues via mobile devices. On the other hand, people's ability to answer spatial questions may be limited either through lack of awareness or confusion over vocabulary and map reading. This strikes at the traditional core principles of GIScience such as data modelling, data handling, generalisation and visualisation. Can objects be described in terms of neighbouring features in exactly the same way that people might describe them after looking at a map? The precise relation of cognition to language remains controversial (Mark, 1999). Can we arrive at a common semantic for spatial descriptive terms between systems and people when they are receiving information through handheld mobile devices in the field?

What has come to light in this Chapter is a considerable research agenda that has been prompted by the introduction of mobile devices for spatial information query and delivery into wayfinding tasks – more than can be addressed within this thesis. Moreover, many of the interwoven issues are real in as much as they have been triangulated from the perspectives of different disciplines. In this setting, the overarching aim of this thesis is to investigate aspects of urban pedestrian wayfinding using mobile devices that fall within this wider research agenda. In Chapter 3 the relevant research review is put forward and the specific research objectives for thesis refined.