# Assessing Spatial Data Infrastructure Architecture for Integration with Wireless Location Services

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Keywords: spatial data infrastructure, wireless communication, personal navigation

## ABSTRACT

Spatial Data Infrastructures (SDIs) have been identified as a mechanism through which complete and consistent spatial data sets can be accessed and retrieved. Whilst SDIs have been developing, wireless communication technologies have been undergoing a rapid evolution. The convergence of wireless communications, positioning technology and SDIs are providing new facilities, new applications and as a result, new challenges for spatial data providers and users.

To capitalise on the opportunities presented through the merger of these key areas, the design of SDIs may require modification. Naturally, different applications will have different spatial data requirements, however it is envisaged that there will be common infrastructure requirements (such as data sets, query and delivery mechanisms) that will be applicable for a range of wireless applications.

One of the most important issues in relation to delivering information to wireless users is that of data currency. It is imperative that a mobile user be provided with accurate, up to date data. Whilst this is also an important issue for non-mobile users, it is particularly important for users ‘on the move’. Thus rather than individual organisations duplicating and maintaining data sets, providing access through a standard SDI would be most beneficial.

Infrastructure requirements for Australian wireless applications that utilise spatial information will be determined through the development of a personal navigation system for the visually impaired. The accuracy and reliability requirements of a navigation solution for a visually impaired person are much greater than for a sighted person, thus the rigour of the data content and delivery methods is of paramount importance. This paper overviews the components and issues that need to be considered when building wireless applications that utilise location information. The prototype development will also be discussed to highlight the infrastructure requirements necessary for the proposed technology combination.

## INTRODUCTION

Since the early 1990s, researchers have been predicting that wireless access in association with user mobility will be the norm rather than the exception (refer to Weiser, 1993). Whilst the ‘norm’ level has not been reached nearly a decade on, significant developments in the fields of wireless communication and handheld computing mean that mobile computing and information access is now a reality. General consumers can purchase a mobile phone with Wireless Application Protocol capabilities that will allow them to access the wireless Internet for a price comparable to that of a standard mobile phone.

The ability to access the Internet from a mobile phone is possible and practical, but the mobile Internet browsing experience is far from ideal, and very different than the browsing performed from a desktop PC. Limitations imposed by mobile devices restrict the possible content and quantity of information that can be displayed. However, the opportunities presented by being able to access information away from a desktop computer and telephone line are contributing to enhanced mobility.

Traditionally, mobility in the telecommunications context has referred to the ability of a user to access telecommunication services from any location within the telecommunications network (FED-STD-1037C, 1996). More recently, this definition has broadened to encompass the seamless access of information and applications via the telecommunications network. Mobility offers a unique opportunity in that calls and information access have a natural synergy with location and time. Ideally, information access should be tailored to make the most of this opportunity and it is this principle that forms the basis of this research.

With the rapid development of wireless applications that deliver spatially related information to users, detailed consideration is required into how spatial information needs to be stored, managed and accessed in order to be disseminated efficiently via wireless technology. Capitalising on the combination of wireless communication (as a communication mechanism), the Internet (a method of distributed information access and dissemination) and location (the position from which wireless communication takes place), the issues involved in developing an application that operates on a mobile device and makes use of location information are under investigation.

An integrated system architecture for spatial data infrastructures that supports real-time location based wireless applications is currently under development. A preliminary review of the issues involved in developing such a system linked to a spatial data infrastructure will be examined in this paper.

The prototype development encompasses three main areas of focus:

1. Development of an integrated navigation module with continuous GPS positioning;
2. Integration of the navigation module with a spatial data infrastructure; and
3. Communication and dissemination of the navigation solution (essentially the provision of intelligent information in real time).

The prototype will be developed for visually impaired users and will utilise algorithms for the dissemination of spatial data from the SDI over wireless communication protocols. The navigation module will link position information (obtained at the mobile terminal) to spatial data sets residing on servers, extract the relevant attribute information attached to corresponding spatial entities and return this information in a useful format (spoken voice) to the mobile device.

Through examining the infrastructure required for wireless applications to make use of spatial information via a spatial data infrastructure, it is anticipated that access to and use of spatial information can be improved. Developing a prototype for the visually impaired will contribute to determining an enhanced SDI model.

## MOBILITY AND WIRELESS COMMUNICATION

Handheld devices are enabling a new environment for information access and are likely to continue to do so on an increasingly larger scale. Based on industry forecasts, it is predicted that within one year, the number of mobile internet capable wireless terminals will outnumber terminals using fixed lines to access the Internet (Koh and Kim, 2000). By the year 2003, there are expected to be more than one billion mobile phones in use (Rainio, 2001). These mobile phones will not only be capable of accessing the Internet, but are likely to be merged with palm-top computers and personal digital assistants providing additional functionality (including scheduling, phone or address books, the ability to connect wirelessly with local area networks etc.) to support mobility.

Devices that can be taken anywhere, linked into corporate networks, and facilitate work in the field are undoubtedly going to change the way in which work is conducted and information is collected, updated and accessed. The ability of devices and mechanisms through which data may be transmitted from the field to the office have revolutionised business practices in the last decade. However, the benefits of mobile computing do not come without constraints. Satyanarayanan (1996) suggests that mobile computing is characterised by constraints which are intrinsically linked to mobility (as opposed to being artefacts of current technology); compared to desktop PCs mobile devices are resource-poor – minimal display and CPU features contribute to the mobility of the device, but detract from performance; mobile communication is variable in performance and reliability – connection with other callers/data providers may ‘drop out’ or disconnect unexpectedly; mobile devices rely on a finite energy source – although increasing, battery life is always limited. These issues ‘complicate the design of mobile information systems and require us to rethink traditional approaches to information access’ (Satyanarayanan, 1996).

The potential to access information from mobile terminals has led to the emergence of a wide range of applications, but as Torrieri (2000) points out, it is the *location services* aspect that marks the wireless experience as unique.

> Location Services deliver information about the geographic location of mobile telecommunications devices. This includes mobile telephones, mobile interactive browsers and devices attached to other moveable items such as people, packages and vehicles. Location Based Services deliver end-user applications based on Location Services.
> (Davies, 2000)

Thus it is location based services that reinforce geography and a sense of place to mobile subscribers. The provision of information that is relevant to a user’s current position through these type of services is slowly entering the consumer market place, and can already provide services such as driving directions and locating nearby stores. It is the integration of network computing, positioning technology and wireless communications that has led to the development of location based services. Each of these technologies is well established in its own right, and will to continue to evolve. As a result, it is expected that location based services will benefit from the developments in each area and hence provide improved services to consumers.

## POSITIONING TECHNIQUES

As detailed previously, an important aspect associated with mobile computing or communications is that of location. Wireless communication is inherently linked with location and technological advances in satellite navigation, inertial technology and integrated systems are a significant driving force enabling the wide range of emerging wireless applications that utilise location information.

The computer science industry has been investigating the position determination of mobile devices for some time. More recently these techniques have been adapted and integrated with other technologies to determine the position of mobile phones (refer to Drane and Rizos, 1998; ETSI, 2000; Hayes, 2000). Research in this area has been spurred on by the US Federal Communications Commission E-911 mandate that aims to 'improve the reliability of wireless 911 services and to provide the enhanced features generally available for wireline calls' (FCC, 1999a). Implemented in two phases, the mandate requires that by October 2001, the location of wireless callers be provided (to an accuracy of 300m for 95% of calls utilising a network based positioning solution, or to an accuracy of 150m for 95% of calls utilising a handset based method) to the emergency service contact (FCC, 1999b). As the ability to precisely determine the position of a mobile phone improves, these standards are likely to become more stringent.

A terminal or handset based positioning system relates to positioning intelligence that is stored in the mobile terminal or on its SIM card (a card that gives a GSM phone its user identity, can store messages and applications). The fundamental information required to locate the handset is measured at the handset itself, with the network playing only a minor role. This positioning technique requires users to purchase a new phone, SIM card or both in order to use the system. Network based positioning solutions do not require positioning intelligence to be built into the handset, but instead obtain positioning information using observations of handset signals and the network infrastructure. This means that all subscribers can use the system as soon as it is launched. These two positioning systems have different characteristics and as a result different accuracy ranges (refer to the FCC specifications noted previously).

The European Telecommunications Standards Institute and T1P1 committee (a subcommittee of T1, a US telecommunications standards committee, concerned with wireless/mobile services and systems) have decided on the standardisation of three location systems:

- Enhanced Observed Time Difference (E-OTD) (handset)
- Time of Arrival (TOA) (network)
- Assisted Global Positioning System (A-GPS) (handset)

(ETSI, 2000)

The mobile phone network has an inbuilt positioning system – Cell of Origin – which is used to keep track of the position of mobile phones so that a call may be placed successfully through to the mobile subscriber. Even though this system operates for all mobile phones without handset or network modifications, the accuracy of this positioning system is dependent on the coverage area of the base station. This can range from 100m in urban centres, to 3000m in rural areas. Base stations have been placed to accommodate the expected communication patterns of use, rather than for geometric positioning. The three standardised location systems offer improved positioning accuracies when compared with the Cell of Origin technique.

## Enhanced Observed Time Difference

The Enhanced Observed Time Difference (E-OTD) method is based on measurements at the mobile terminal of observed time differences between pairs of local base transceiver stations. Since transmissions from base stations are not synchronised, the network must measure the relative time difference between the transmissions. For any particular pair of stations, the time difference is related to the difference in distance from the mobile to the two stations. A hyperbolic line of constant distance difference can be drawn for three station pairs. The intersection of the hyperbolae is the position of the mobile phone – Figure 1. This can be calculated at the mobile terminal (if all the information is available) or in the network. This method is capable of positioning a mobile phone with an accuracy of 60 to 200 metres and requires network and handset modifications (Swedberg, 1999).

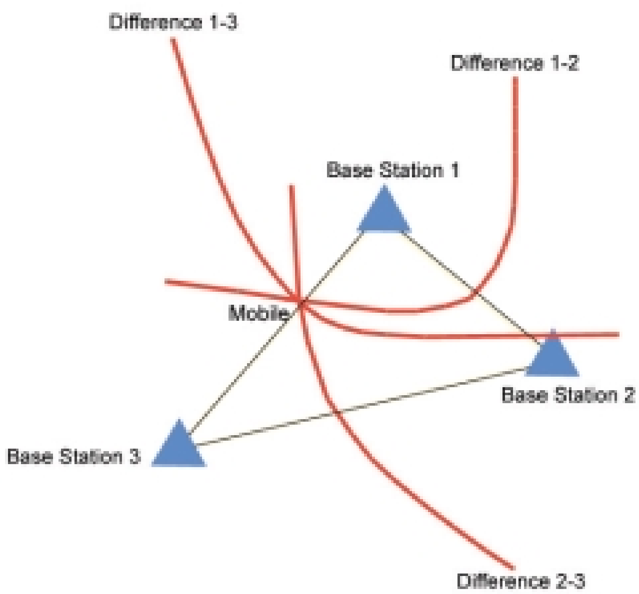


Figure 1 – Enhanced Observed Time Difference Positioning Technique

## Time of Arrival

Working almost in reverse to the previous method, the Time of Arrival (TOA) method measures the time of arrival of a signal from a mobile terminal to three or more base stations. The signal burst from the mobile radiates equally in all directions at a constant speed. Location Measurement Units at the base stations receive the bursts and measure the value of the uplink time of arrival. A circle, of radius equal to the distance travelled by the signal in the measured time, can be drawn from each base station. The intersection point of the circles from three base stations uniquely determines the position of the mobile phone – Figure 2. Retscher (2001) indicates that in the case of redundant observations, 'the position fix together with the time offset and error of the clock of the mobile station is estimated using a least-squares adjustment'.

This method does not require any modification to existing handsets, but network modification is required. Accuracy typically varies between 50 and 150 metres (Swedberg, 1999).

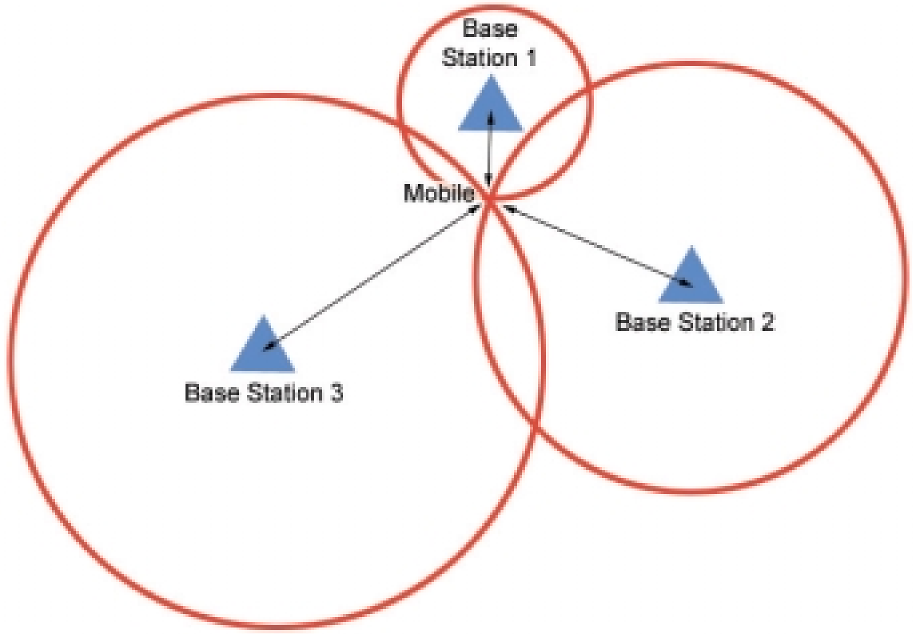


Figure 2 – Time of Arrival Positioning

**Assisted GPS**

The most accurate of the standardised methods, Assisted GPS relies on the GSM network providing additional information to provide integrated GPS receivers improved coverage compared to stand-alone receivers (Swedberg, 1999). Different kinds of Location Measurement Units are used to collect the assistance data (refer to Table 1). In order to provide satellite ephemeris and differential GPS correction, one Measurement Unit must be deployed approximately every 300km in the network. This enhancement provides accuracies to within 10 or 20 metres (Swedberg, 1999). To further increase GPS coverage, a highly accurate time reference needs to be provided and could be achieved through the deployment of one Measurement Unit in every third base station.

| Type of Assistance | Benefit |
|---|---|
| Satellite ephemeris | Improves time-to-fix or sensitivity, or both, by focusing acquisition. Improves time-to-fix by eliminating the need to demodulate navigation messages. |
| Frequency accuracy | Improves time-to-fix by focusing acquisition. |
| Location estimate | Initialises the position computation procedure. Improves the acquisition of second and subsequent signals. |
| Differential GPS correction | Improves the accuracy of position estimates (10-20m). |
| Time reference | Improves time-to-fix for all receivers. Improves sensitivity for receivers in poor signal environments. |

Table 1 – GSM network assistance for Assisted GPS (Swedberg, 1999)

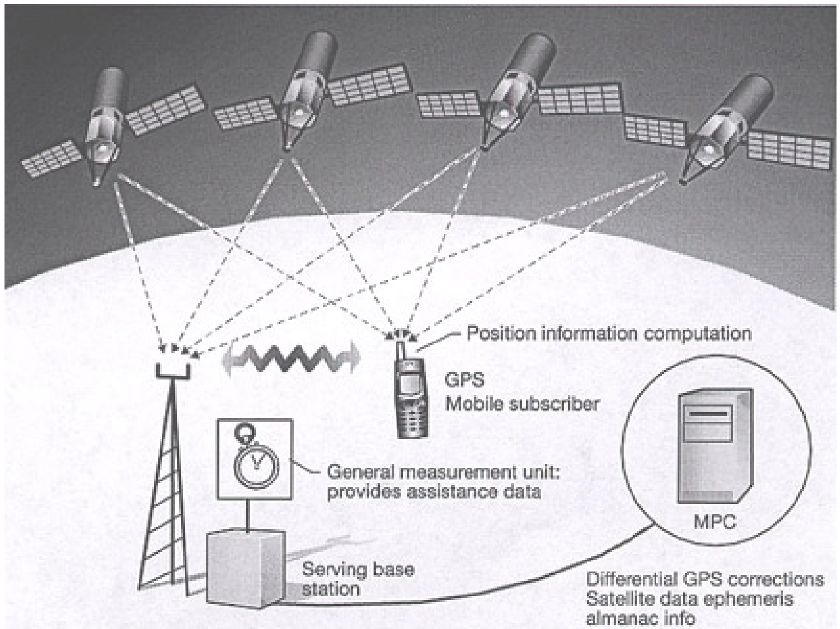


Figure 3 – Assisted GPS positioning (Swedberg, 1999)

The accuracy of the position fix for the systems described above, as is also the case with other positioning systems, is dependent on the number of measurements and their geometric configuration. Retscher (2001) identifies that the geometric configuration is the limiting factor for these technologies due to the fact that generally base stations are located to provide adequate coverage for communication rather than assist with position determination. Additionally, priority on the GSM network is assigned for communication services, thus only a limited number of users can perform location determination at any time. Multipath also plays a major role in limiting position accuracies in network-based positioning techniques.

Once the position of a mobile device is determined it can be linked to spatial and non-spatial databases on a server which can transmit location relevant information to the mobile device. It is this infrastructure, linking spatial information servers with wireless technology that is under investigation as part of this research.

## SPATIAL DATA INFRASTRUCTURES

The need for Spatial Data Infrastructures has arisen from an increased importance and use of geographical information. SDIs are intended to provide an environment which enables a variety of users to access and retrieve complete and consistent data sets in an easy and secure manner (Rajabifard et al., 2000). The SDI environment encourages co-operation and sharing between various stakeholders and data custodians, ultimately resulting in human and resource savings and returns.

As identified by ANZLIC (1996), the ASDI implementation requires a solid infrastructure based on policy and administrative arrangements, technical standards, fundamental data sets, and a means by which community members may access spatial data. In addition to these four components, Rajabifard and Williamson (2001) note that people are also a critical component – refer to Figure 4 for the component relationships.

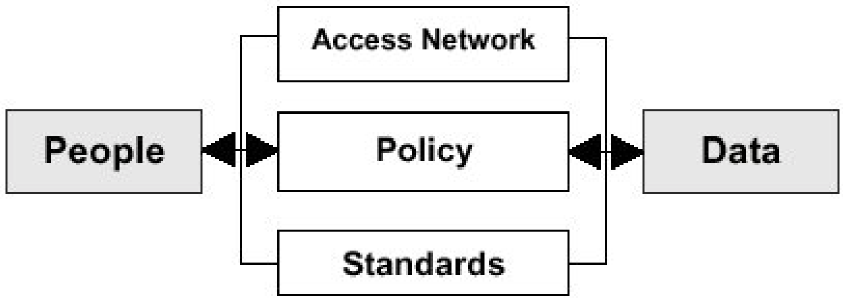


Figure 4 – Nature and Relation between SDI components (Rajabifard and Williamson, 2001)

SDIs are being developed at many levels – by nations in order to better manage and utilise their spatial data sets, by regional organisations (incorporating a number of national SDIs) to improve the management and decision making relevant across national boundaries, and by local governments and corporations to provide more efficient data handling practices. Whilst each of these SDIs will be unique, Rajabifard et al. (1999) identify some commonalities between the SDIs and propose a hierarchical structure in which SDIs may be examined. There are two views of the hierarchical structure (refer to Figure 5 below). The umbrella view examines the hierarchy from the top down. An SDI at the higher level encompasses all of the components of the underlying SDIs. The building block view examines the hierarchy in the opposite direction, with each of the lower level SDIs acting as supporting blocks, providing the spatial data needed by those at the higher levels. According to Rajabifard et al. (1999), this double view of the SDI hierarchy creates an environment in which decision makers working at any level can draw on data from other levels.

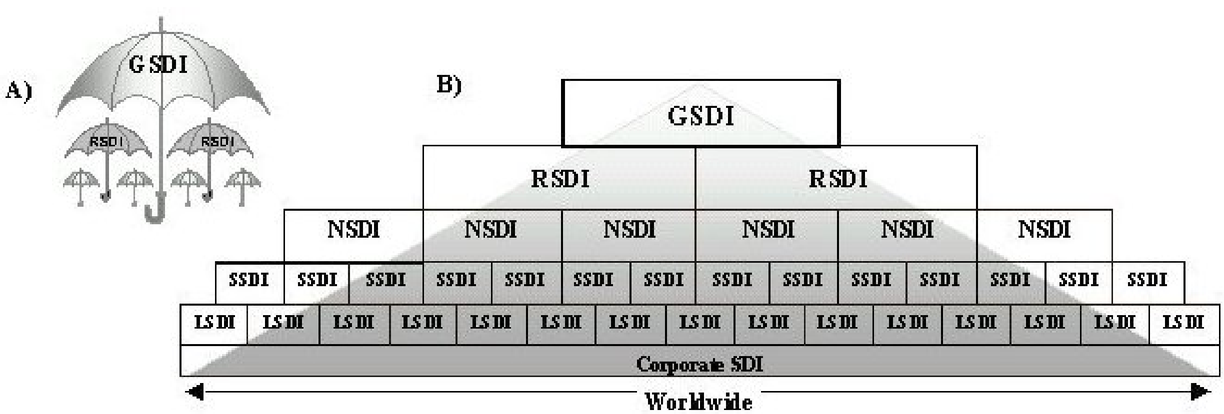


Figure 5 – View of SDI Hierarchy A) Umbrella View B) Building Block View (Rajabifard et al., 1999)

SDIs hold the potential, and have already begun to make spatial information more readily available. The specific infrastructure requirements necessary for ensuring that SDI data is accessible over wireless devices however are still to be determined. This link between spatial information systems and mobile devices has been identified by The Open Location Services initiative, a sub-group of the Open GIS Consortium:

> Spatial connectivity is a primary, universal construct for business planning and modelling, service development and deployment, network provisioning and operation and customer satisfaction. Location application services are of universal industry significance and depend upon the availability of relevant spatial information infrastructures in forms useful for small devices.
> (Open GIS Consortium, 2000)

Capitalising on these issues, this research aims to determine whether spatial data infrastructures (in their current form) can adequately support wireless applications that use spatial information. To determine this a prototype application will be developed. The application will be a personal navigation tool (operating on a mobile phone) to assist visually impaired people with their daily mobility.

Limitations in making use of visual clues of their surroundings mean that visually impaired people require great accuracy and reliability in services that provide spatial information or feedback regarding their spatial surroundings. In this way, visually impaired users have a need for high integrity spatial information.

For sighted people, pedestrian navigation is a relatively easy task, however without visual clues it can be a very daunting one. As such, a navigation application for people who are unable to use visual clues requires a high integrity and reliability of the spatial information presented. Thus investigating the mechanisms by which to rapidly access accurate data in situations where the resulting information will be depended upon quite heavily is anticipated to yield a specific set of requirements for data access and delivery. These requirements are expected to hold true in less critical situations, for example someone in a foreign town trying to find a nearby Chinese restaurant.

As noted by Rainio (2001), the fundamental idea underlying personal navigation is the user's need to move about without getting lost in unfamiliar surroundings, receiving appropriate guidance in relation to their needs and circumstances at any given time. Wireless data transfer can facilitate the dissemination of guidance information to users, however the underlying data sets must contain appropriate attributes. This is particularly important for visually impaired people; 'Information such as location of transit stops, whether or not a shelter is present, proximity and direction of the nearest intersection, whether the intersection has a traffic control system or curb cuts, or how far a bus stop is from a corner are more important to blind travellers than cadastral features such as parcel size, planning features such as age of nearby buildings and number of occupants, or design features such as colour, number of rooms or age of building' (Golledge et al., 1998). It is expected that each location based application will have its own 'essential' attributes. However, if these specialty databases could be linked with the fundamental databases within an SDI, services could be developed that capitalise on all the available data delivering the most appropriate information at any time.

The operating environment and situation in which wireless applications are used also impact on the content, structure, rate of delivery, quantity and format of the information to be presented. In particular, information content and structure have been identified as critical components having a significant effect on service usability (Rainio, 2001). It is imperative that information is not contradictory, does not lead to incorrect actions and does not overload the user cognitively. Whilst these issues have been identified with vehicle navigation in mind, they are equally relevant to the situation of visually impaired pedestrian navigation. Additionally, Rainio (2001) specifies that users should always be well informed with regards to the quality of the information, and with whom this responsibility lies.

The majority of navigation aids that have been constructed for visually impaired travellers to date[1] aim to assist with macro-navigation or the orientation and movement through a large environment. Primary aids (such as canes and guide dogs) are sufficient for micro-navigation (the avoidance of obstacles to find a clear path through an immediate environment), and are likely to remain so for some time – spatial data sets are unlikely to contain information at the accuracy and currency standards required for a visually impaired person to travel without the need for a primary aid. However, a tool that can assist a visually impaired traveller by providing contextual information on a non-specialised device such as a mobile phone would be most useful.

[1] Refer to (Golledge, 1993; Loomis and Golledge, 1993; Kitchin et al., 1997; Golledge et al., 1998; Golledge, 1999; Strothotte, n.d.)

## CONCLUSIONS

The potential to provide mobile members of the workforce with access to necessary and quality spatial information is almost a reality due to technological advancements and the wireless transmission of data. The convergence of the wireless communication, position technology and SDI areas is expected to continue to facilitate information access, with a focus on the delivery of position dependent relevant and timely information. Given the inherent limitations of mobile devices, it is necessary to determine the mechanisms that will enable mobile users to gain access to small, appropriate sections of larger data sets (such as those stored in SDIs).

Around the world, wireless phone carriers are committing enormous resources to building the communications infrastructure to make wireless services reliable and widely accessible. Location services are consistently cited as one of the main applications that will enable the carriers to recoup their investments. Whilst they can take on many forms and provide value in many ways, all location services require spatial data handling capabilities to link location with other data sources. The management and dissemination of relevant information to mobile users requires technology that can be used to integrate it with the rapidly evolving Internet and communications standards.

A prototype navigation application for the visually impaired is under development to determine whether the current design of the SDI inhibits the use of SDI data in wireless applications. Some of the issues involved in developing this sort of an application, that requires significant technology integration, have been discussed. If the SDI model is found to limit SDI data use wireless applications, a revised model will be proposed which will allow location specific portions of SDI data to be disseminated over a wireless medium.

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## ACKNOWLEDGEMENTS

The authors wish to gratefully acknowledge the support of Land Victoria and the members of the Spatial Data Infrastructure and Cadastral Research Group at the Department of Geomatics (http://www.geom.unimelb.edu.au/research/SDI_research/), The University of Melbourne in the preparation of this paper and the associated research. The views expressed in the paper are those of the authors and do not necessarily reflect the views of these groups.

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**Jessica Smith** commenced her PhD at The University of Melbourne in March 2000 following the successful completion of Bachelor of Geomatics and Bachelor of Science (Computer Science) degrees in 1999. Her research focuses on communications technology in relation to the dissemination of spatial data and has been inspired by an interest in the utilisation and management of spatial information, computer systems and other spatial information tools. Jessica is a member of the Institution of Surveyors Australia and the Institution of Engineers Australia.

**Allison Kealy** was born in Trinidad, where she completed her BSc in Surveying at the University of the West Indies. She holds a PhD from the University of Newcastle upon Tyne, UK (1996) specialising in the areas of Kalman filtering, integrated positioning systems and quality control. Allison combined her theoretical expertise with practical knowledge through two years of industrial experience. This involved technical support and product management for GPS/GLONASS manufacturers Ashtech Ltd. Allison is currently employed as a lecturer at The University of Melbourne.

**Professor Ian Williamson** has worked in government and the private sector as a professional land surveyor in Australia and the USA. He is a Fellow of the Academy of Technological Sciences and Engineering, Australia, a Fellow of the Institution of Surveyors Australia Inc. a Fellow of the Institution of Engineers Australia, an Honorary Member of the International Federation of Surveyors (FIG) and an Honorary Fellow of The Mapping Sciences Institute, Australia. His teaching and research is concerned with cadastral, land and geographic information systems in both developed and developing countries. He has published extensively on these topics. He has undertaken research or consultancies world-wide for organisations including AusAID, the United Nations and the World Bank. He was Chairperson of Commission 7 (Cadastre and Land Management) 1994-98 and is currently Director, United Nations Liaison of the International Federation of Surveyors. At Melbourne University he has been President of the Academic Board and Pro-Vice-Chancellor, and is currently Head of the Department of Geomatics.